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# SINGLE COMMON POWERTRAIN LUBRICANT (SCPL) DEVELOPMENT (PART 2)

## INTERIM REPORT
## TFLRF No. 442

by
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Edwin A. Frame
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U.S. Army TARDEC Fuels and Lubricants Research Facility
Southwest Research Institute® (SwRI®)
San Antonio, TX

for
Allen S. Comfort

U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

Contract No. W56HZV-09-C-0100 (WD17-Task 3)

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April 2014

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| **14. ABSTRACT** The U.S. Army has a desire to consolidate multiple MIL specification fluids into a single specification, or Single Common Powertrain Lubricant (SCPL). The application of this fluid would include engine lubrication, power shift transmission operation, and limited use in hydraulic systems, and must be designed to operate in ambients ranging from low temperature arctic, to high temperature desert type conditions. The U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF) located at Southwest Research Institute (SwRI) has aided TARDEC in the initial development of the SCPL. This report covers the testing of two revised candidates identified in TFLRF Report No. 418. Testing included high temperate endurance in the General Engine Products 6.5L(T) diesel engine to assess engine protection and oil performance at elevated temperatures, 2-cycle diesel engine compatibility using the Detroit Diesel 6V53T, multiple industry standardized transmission tests (Allison C4, Caterpillar TO-4, John Deere JDQ) to assess frictional performance and driveline durability, and quantification of fuel consumption improvement over standard military oils through viscosity reduction in the SCPL. | | | | | | |
| **15. SUBJECT TERMS** Single Common Powertrain Lubricant (SCPL), General Engine Products (GEP) 6.5L(T), Detroit Diesel Corporation (DDC) 6V53T, High Temperature Oil Endurance, MIL-PRF-46167, MIL-PRF-2104, Total Acid Number (TAN), Total Base Number (TBN), Wear Metals, Oxidation, Fuel Economy, Pumping Losses, Transmission, Caterpillar TO-4, Allison C4, John Deere JDQ-96 | | | | | | |
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# EXECUTIVE SUMMARY

The U.S. Army has a desire to consolidate multiple lubricant specifications into a single specification, or Single Common Powertrain Lubricant (SCPL). The application of this fluid would include engine lubrication, power shift transmission operation, and limited use in hydraulic systems where MIL-PRF-2104 is currently used. The SCPL must be designed to operate in ambients ranging from low temperature arctic, to high temperature desert type conditions, representative of the wide range of potential military operating conditions.

This report is the second in a series covering the SCPL development, and focuses on the refinement of two initial SCPL candidates identified during research reported under TFLRF Interim Report 418, Single Common Powertrain Lubricant (SCPL) Development (Part 1). All SCPL testing reported was completed at the U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF), located at Southwest Research Institute (SwRI) in San Antonio, Texas. Performance investigations reported here of the revised SCPL candidates included: chemical and physical analysis, high temperature endurance testing in the General Engine Products (GEP) 6.5L(T) engine, 2-cycle diesel engine compatibility using the Detroit Diesel Corporation (DDC) 6V53T, American Society for Testing and Materials (ASTM) D5966 roller follower wear protection, frictional analysis in industry standardized transmission tests, and the quantification of fuel consumption improvement through lowered viscosities.

Two initial SCPL candidates were identified in TFLRF Interim Report 418 to receive further development and testing for the U.S. Army SCPL program. Results from initial testing was shared with industry suppliers, and specific goals were outlined for their improvement. The two initial SCPL candidates were then reformulated by each respective supplier and resubmitted as revised candidates for continued testing.

Consistent with the initial testing, the General Engine Products (GEP) 6.5L(T) engine, from the High Mobility Multipurpose Wheeled Vehicle (HMMWV), was used to complete high temperature oil endurance evaluations on each revised candidate. This allowed for comparisons between revised and initial candidates, as well as performance comparisons to current

commercial products and current MIL specification products tested and reported in IR418. End of test used oil analysis for each of these tests can be seen below in Table ES1 (Note – Full data for 2104G, 2104H, CJ-4, LO253071, and LO251746 oils were reported in IR418). Both candidates improved their performance in the GEP 6.5L(T) test from their respective initial evaluations. Revised candidate LO271510 improved from 168 hours to 196 hours, still falling slightly short of the 210 hour target. Revised candidate LO268869 improved from 126 hours to the targeted 210 hours, while still maintaining favorable oil condition and low accumulation rates of critical wear metals.

**Table ES1. All Tests, End of Test Used Oil Analysis**

| Property | ASTM Test | MIL SPEC & Commercial | | | SCPL Candidates | | | |
|---|---|---|---|---|---|---|---|---|
| Lubricant | | 2104G | 2104H | CJ-4 | LO253071 *Initial* | LO268869 *Revised* | LO251746 *Initial* | LO271510 *Revised* |
| Hours | | 84 | 154 | 210 | 126 | 210 | 168 | 196 |
| Density | D4052 | 0.9161 | 0.9276 | 0.920 | 0.896 | 0.8874 | 0.8859 | 0.894 |
| Viscosity @ 100°C (cSt) | D445 | 17.58 | 25.47 | 25.59 | 12.17 | 13.64 | 11.96 | 15.63 |
| Total Base Number (mg KOH/g) | D4739 | 0.74 | 1.17 | 0.82 | 2.61 | 4.37 | 3.84 | 4.55 |
| Total Acid Number (mg KOH/g) | D664 | 12.87 | 17.1 | 11.06 | 10.86 | 7.33 | 9.19 | 9.67 |
| Oxidation (Abs./cm) | E168 FTNG | 171.63 | 217.99 | 117.53 | 136.69 | 68.76 | 99.08 | 111.73 |
| Nitration (Abs./cm) | E168 FTNG | 36.6 | 33.76 | 39.21 | 80.5 | 25.97 | 52.77 | 51.99 |
| Soot | Soot | 1.982 | 2.864 | 2.695 | 2.214 | 2.082 | 2.597 | 2.568 |
| Wear Metals (ppm) | D5185 | | | | | | | |
| Al | | 5 | 5 | 5.0 | 11 | 11 | 6 | 5 |
| Sb | | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Ba | | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| B | | 5 | 4 | 40.0 | 4 | 3 | 55 | 22 |
| Ca | | 3620 | 3056 | 3522.0 | 4629 | 5393 | 1183 | 1469 |
| Cr | | 6 | 6 | 6.0 | 6 | 10 | 7 | 6 |
| Cu | | 234 | 345 | 65.0 | 311 | 47 | 48 | 61 |
| Fe | | 264 | 468 | 355.0 | 476 | 447 | 541 | 452 |
| Pb | | 332 | 693 | 378.0 | 564 | 92 | 152 | 232 |
| Mg | | 13 | 380 | 30.0 | 17 | 21 | 1669 | 1995 |
| Mn | | 5 | 6 | 6.0 | 6 | 7 | 7 | 6 |
| Mo | | 22 | 21 | 24.0 | 28 | 32 | 124 | 132 |
| Ni | | 6 | 6 | 6.0 | 8 | 8 | 9 | 9 |
| P | | 1089 | 1302 | 1334.0 | 1366 | 1607 | 1318 | 1476 |
| Si | | 51 | 38 | 46.0 | 56 | 46 | 53 | 56 |
| Ag | | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Na | | 8 | <5 | 8.0 | 22 | 10 | 12 | 9 |
| Sn | | 17 | 24 | 17.0 | 20 | 18 | 18 | 15 |
| Zn | | 1544 | 1914 | 1775.0 | 2306 | 2747 | 1780 | 1979 |
| K | | <5 | <5 | 13.0 | 8 | 10 | <5 | <5 |
| Sr | | 1 | <1 | 1.0 | 2 | 2 | <1 | <1 |
| V | | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Ti | | <1 | <1 | <1 | <1 | 1 | <1 | <1 |
| Cd | | 1 | <1 | <1 | 2 | <1 | <1 | <1 |

New in this round of testing was a 2-cycle diesel compatibility test with the SCPL candidates. A Detroit Diesel Corporation (DDC) 6V53T, from the M113A3 Armored Personnel Carrier (APC), was used to evaluate the two revised candidates and a MIL-PRF-2104H OE/HDO 15W-40 baseline to determine compatibility and performance in a 2-cycle diesel application. Both SCPL candidates provided comparable engine protection of the critical piston and liner interface in the 2-cycle engine when compared to the baseline MIL-PRF-2104H OE/HDO 15W-40 evaluation at normal ambient type engine operation. With respect to engine cleanliness, both revised SCPL candidates showed a reduced trend of deposit formation, reducing overall deposits and a tendency to experience a cold stuck condition on the 2$^{nd}$ compression ring when compared to the baseline 2104H evaluation.

To determine transmission compatibility, several industry standardized transmission tests were completed on the revised SCPL candidates, including selected: Allison C4, Caterpillar TO-4, and John Deer Qualification tests. As with testing reported in IR418, the revised SCPL candidates were found to have mixed results overall, with no candidates being able to pass all tests (Note: JDQ and CAT TO-4 Seq 1222 tests are not required tests by the MIL-PRF-2104 product specification). There was some improvements from the first round of testing, and none of the oils tested showed signs of catastrophic incompatibilities. It is again expected that the revised candidates will be able to pass the various frictional evaluations with minor formulation changes.

Fuel consumption improvement evaluations were completed to quantify improvement with the use of low viscosity lubricants over traditional higher viscosity diesel engine oils. The GEP 6.5L(T) engine was used for testing due to its utilization of a fully mechanical fuel injection system which adds greater consistency to fuel consumption measurements. The 14 mode fuel consumption test cycle developed and reported in IR418 from data acquired during HMMWV field operations at Ft. Hood, Texas, was used to quantify fuel consumption changes. As expected, the revised candidate SCPL oils showed similar fuel consumption improvement results as seen from the initial candidates compared to the straight SAE 40 grade. This is attributed to the similar viscometric properties measured from the revised candidates. Overall, the fuel consumption improvement was greater than 1.5% over standard military diesel engine oils.

It is the recommendation of TFLRF staff that both revised candidates continue to be considered for the SCPL program. Focused formulation changes need to be made for both candidates to improve transmission performance without negatively impacting engine durability, oil degradation, and 2–cycle compatibility. Long term considerations for the SCPL program should include: high temperature 2–cycle diesel engine compatibility testing, high output air-cooled diesel engine compatibility, detailed investigation of ring pack wear changes due to lowered viscosities, and the conduct of SCPL field demonstrations at U.S. Army Installations at cold, moderate, and high temperature climate conditions.

# FOREWORD/ACKNOWLEDGMENTS

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The authors would like to acknowledge the contribution of the TFLRF technical support staff.

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# ACRONYMS AND ABBREVIATIONS

API – American Petroleum Institute

ASTM – American Society of Testing Materials

ATF – automatic transmission fluid

bhp – brake horse power

bsfc – brake specific fuel consumption

CAT - Caterpillar

CL – chem. lab

coeff – coefficient

COTR – Contracting Officer Technical Representative

cP – centipoise

CRC – Coordinating Research Council

cSt – centistokes

DDC – Detroit Diesel Corporation

EOT – end of test

FRRET – friction retention

ft – feet

GEP – General Engine Products

GM – General Motors

GOCO – Government Owned, Contractor Operated

HDO – heavy duty oil

HMMWV – High Mobility Multipurpose Wheeled Vehicle

hp – horsepower

hr – hour

JDQ – John Deere Qualification

JP8 – jet propulsion 8

lb – pound

ft-lb – pound feet

LO – lab oil

MIL – military

mils – (unit of measure) thousands of an inch

N – Newton

NA – naturally aspriated

NVH – noise, vibration, and harshness

OE – oil engine

OEA – oil engine arctic

OEM – original equipment manufacturer

ppm – parts per million

psi – pounds per square inch

psiA – pounds per square inch absolute

RPM – revolutions per minute

SAE – Society of Automotive Engineers

SCPL – Single Common Powertrain Lubricant

SwRI – Southwest Research Institute

TAN – total acid number

TARDEC – Tank Automotive Research and Development Engineering Center

TBN – total base number

TFLRF – TARDEC Fuels and Lubricants Research Facility

# 1.0 INTRODUCTION & BACKGROUND

The U.S. Army has a desire to consolidate multiple lubricant specifications into a single specification, or Single Common Powertrain Lubricant (SCPL). The application of this fluid would include engine lubrication, power shift transmission operation, and limited use in hydraulic systems where MIL-PRF-2104 products are currently used. The SCPL must be designed to operate in ambients ranging from low temperature arctic to high temperature desert conditions, representative of the wide range of potential military operating conditions. In addition to this universal application, the SCPL must meet or exceed performance currently attained by approved MIL specification products. By achieving these goals, multiple lubricant specifications could be reduced into a single specification, or SCPL, that could be used successfully in tactical and combat vehicles in any seasonal or geographical location. The development of this lubricant has the potential to reduce the logistical burden on the military's supply chain, reduce operating costs, and improve performance beyond current approved and fielded products.

Due to the extreme application requirements and performance goals, it is desirable that the SCPL be formulated from synthetic basestocks. These synthetic basestocks typically have a higher cost when compared to traditional petroleum derived basestocks. To offset the increased price, several additional performance goals must be met, such as increased vehicle fuel efficiency, and extended drain intervals. Current research has shown that there is a potential reduction in fuel consumption through the use of low viscosity lubricating fluids [1,2]. This change in fuel consumption is attributed to the reduction in mechanical losses within the system. These mechanical losses can be related to shifts in frictional properties, pumping efficiencies, and overall bulk churning of the lubricant in mechanical applications. Although reductions in fuel consumption through viscosity changes are expected to be relatively small (1-2%), when incrementally multiplied over a large group of vehicles such as the military's combat and tactical fleet, the fuel savings can be substantial. These efficiency increases through reduced viscosities complement the SCPL’s requirement to provide extreme cold climate performance, as lower fluid viscosities must be obtained to ensure pumpability at low temperatures than typical average climate heavy duty diesel oils. Premium synthetic basestocks also typically offer an increased resistance to oil degradation, which allows the extension of time required between drain intervals. This extension of service intervals, combined with the increased efficiency through lowered viscosity, helps counteract increased costs associated with synthetic basestocks [3].

This report is the second in a series covering the SCPL development, and focuses on the refinement of two initial SCPL candidates identified during research reported in TFLRF Interim Report 418, Single Common Powertrain Lubricant (SCPL) Development (hereinafter referred to as Part 1) [4]. All SCPL testing reported was completed at the government owned, contractor operated (GOCO) U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF), located at Southwest Research Institute (SwRI) in San Antonio, Texas. Performance investigations reported here of the revised SCPL candidates included: chemical and physical analysis, high temperature endurance testing in the General Engine Products (GEP) 6.5L(T) engine, 2-cycle diesel engine compatibility using the Detroit Diesel Corporation (DDC) 6V53T, American Society for Testing and Materials (ASTM) D5966 roller follower wear protection, frictional analysis in industry standardized transmission tests, and the quantification of fuel consumption improvement through lowered viscosities.

# 2.0 OBJECTIVE & APPROACH

The overall objective of this project was to evaluate two SCPL candidates that have been revised for improved performance based off of previously attained performance results from SCPL Development Part 1. This data would reinforce the previously completed feasibility study [5,6,7], preliminary development efforts (Part 1), and verify candidate advancement towards the goals of the SCPL.

## 2.1 ENGINE DURABILITY TESTING

Due to the low temperature properties required to meet SCPL performance guidelines, candidate SCPLs were expected to be formulated to attain lower viscometric properties than those seen in traditional heavy duty diesel engine oils. To ensure that these low viscosity lubricants provided adequate engine component protection at all operating conditions, particularly desert operation, high temperature engine oil endurance testing was completed in an effort to assess each revised candidates performance at worst case conditions. Consistent with testing completed during Part 1, the General Engine Products (GEP) 6.5L(T) diesel engine, as used in the High Mobility Multipurpose Wheeled Vehicles (HMMWV), was selected as the test bed for determining overall engine durability. The GEP 6.5L(T) engine is a 6.5L V8, turbocharged, non-intercooled, indirect injected, roller follower, cam in block engine. Fueling is controlled by a mechanical Stanadyne DB2-5079 rotary injection pump in a pump-line-nozzle configuration, and produces approximately 170hp on JP-8 fuel. The GEP 6.5L(T) engine was selected primarily because of its traditionally rapid degradation of engine oil during use (i.e., high severity), and the engine family's high density in the current military fleet (engine family includes the GEP 6.2L(NA), 6.5L(NA), and 6.5L(T) in all variants of the HMMWV). Results from revised candidate testing were used to determine performance improvement in comparison to each initial first round candidate evaluation, MIL-PRF-2104 (G and H revisions) evaluations, and the commercial 15W-40 baselines completed during Part 1.

In addition to engine durability using the GEP 6.5L(T), each revised candidate was also evaluated using the Detroit Diesel Corporation (DDC) 6V53T. The DDC 6V53T test was used to determine 2-cycle diesel compatibility, as 2-cycle engines have historically shown to be sensitive to variation in engine oils due to their own unique lubricant requirements. The 6V53T was chosen over other 2-cycle variants as it represents the highest power density two-cycle diesel engine in the Army's fleet. For this test, candidate oils must be able to provide adequate protection of the interface between the piston and liner surface to prevent cylinder scuffing, as well as protect the load bearing slipper bushings located between each connecting rod and articulated piston assembly. The DDC 6V53T is a 318C.I., turbo-supercharged, non-intercooled, direct injected, V6 diesel engine. Fueling is controlled through cam driven mechanical unit injectors, and the engine produces approximately 235hp using JP-8 fuel. The DDC 6V53T tested was configured as used in the M113A3 Armored Personnel Carrier (APC). A MIL-PRF-2104H oil evaluation was completed prior to SCPL testing to establish a current baseline for revised SCPL candidate comparison. Following the baseline, each revised candidate SCPL was tested to determine performance with respect to engine wear, oil life expectancy, and deposit formation.

In addition, each revised candidate SCPL was also evaluated in the American Society of Testing Methods (ASTM) D5966-10 roller follower wear test. This test evaluates a lubricants ability to protect roller follower valve train components from wear in high load at low to moderate engine speed scenarios. This test utilizes a General Motors (GM) 6.5L(NA) diesel engine which is the basis of GEP family of engines powering the HMMWV, and specifically monitors critical roller axle wear on the hydraulic lifters.

## 2.2 TRANSMISSION COMPATIBILITY

In addition to engine crankcase applications, the SCPL is intended to be used in power shift transmissions where MIL-PRF-2104 products are currently utilized. To ensure revised SCPL candidate compatibility in these applications, several industry established standardized transmission tests were completed to assess each of the candidates' frictional properties. These tests included:

- Caterpillar TO-4
  - Sequence 1220 – Sintered Bronze
  - Sequence 1222 – Wheel Brake Paper
- Allison C4
  - High Energy Friction – Graphite
  - High Energy Friction – Paper
- John Deere Qualification
  - JDQ-96 Wet Brake (abbreviated 1k cycles)

From these standardized transmission tests, revised candidate SCPL results could be compared to automatic transmission fluid (ATF) reference tests and past results of current MIL-PRF-2104 products. As with current MIL-PRF-2104 products, it is expected that the utilization of formulated engine oils in powershift transmission applications could forfeit some of the refined benefits of a purpose built ATF. Although these refinements are good goals for the SCPL, the primary requirement for candidates in these tests was to ensure that adequate performance was retained (i.e., acceptable frictional properties, torque capacity, protection, etc), and that the SCPL would meet or exceed the performance of MIL-PRF-2104 oils currently in utilization. Operator feel and noise, vibration, and harshness (NVH) effects are important in the commercial formulation of an ATF, but are of lesser concern to the military in comparison to overall functionality and durability of the equipment.

### 2.3 ENGINE FUEL CONSUMPTION IMPROVEMENT

Revised SCPL candidate lubricants were also evaluated for fuel consumption changes using a GEP 6.5L(T) diesel engine dynamometer test. Consistent with testing under Part 1, the cycle used to measure fuel consumption changes evaluated each lubricant over a range of load points and oil sump temperatures derived from previously acquired data from HMMWV operation at Ft. Hood, TX [8]. Unlike testing completed during Part 1 that used both new and “aged” lubricants to determine fuel consumption changes, only the new lubricants were tested on the revised candidate evaluations.

# 3.0 DISCUSSION OF RESULTS

The following sections outline and discuss test results acquired during revised candidate testing of the SCPL. These include: revised candidate chemical and physical analysis results, engine compatibility and oil endurance testing (includes GEP 6.5L(T), DDC 6V53T, and ASTM D5966 RFWT), standardized transmission compatibility tests, and fuel consumption improvement quantification.

## 3.1 SCPL CANDIDATE CHEMICAL & PHYSICAL PROPERTIES

Each revised SCPL candidate received was initially tested to document its chemical and physical properties to determine how closely it aligned with the goals of the SCPL. Analytical test results from each revised SCPL candidate can be seen in Table 1. Results from their respective initial candidates from Part 1 were included into the table for comparison. Observations from the analyses are listed below:

- Both revised candidates appear to have a slightly increased viscosity from the initial candidates, but still classify as an SAE 0W20 viscosity grade lubricant
- NOACK volatility increased for both candidates outside of the desired range as stated in the original request for experimental products (target 10%, minimum acceptable 11%)
- Shear stability improved for LO268869, remained consistent with LO271510
- All other properties were comparable from initial to revised candidate

**Table 1. Baseline & SCPL Candidate Preliminary Chemical & Physical Properties**

| - | - | - | - | Initial Candidates (Part 1) | | Revised Candidates (Part 2) | |
|---|---|---|---|---|---|---|---|
| - | - | - | - | a | b | a | b |
| - | - | - | - | LO-253071 | LO-251746 | LO-268869 | LO-271510 |
| **Method** | **Temp** | **Property** | **Units** | | | | |
| **D445** | **-40°C** | **Viscosity** | cSt | 7661.6 | 11158 | 14798.2 | 12885.34 |
| **D445** | **40°C** | **Viscosity** | cSt | 43.36 | 42.52 | 47.39 | 45.34 |
| **D445** | **100°C** | **High Temp Viscosity** | cSt | 8.42 | 8.13 | 8.6 | 8.49 |
| **D445 LT** | **-48°C** | **Low Temp Viscosity** | cSt | 36325.09 | 38427.23 | 27003.4* | ** |
| **D2983** | **-40°C** | **Brookfield Viscosity** | cPs | 10878 | 11158 | 12517 | 11917 |
| **D4683 TBS** | **150°C** | **Tapered Bearing Shear Viscosity** | cPs | 2.69 | 2.59 | 2.73 | 2.68 |
| **D4684** | **-40°C** | **Apparent Viscosity** | mPa/s | 10300 | 10000 | 12000 | 11000 |
| **D5293 COLD** | **-35°C** | **Cold Cranking** | mPa/s | 4190 | 4070 | 4864 | 4319 |
| **D5800** | | **Noack Volitility** | wt% | 10 | 12.4 | 12 | 14.3 |
| **D7109** | **100°C** | **Shear Stability** | | | | | |
| | | *Viscosity @ 100C after 30 Passes* | cSt | 8.33 | 8.11 | 8.59 | 8.43 |
| | | *Viscosity loss after 30 Passes* | % Loss | 1.07 | 0.25 | 0.12 | 0.71 |
| | | *Viscosity @ 100C after 90 Passes* | cSt | 8.22 | 8.07 | 8.55 | 8.47 |
| | | *Viscosity loss after 90 Passes* | % Loss | 2.38 | 0.74 | 0.58 | 0.24 |
| **D97** | | **Pour Point** | °C | -60 | <-60 | <-63 | <-60 |

*Results is suspect. No re-test results available.
**Initial sample found too viscous to obtain repeatable results. Re-test conducted by lube supplier yielded 47,939 cSt.

## 3.2 GEP 6.5L(T) Engine Durability Testing

The following section discusses the results obtained during the GEP 6.5L(T) engine durability portion of the SCPL development. Focus areas include construction of the engine durability test stand, description of the test cycle, and the revised SCPL candidate evaluation results (used oil analysis, engine metrology, and deposit ratings).

### 3.2.1 Test Stand Construction

The same GEP 6.5L(T) high temperature engine oil endurance test stand constructed during Part 1 of the SCPL development was used to evaluate each revised candidate during Part 2. As previously discussed, the GEP 6.5L(T) diesel engine was selected for SCPL evaluations due to its high severity on engine lubricants, and its high density in the military's tactical wheeled fleet. The GEP 6.5L(T) engine utilized for testing was purchased directly from General Engine Products, a subsidiary of AM General, the original equipment manufacturer (OEM) for the HMMWV. The 2HT GEP 6.5L(T) engine model tested is rated at 190 hp at 3400 rpm, and 380 lb-ft at 1800 rpm using diesel fuel. When utilizing JP-8, as was the case during the SCPL testing, power levels typically drop to around 170 hp and 320 lb-ft of torque at their respective peaks. To serve as a consistent test bed, this dedicated engine test stand was built to complete all of the high temperature evaluations for each initial and revised SCPL candidates. A picture of the GEP 6.5L(T) engine installation can be seen in Figure 1.

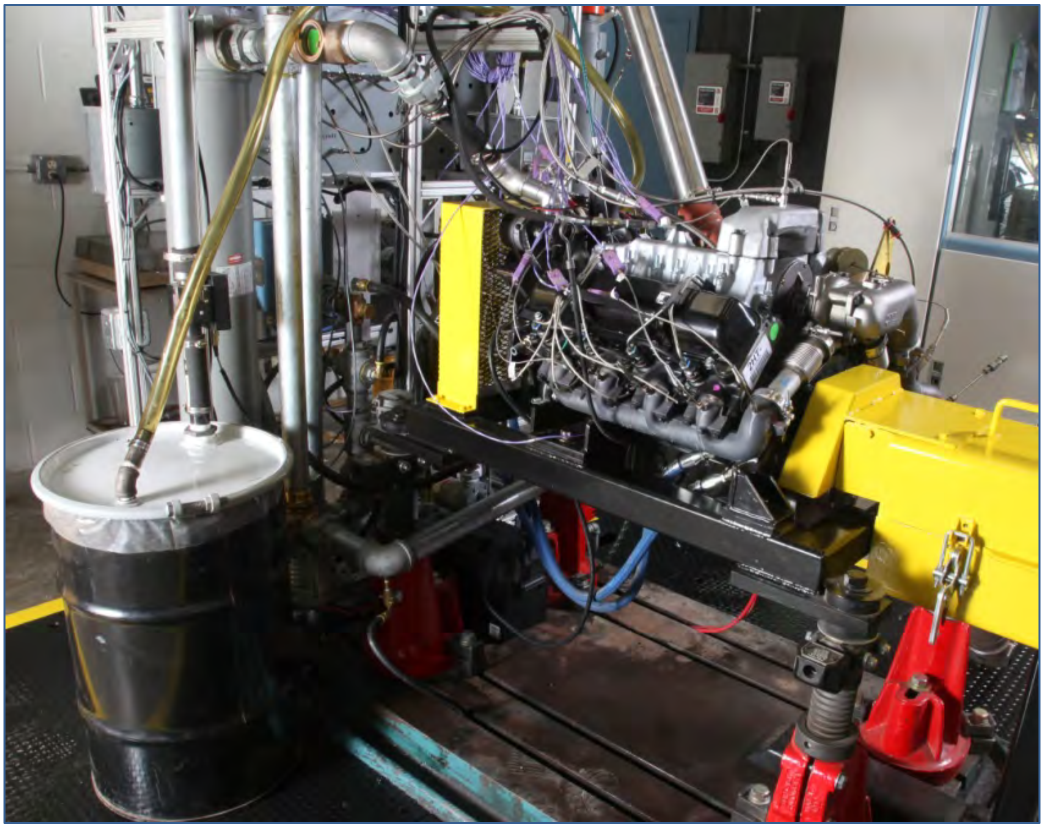

**Figure 1. General Engine Products 6.5L(T) Test Cell Installation**

The 6.5L(T) engine was mounted in a test cell at TFLRF with an engine dynamometer and equipped with all necessary ancillary equipment to operate the engine, with the exception of accessory equipment that would be installed and utilized in a vehicle (i.e., alternator, cooling fan, etc.). The bulleted list below outlines the basic hardware configuration utilized on the GEP 6.5L(T) engine dyno evaluations:

- The engine used SwRI developed PRISM data acquisition software to monitor and control engine operation throughout testing. Monitored engine parameters included all critical temperatures, pressures, and flow rates, as well as the engine's speed and output power/torque.
- Engine loading was provided by an eddy current engine dynamometer and an electro mechanical throttle actuation system. The dynamometer controlled overall engine speed, while the throttle actuation system adjusted the injection pump's rack position via a throttle cable to the injection pump rack.

- Liquid-liquid heat exchangers were used to regulate the engine water jacket and oil sump temperatures with building supplied process water.
- Fuel was supplied from bulk storage tanks to an engine "day-tank" that served as a common location for the engine supply and return lines. The engine's fuel consumption was monitored by a coriolis flow meter for measuring the make-up fuel required to maintain the day tank at a constant volume.
- Inlet fuel temperature was controlled by a secondary heater control loop to maintain steady temperatures throughout testing. The control loop maintained a reservoir of a glycol-water solution at a specified temperature, and was then used as a heat source to elevate the incoming fuel to the desired set point through a liquid-liquid heat exchanger.
- Engine inlet air was drawn past a chilled water core to lower intake air temperatures prior to the engine air filtering system. This was required to maintain exhaust gas temperatures at safe levels during the long segments of continuous operation at rated speed and load during the test cycle. Air was filtered through an OEM-style air filter housing with an adjusting valve to vary intake air depression prior to the turbocharger inlet.
- Engine exhaust gases were ducted into an exhaust ventilation system integrated into the engine laboratory building. Back-pressure was controlled through a butterfly valve located in the exhaust stack prior to the buildings common exhaust header exiting the test cell.
- Engine blow-by gases were ducted into a drum to capture any entrained oil, and then vented through a hot-wire flow meter to monitor engine blow-by rates. Waste gases were then ducted to the buildings exhaust ventilation system at ambient pressure (to not effect crankcase pressure) to expel blow-by gasses from the test cell.
- Engine coolant was a 60/40 blend of ethylene glycol and de-ionized water.
- Fuel used during testing was JP-8 blended at location from commercially available Jet A with a double max-treat rate of lubricity enhancer DCI-4A. (Appendix G).

### 3.2.2 Test Cycle Operation

Consistent with Part 1, the test cycle used for revised candidate evaluations was a modified version of the 210 hour Tactical Wheeled Vehicle cycle as outlined in CRC Report No. 406, Development of Military Fuel/Lubricant/Engine Compatibility Test [9]. At time of its publishing, the standard 210 hour tactical wheeled vehicle laboratory engine cycle was correlated to 20,000 miles of actual military vehicle proving ground operation. For SCPL testing, modifications were made to the test temperature specifications to further increase the severity on the oil being tested in an effort to raise the standards for the baseline and candidate tests. Test termination would occur at the completion of the scheduled 210 hours, or upon major oil degradation, which ever occurred first. The test cycle consisted of alternating between two hours at rated speed and load followed by one hour at no-load idle. This was completed for 14 hours daily, followed by a 10 hour engine-off soak period to allow time for chemical reactions to take place in the oil sump. Engine oil temperatures were elevated during rated speed and load test conditions to simulate high ambient temperatures typical of desert operations. During no-load idle steps, engine temperatures (oil sump and coolant) were lowered to stress the lubricant through thermal cycling. The critical engine operating parameters controlled throughout testing are specified in Table 2. For consistency, engine output torque was controlled to a value of 256 lb-ft of torque for each test. This is a slight reduction of the typical total capable torque output of the GEP 6.5L(T), but was selected so that any full load output variation between test engines would not bias any single SCPL evaluation. To target this output torque, the throttle actuation control system would slightly back off of the injection pump rack position to meet the specified output, and control it over the test duration. This provided a consistent loading of all the internal engine components, so that each lubricant tested would be subjected to the same internal engine conditions as possible. The oil sump temperature specification of 260 °F for the rated speed and load step was selected based off a 4% increase in general requirement for MIL-PRF-2104 lubricants to be capable of continuous operation at 250 °F. This further stressed the SCPL candidates ability to control engine oil oxidation, which is a function of time at elevated temperatures. Coolant jacket outlet temperature during the rated speed and load step was maintained at 205 °F to maintain engine integrity throughout the test cycle.

**Table 2. Tactical Wheeled Vehicle Test Cycle Operating Conditions**

| Parameter | Rated Speed & Load | No-Load Idle |
|---|---|---|
| Engine Speed [RPM] | 3400 +/- 25 | 900 +/- 25 |
| Engine Output Torque [lb-ft] | 256 +/- 5 | Not specified |
| Water Jacket Out [°F] | 205 +/- 5 | 100 +/- 5 |
| Oil Sump [°F] | 260 +/- 5 | 125 +/- 5 |

Used engine oil samples were collected every 14 hours for chemical and physical analysis. These data were used to assess the condition of the lubricant and to determine test termination if necessary. Tests conducted on daily samples are outlined below in Table 3. The oil level of the engine was replenished daily after sampling to restore it to its proper level. All engine oil additions and samples were weighed throughout testing to track engine oil consumption.

**Table 3. Used Oil Analysis Tests**

| *Every 14hrs* | | |
|---|---|---|
| **ASTM** | **D4739** | Total Base Number |
| **ASTM** | **D664** | Total Acid Number |
| **ASTM** | **D445** | Kinematic Viscosity @ 100°C |
| **ASTM** | **API Gravity** | API Gravity |
| **ASTM** | **D4052** | Density |
| **ASTM** | **TGA SOOT** | TGA Soot |
| **ASTM** | **E168** | Oxidation |
| **ASTM** | **E168** | Nitration |
| **ASTM** | **D5185** | Wear Metals by ICP |

| *Every 70hrs* | | |
|---|---|---|
| **ASTM** | **D445** | Kinematic Viscosity @ 40°C |
| **ASTM** | **D2270** | Kinematic Viscosity Index |

### 3.2.3 Engine Metrology and Ratings

Each revised SCPL evaluation started with a new GEP 6.5L(T) engine. Prior to testing, each engine was disassembled to complete a pre-test inspection and metrology process. Engines were inspected for manufacturing defects (corrected as needed), and measurements of critical engine components were taken to document pre-test engine condition. These pre-test metrology procedures included measurements of:

- Crankshaft main bearing mass
- Connecting rod bearing mass
- Top, second, and bottom piston ring mass
- Top, and second piston ring radial thickness
- Piston ring end gap (in block)
- Piston skirt diameter

Piston bore diameter (measured top, mid, and bottom of bore in the transverse and longitudinal directions)

After the inspection and metrology process was completed, engines were reassembled according to factory specifications. During assembly, parts requiring lubrication were assembled using an additive free assembly lubricant. This is consistent with many ASTM standardized tests procedures, as to remove any bias on subsequent lubricant test data.

At the completion of each endurance test, the engine was once again disassembled and inspected. This allowed for documentation of wear experienced over the test duration. Since each test was terminated based on used oil condition and not operated for a fixed period of time, straight across comparisons of engine wear for each lubricant from metrology measurements cannot be completed. Many wear parameters are a function of total engine operation time, with the lubricant condition having a smaller impact. For example, ring wear experienced in an 84 hour test cannot be directly compared to a 140 hour test due to the difference in test length. Regardless, metrology measurements still prove useful in showing indications of overall wear patterns, and help to identify any large outliers during testing. Similar to pretest metrology, post-test procedures included measurements of:

- Crankshaft main bearing mass
- Connecting rod bearing mass
- Top, second, and bottom piston ring mass
- Top, and second piston ring radial thickness
- Piston ring end gap (in block)
- Piston skirt diameter
- Piston bore diameter (measured top, mid, and bottom bore in the transverse and longitudinal direction)

In addition to post-test metrology, engine pistons and valves received deposit ratings to quantify the amount and location of carbonaceous and lacquer type deposits present. This process was completed following industry standardized ASTM deposits and rating procedures [10]. This was done to quantify the overall cleanliness of the lubricant and its ability to control harmful engine deposits when tested under severe conditions.

### 3.2.4 Revised Candidate Evaluation Results

Table 4 shows the engine operating summary for each revised SCPL candidate run during the rated speed and load step compared to its initial candidate evaluation. This shows the consistency that was achieved between the two revised candidate evaluation tests, and the initial candidates evaluated during Part 1. For both revised candidates, the overall averaged torque was slightly below the target 256 lb-ft, but within the +/- 5 lb-ft repeatability margin. Due to variation in absolute engine output between each production based engine, some engines only marginally meet the 256 lb-ft target at the start of testing, and upon oil aging and thickening within the crankcase, the engine output power/torque would begin to drop below the threshold. This small variation in engine torque output is not considered to have biased these evaluations, as overall engine oil sump temperature is expected to be the driving factor in lubricant degradation. The consistency achieved for the more critical engine oil sump temperature can be seen in Table 4.

**Table 4. SCPL Revised Candidate Evaluations, Rated Engine Operation Summary**

| | | LO253071 Initial Candidate **Rated Conditions (3400 RPM)** | | LO268869 Revised Candidate **Rated Conditions (3400 RPM)** | | LO251746 Initial Candidate **Rated Conditions (3400 RPM)** | | LO271510 Revised Candidate **Rated Conditions (3400 RPM)** | |
|---|---|---|---|---|---|---|---|---|---|
| **Perameter:** | **Units:** | **Average** | **Std. Dev.** | **Average** | **Std. Dev.** | **Average** | **Std. Dev.** | **Average** | **Std. Dev.** |
| Engine Speed | RPM | 3400.02 | 0.82 | 3400.01 | 0.73 | 3400.00 | 0.72 | 3400.01 | 0.76 |
| Torque* | lb-ft | 251.40 | 4.43 | 253.98 | 2.61 | 256.24 | 1.74 | 254.23 | 2.88 |
| Fuel Flow | lb/hr | 82.51 | 1.06 | 79.24 | 0.79 | 77.86 | 0.89 | 80.52 | 0.83 |
| Power* | bhp | 162.74 | 2.87 | 164.42 | 1.68 | 165.88 | 1.11 | 164.58 | 1.86 |
| BSFC* | lb/bhp*hr | 0.507 | 0.012 | 0.482 | 0.007 | 0.469 | 0.006 | 0.489 | 0.006 |
| **Temperatures:** | | | | | | | | | |
| Coolant In | °F | 190.31 | 0.92 | 190.06 | 1.09 | 191.39 | 0.73 | 190.40 | 0.92 |
| Coolant Out | °F | 205.00 | 0.84 | 205.00 | 1.01 | 204.99 | 0.66 | 204.99 | 0.84 |
| Oil Sump | °F | 260.02 | 0.41 | 260.05 | 0.44 | 259.96 | 0.37 | 260.05 | 0.50 |
| Fuel In | °F | 95.00 | 0.31 | 95.02 | 0.31 | 95.01 | 0.33 | 95.01 | 0.34 |
| Intake Air | °F | 69.72 | 4.99 | 74.94 | 3.62 | 69.95 | 2.24 | 68.33 | 3.34 |
| Cylinder 1 Exhaust | °F | 1148.60 | 9.38 | 1136.32 | 15.48 | 1098.38 | 14.59 | 1135.40 | 16.16 |
| Cylinder 2 Exhaust | °F | 1104.56 | 14.95 | 1204.35 | 10.67 | 1158.88 | 18.88 | 1205.01 | 13.90 |
| Cylinder 3 Exhaust | °F | 1216.91 | 13.84 | 1186.67 | 14.53 | 1224.78 | 31.99 | 1206.48 | 16.88 |
| Cylinder 4 Exhaust | °F | 1158.22 | 17.08 | 1141.38 | 14.00 | 1115.13 | 16.48 | 1144.29 | 15.49 |
| Cylinder 5 Exhaust | °F | 1173.29 | 9.48 | 1152.53 | 16.09 | 1181.29 | 25.83 | 1162.88 | 14.26 |
| Cylinder 6 Exhaust | °F | 1206.17 | 21.87 | 1162.03 | 13.27 | 1118.51 | 17.07 | 1166.94 | 17.23 |
| Cylinder 7 Exhaust | °F | 1133.30 | 10.52 | 1150.77 | 14.52 | 1123.50 | 19.87 | 1144.28 | 18.44 |
| Cylinder 8 Exhaust | °F | 1189.49 | 23.12 | 1147.97 | 11.32 | 1144.84 | 18.46 | 1164.26 | 13.81 |
| **Pressures:** | | | | | | | | | |
| Oil Galley | psi | 34.70 | 0.74 | 35.94 | 0.56 | 37.13 | 0.99 | 36.96 | 1.59 |
| Ambient Pressure | psiA | 14.25 | 0.05 | 14.26 | 0.05 | 14.23 | 0.04 | 14.30 | 0.07 |
| Boost Pressure | psi | 4.95 | 0.11 | 4.32 | 0.08 | 3.96 | 0.09 | 4.84 | 0.12 |

* Non-corrected Values

Figure 2 shows the TAN/TBN response of each revised candidate and its respective initial evaluation. Revised candidate LO268869 showed a large improvement in TAN/TBN control compared to its initial evaluation (LO253071). The TAN/TBN cross over for its evaluation occurred approximately 50 hours later in the test cycle, and the useful lubricant life was extended by over 80 hours. Revised candidate LO271510 showed a smaller improvement over its initial evaluation (LO251746), but still extended the useful lubricant life by 28 hours. Although this improvement was smaller, the performance achieved by its initial candidate (LO251746) was greater than that shown by LO268869's initial candidate during Part 1, so less change was expected overall. Despite the improvement shown by candidate LO271510, it still did not reach the full 210 hour test target, with testing being terminated at 196 hours due to oil condition. From comparing the slopes of the TAN/TBN curves for LO271510 to its initial evaluation (LO251746), it appears that the formulation changes had little impact on the oils overall ability to resist degradation, resulting in similar degradation rates being observed during both evaluations. In the end, the used oil condition of LO268869 at EOT is more favorable than that of LO271510.

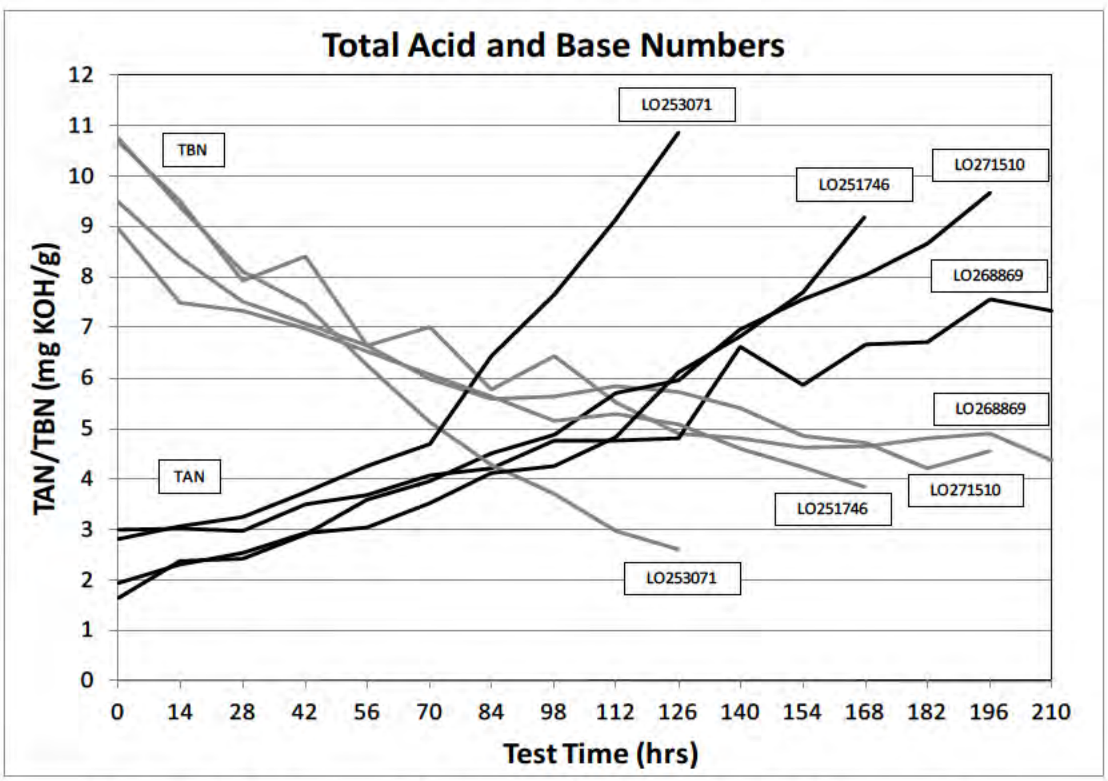


**Figure 2. SCPL Revised Candidate Evaluations, TAN/TBN Response**

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Like the TAN/TBN results, the used oil oxidation and nitration curves presented in Figure 3 show similar trends. LO268869 showed the largest improvement over its initial candidate (LO253071) with an approximate 50% reduction in overall oxidation at end of test (EOT). LO271510 showed overall similar oxidation rates as its initial candidate (LO251746) testing which resulted in a slightly higher end of test oxidation rate due to the extended length of operation.

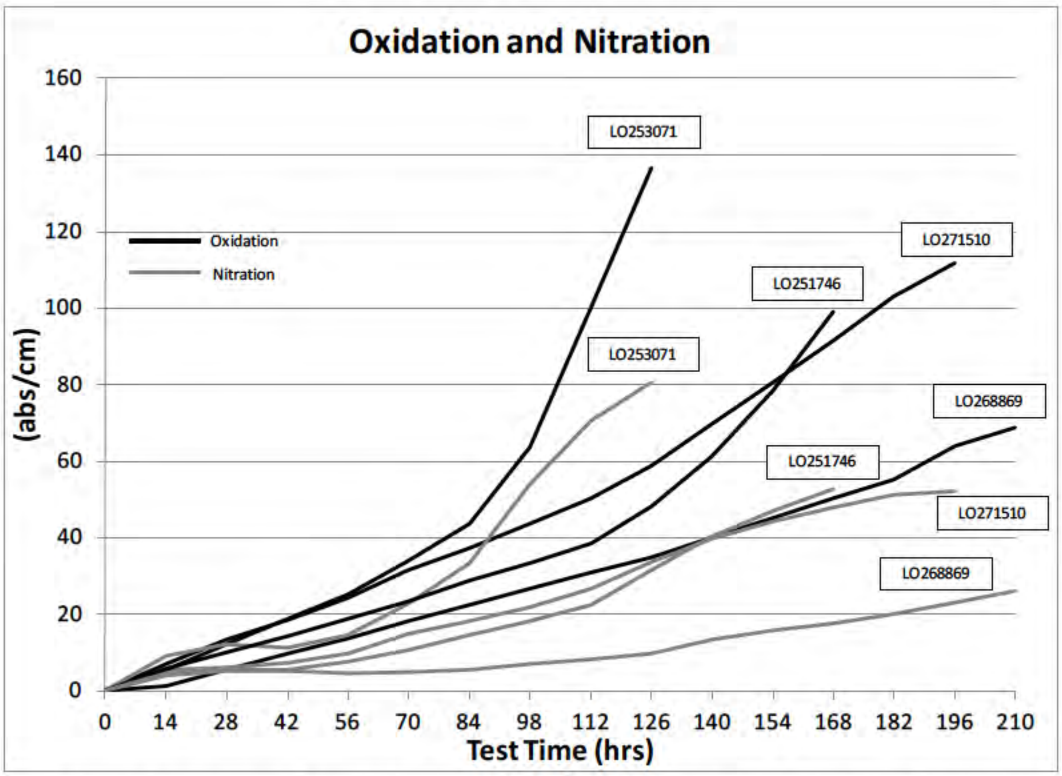


Figure 3. SCPL Revised Candidate Evaluations, Oxidation and Nitration Response

Figure 4 shows the lead and copper wear metal accumulations for the initial and revised SCPL evaluations. As before, revised candidate LO268869 showed much improvement from its initial evaluation (LO253071,) in which the initial candidate broke early in the test and experienced rapid accumulation of lead (Pb) and copper (Cu) wear metals topping 500 ppm and 300 ppm respectively. These wear metals are indicative of main bearing and connecting rod bearing distress, and serve as a good litmus test for this engine to monitor how well an oil is protecting critical engine components. During the LO268869 revised candidate evaluation, the overall oil condition remained favorable, which showed in these reduced key wear metals that remained under 100 ppm for over the entire 210 hour duration. Conversely, revised candidate LO271510 showed effectively no change in wear metal accumulation rates from its initial evaluation. This resulted in an overall higher total accumulation by the end of testing due to the increased test length. Lead wear metals in this evaluation approached 250 ppm at EOT.

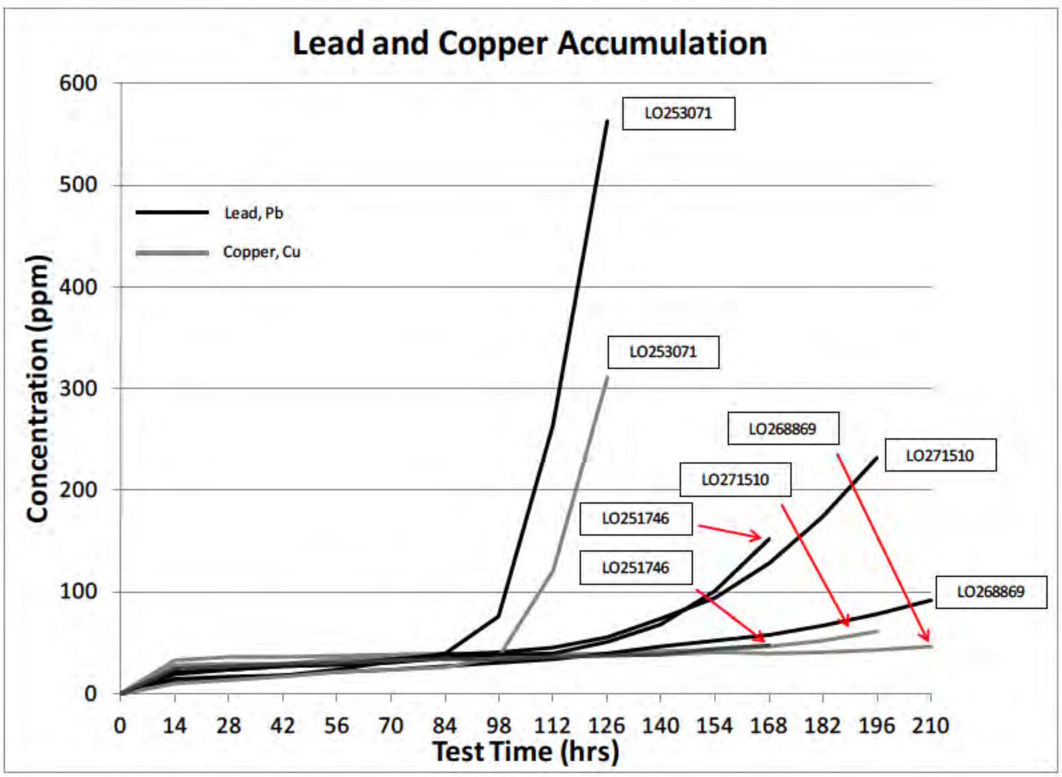


**Figure 4. SCPL Revised Candidate Evaluations, Lead and Copper Accumulation**

Table 5 shows the overall accumulated oil consumption rates for the revised and initial SCPL evaluation runs. Hourly consumption rates for each revised candidate were in line with what was seen previously in Part 1. Both revised candidates showed a slightly higher consumption rate than their initial evaluation. This is likely attributed to the increased volatility that both revised candidates showed over their initial submittals.

**Table 5. SCPL Candidate Evaluations, Accumulated Oil Consumption Rate**

| | LO253071 | LO268869 | LO251746 | LO271510 |
|---|---|---|---|---|
| **Engine Oil Consumption [lb/hr]** | 0.069 | 0.081 | 0.072 | 0.084 |

Table 6 shows the main bearing mass changes for each of the revised and initial SCPL candidate evaluations. As reported during Part 1, the number three thrust bearing mass is omitted from calculations. This is due to a large variation in thrust surface wear on the number three main bearing from loading attributed to interactions between the dynamometer and engine coupling. From past experience, these varying thrust loads applied during testing have resulted in inconsistent thrust surface wear which biases main bearing mass change measurements. Both maximum and average weight change for the remaining bearings were increased from their initial evaluations. Although unusual, the overall values still fall within the range of variations (0.03 to 0.15 grams) seen during the MIL Spec and commercial 15W-40 oil evaluations completed during Part 1, and thus are not considered out of line.

**Table 6. SCPL Revised Candidate Evaluations, Main Bearing Mass Changes, grams**

| | | Main Bearing Mass Changes (grams) | | | |
|---|---|---|---|---|---|
| | | *initial* | *revised* | *initial* | *revised* |
| **Main Bearing** | **Shell** | **LO253071** | **LO268869** | **LO251746** | **LO271510** |
| **1** | Top | 0.0171 | 0.0471 | 0.0257 | 0.0328 |
| | Bottom | 0.0146 | 0.0983 | 0.0237 | 0.0581 |
| **2** | Top | 0.0205 | 0.0323 | 0.0240 | 0.0319 |
| | Bottom | 0.0891 | 0.2106 | 0.0338 | 0.2133 |
| **3** | Thrust Bearing Excluded From Calculations | | | | |
| **4** | Top | 0.0124 | 0.0272 | 0.0293 | 0.0359 |
| | Bottom | 0.0385 | 0.1414 | 0.0305 | 0.1148 |
| **5** | Top | 0.0777 | 0.0603 | 0.0411 | 0.0563 |
| | Bottom | 0.1066 | 0.0934 | 0.0830 | 0.1152 |
| | Maximum | 0.1066 | 0.2106 | 0.0830 | 0.2133 |
| | Average | 0.0471 | 0.0888 | 0.0364 | 0.0823 |

Table 7 shows the connecting rod bearing mass changes for the revised and initial SCPL candidate evaluations. Average and maximum connecting rod bearing mass changes for the revised SCPL evaluations were reduced from their initial evaluations, and result in some of the lowest values seen compared to the previous testing completed during Part 1 (0.02 to 0.04 gram variation).

**Table 7. SCPL Revised Candidate Evaluations, Connecting Rod Bearing Mass Changes, grams**

| | | Rod Bearing Mass Changes (grams) | | | |
|---|---|---|---|---|---|
| | | *initial* | *revised* | *initial* | *revised* |
| **Rod Bearing** | **Shell** | **LO253071** | **LO268869** | **LO251746** | **LO271510** |
| **1** | Top | 0.1668 | 0.0239 | 0.0339 | 0.0131 |
| | Bottom | 0.0598 | 0.0106 | 0.0347 | 0.0165 |
| **2** | Top | 0.0289 | 0.0172 | 0.0147 | 0.0157 |
| | Bottom | 0.0374 | 0.0088 | 0.0177 | 0.0134 |
| **3** | Top | 0.0520 | 0.0473 | 0.0239 | 0.0231 |
| | Bottom | 0.0540 | 0.0361 | 0.0290 | 0.0070 |
| **4** | Top | 0.0135 | 0.0175 | 0.0431 | 0.0165 |
| | Bottom | 0.0082 | 0.0124 | 0.0695 | 0.0105 |
| **5** | Top | 0.0316 | 0.0275 | 0.0158 | 0.0136 |
| | Bottom | 0.0612 | 0.0134 | 0.0155 | 0.0139 |
| **6** | Top | 0.0338 | 0.0264 | 0.0454 | 0.0127 |
| | Bottom | 0.0342 | 0.0153 | 0.0703 | 0.0078 |
| **7** | Top | 0.0139 | 0.0250 | 0.0664 | 0.0169 |
| | Bottom | 0.0188 | 0.0189 | 0.0564 | 0.0178 |
| **8** | Top | 0.0115 | 0.0142 | 0.0416 | 0.0164 |
| | Bottom | 0.0098 | 0.0130 | 0.0542 | 0.0165 |
| | Maximum | 0.1668 | 0.0473 | 0.0703 | 0.0231 |
| | Average | 0.0397 | 0.0205 | 0.0395 | 0.0145 |

Table 8 shows the camshaft lobe peak surface variation for each of the revised and initial SCPL candidate evaluations. From testing completed during Part 1, a typical range of 1.4 to 1.9 microns was established as normal. During its initial evaluation, candidate LO253071 showed an unusually high value of 3.1 micron variation, but its revised candidate LO268869 improved on this and brought total average variation in line with normally expected values yielding a total variation of 1.7 microns. Revised candidate LO271510 also improved from its initial (LO251746) evaluation, and showed the lowest variation seen to date at 1.1 microns. This suggest that both revised candidates are adequately protecting the camshaft from wear.

**Table 8. SCPL Revised Candidate Evaluations, Cam Lobe Peak Surface Variation**

| Cam Lobe Waviness Parameter [µm] | | | | |
|---|---|---|---|---|
| | *initial* | *revised* | *initial* | *revised* |
| Cam Lobe | LO253071 | LO268869 | LO251746 | LO271510 |
| 1 | 3.49 | 1.73 | 1.74 | 1.07 |
| 2 | 3.00 | 1.24 | 1.47 | 0.95 |
| 3 | 3.80 | 1.47 | 1.60 | 0.92 |
| 4 | 2.79 | 1.17 | 1.58 | 1.32 |
| 5 | 2.24 | 1.66 | 1.38 | 0.83 |
| 6 | 2.40 | 2.21 | 1.94 | 1.44 |
| 7 | 2.78 | 1.82 | 1.46 | 1.01 |
| 8 | 3.37 | 1.31 | 2.25 | 1.23 |
| 9 | 5.34 | 2.24 | 1.53 | 1.18 |
| 10 | 2.97 | 1.43 | 1.92 | 1.03 |
| 11 | 2.39 | 0.91 | 1.41 | 1.06 |
| 12 | 4.16 | 1.24 | 3.33 | 1.05 |
| 13 | 3.04 | 2.06 | 1.72 | 1.10 |
| 14 | 2.44 | 2.98 | 1.49 | 1.14 |
| 15 | 3.10 | 1.59 | 1.54 | 1.25 |
| 16 | 2.06 | 1.42 | 1.67 | 1.02 |
| Maximum | 5.34 | 2.98 | 3.33 | 1.44 |
| Average | 3.09 | 1.66 | 1.75 | 1.10 |

Table 9 shows the ring pack mass loss for each of the revised and initial SCPL candidate evaluations. Average and maximum weight loss changes for both revised SCPL candidates were generally in line with what was seen during the initial evaluations (Note: for candidate LO251746 piston number 8 oil control ring, mass loss shows as 0.5625 grams. This appears to be an isolated anomaly, and is not representative of the remaining oil control rings changes on pistons 1 through 7). Ring weight loss is predominately attributed to the overall viscosity of the lubricating fluid impacting the film thickness seen at the piston liner wall interface. Since the revised candidates did not have any significant viscosity change, no large changes were expected in the weight loss measurements.

**Table 9. SCPL Candidate Evaluations, Piston Ring Mass Changes**

| Piston Ring Mass Changes | | | | | |
|---|---|---|---|---|---|
| | | *initial* | *revised* | *initial* | *revised* |
| **Cylinder** | **Ring No.** | **LO253071** | **LO268869** | **LO251746** | **LO271510** |
| **1** | 1 | 0.0678 | 0.1008 | 0.0768 | 0.0631 |
| | 2 | 0.0241 | 0.0313 | 0.0260 | 0.0234 |
| | 3 | 0.0160 | 0.0125 | 0.0154 | 0.0121 |
| **2** | 1 | 0.0661 | 0.0987 | 0.0875 | 0.0725 |
| | 2 | 0.0290 | 0.0366 | 0.0262 | 0.0273 |
| | 3 | 0.0160 | 0.0143 | 0.0135 | 0.0115 |
| **3** | 1 | 0.0790 | 0.0899 | 0.0914 | 0.0800 |
| | 2 | 0.0342 | 0.0391 | 0.0247 | 0.0308 |
| | 3 | 0.0198 | 0.0182 | 0.0167 | 0.0138 |
| **4** | 1 | 0.0676 | 0.0845 | 0.0857 | 0.0929 |
| | 2 | 0.0252 | 0.0338 | 0.0273 | 0.0296 |
| | 3 | 0.0163 | 0.0170 | 0.0191 | 0.0127 |
| **5** | 1 | 0.0740 | 0.1054 | 0.0786 | 0.0800 |
| | 2 | 0.0261 | 0.0437 | 0.0264 | 0.0234 |
| | 3 | 0.0182 | 0.0164 | 0.0190 | 0.0116 |
| **6** | 1 | 0.0993 | 0.0918 | 0.0937 | 0.1007 |
| | 2 | 0.0328 | 0.0392 | 0.0277 | 0.0252 |
| | 3 | 0.0223 | 0.0163 | 0.0173 | 0.0123 |
| **7** | 1 | 0.0635 | 0.0809 | 0.0905 | 0.0992 |
| | 2 | 0.0256 | 0.0333 | 0.0236 | 0.0317 |
| | 3 | 0.0188 | 0.0147 | 0.0129 | 0.0131 |
| **8** | 1 | 0.0828 | 0.0865 | 0.0716 | 0.1007 |
| | 2 | 0.0277 | 0.0311 | 0.0268 | 0.0263 |
| | 3 | 0.0186 | 0.0188 | 0.5625 | 0.0122 |
| Maximum Ring 1 | | 0.0993 | 0.1054 | 0.0937 | 0.1007 |
| Maximum Ring 2 | | 0.0342 | 0.0437 | 0.0277 | 0.0317 |
| Maximum Ring 3 | | 0.0223 | 0.0188 | 0.5625 | 0.0138 |
| Average Ring 1 | | 0.0750 | 0.0923 | 0.0845 | 0.0861 |
| Average Ring 2 | | 0.0281 | 0.0360 | 0.0261 | 0.0272 |
| Average Ring 3 | | 0.0183 | 0.0160 | 0.0846 | 0.0124 |

Lastly, Table 10 shows the 8 piston average deposit ratings for each of the revised and initial SCPL candidate evaluations. Overall deposit demerits of the revised candidates slightly increased from their initial evaluations. Total demerits were still well within ranges seen during testing completed in Part 1, and none of the deposits seen during the revised candidate evaluations would be considered excessive and harmful to engine operation.

**Table 10. SCPL Candidate Evaluations, Piston Deposits**

| Piston Deposits | | | | |
|---|---|---|---|---|
| Ratings | Cylinder Average | | | |
| | *initial* | *revised* | *initial* | *revised* |
| | LO253071 | LO268869 | LO251746 | LO271510 |
| **Ring Sticking** | | | | |
| Ring No.1 | No | No | No | No |
| Ring No.2 | No | No | No | No |
| Ring No.3 | No | No | No | No |
| **Scuffing % Area** | | | | |
| Ring No.1 | 0 | 0 | 0 | 0 |
| Ring No.2 | 0 | 0 | 0 | 0 |
| Ring No.3 | 0 | 0 | 0 | 0 |
| Piston Crown | 0 | 0 | 0 | 0 |
| Piston Skirt | 0 | 0 | 0 | 0 |
| Cylinder Liner, % | 0 | 0 | 0 | 0 |
| **Piston Carbon, Demerits** | | | | |
| No.1 Groove | 43.88 | 60.59 | 36.28 | 48.72 |
| No.2 Groove | 0.66 | 3.10 | 5.84 | 3.66 |
| No.3 Groove | 0.31 | 0.00 | 0.00 | 0.00 |
| No.1 Land | 36.50 | 44.38 | 36.31 | 34.63 |
| No.2 Land | 11.69 | 12.75 | 14.25 | 11.91 |
| No.3 Land | 0.00 | 0.34 | 0.88 | 0.41 |
| Upper Skirt | 0.00 | 0.00 | 0.00 | 0.00 |
| Under Crown | 0.00 | 0.00 | 0.00 | 1.56 |
| Front Pin Bore | 0.00 | 0.00 | 0.00 | 0.00 |
| Rear Pin Bore | 0.00 | 0.00 | 0.00 | 0.00 |
| **Piston Lacquer, Demerits** | | | | |
| No.1 Groove | 0.00 | 0.02 | 0.00 | 0.00 |
| No.2 Groove | 3.17 | 2.98 | 2.73 | 2.53 |
| No.3 Groove | 2.57 | 1.71 | 1.41 | 1.83 |
| No.1 Land | 0.05 | 0.07 | 0.02 | 0.03 |
| No.2 Land | 1.89 | 1.77 | 2.20 | 1.30 |
| No.3 Land | 2.37 | 2.08 | 1.21 | 1.79 |
| Upper Skirt | 0.34 | 0.63 | 0.54 | 0.65 |
| Under Crown | 2.95 | 3.64 | 4.77 | 3.86 |
| Front Pin Bore | 1.26 | 1.37 | 0.80 | 1.47 |
| Rear Pin Bore | 1.20 | 1.47 | 0.74 | 1.40 |
| **Total, Demerits** | 108.84 | 136.90 | 107.98 | 115.73 |
| | | | | |
| **Miscellanous** | | | | |
| Top Groove Fill, % | 38.63 | 56.63 | 28.50 | 40.13 |
| Intermediate Groove Fill, % | 0.00 | 2.38 | 2.13 | 1.50 |
| Top Land Heavy Carbon, % | 18.38 | 27.13 | 16.38 | 14.38 |
| Top Lan Flaked Carbon, % | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | |
| **Valve Tulip Deposits, Merits** | | | | |
| Exahust | 9.2 | 9.2 | 9.0 | 9.0 |
| Intake | 8.6 | 7.3 | 8.6 | 7.3 |

Full 6.5L(T) test report data from each revised candidate test (LO268869 and LO271510) can be seen in Appendix A1, and A2 respectively. Full test report data from each initial SCPL candidate can be found attached to TFLRF Interim Report 418, *Single Common Powertrain Development* [4].

### 3.3 2-Cycle Engine Compatibility Testing

The following section discusses the results obtained during the 2-cycle diesel engine compatibility portion of the SCPL development. Focus areas included construction of the engine test stand, description of the test cycle, and the baseline MIL-PRF-2104H 15W-40 and revised SCPL candidate evaluation results (metrology and deposit ratings).

#### 3.3.1 Test Stand Construction

A DDC 6V53T engine test stand was constructed to evaluate SCPL compatibility with a 2-cycle diesel engine. Similar to the GEP 6.5L(T) testing, the same engine test stand was used to evaluate all of the lubricants for consistency. Evaluations included the current MIL-PRF-2104H 15W-40 OE/HDO to establish a known baseline condition (consistent with actual current military applications), followed by testing of the revised candidates LO268869 and LO271510. The DDC 6V53T was purchased new from the manufacturer through the local Detroit Diesel authorized dealer (Stewart and Stevenson LLC of San Antonio TX). The engine was configured in its military version, built according to the specifications for the current M113A3 APC. The DDC 6V53T as tested produced approximately 235hp and 560 lb-ft of torque using JP-8 fuel. A picture of the DDC 6V53T engine installation can be seen on the following page in Figure 5.

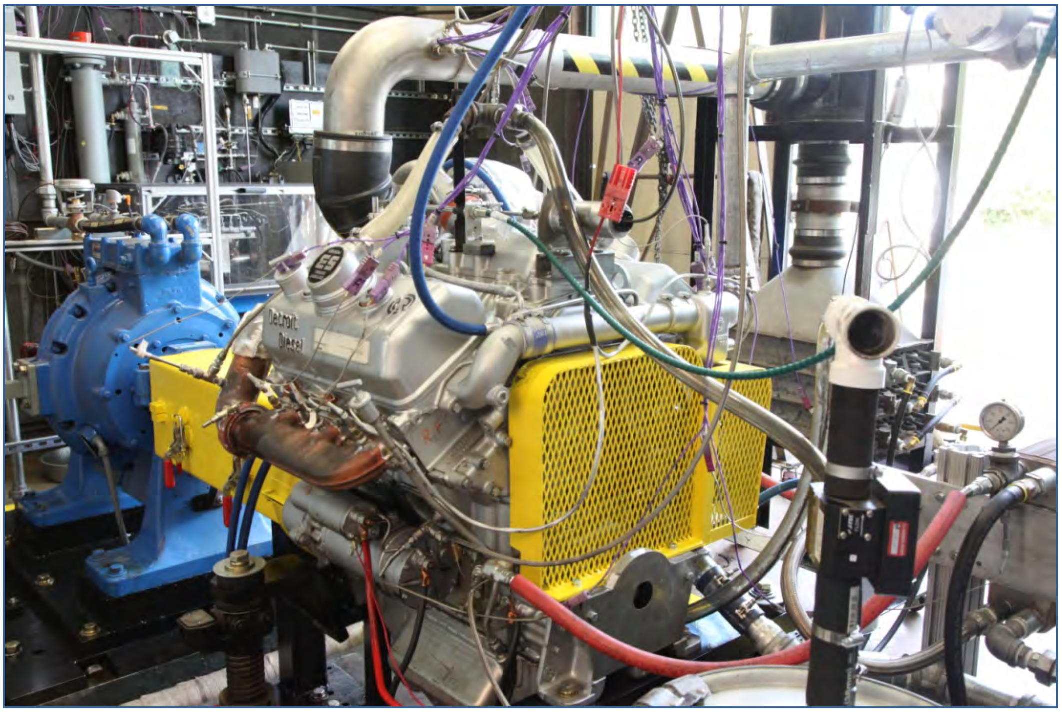


**Figure 5. Detroit Diesel 6V53T Test Cell Installation**

Like the GEP 6.5L(T), the 6V53T engine was mounted in an engine dynamometer test cell for SCPL testing and equipped with all necessary ancillary equipment to operate the engine, with the exception of accessory equipment that would be installed and utilized in a vehicle (i.e., alternator, cooling fan, etc.). The bulleted list below outlines the basic test stand configuration utilized in the SCPL engine oil test program:

- The engine used SwRI developed PRISM data acquisition software to monitor and control engine operation throughout testing. Monitored engine parameters included all critical temperatures, pressures, and flow rates, as well as engine speed and output power/torque.
- Engine loading was provided by an eddy current engine dynamometer and an electro mechanical throttle actuation system. The dynamometer controlled overall engine speed, while the throttle actuation system adjusted the rack position via a throttle cable to manipulate engine load.

- A liquid-liquid heat exchanger was used to regulate the engine water jacket temperature with building supplied process water.

- The oil filter housing and oil cooler was removed from the engine and their inlets and outlets were plugged. The original engine oil filter housing was then remotely mounted to the test stand and connected via steel braided Teflon hose to the engines oil filter outlet port. A remote liquid-liquid heat exchanger was then added in series with the stainless braided Teflon oil lines (after the oil filter), and its return was plumbed back to the engine via the engine's front lower cover. These modifications were completed to allow easier servicing of the engine's airbox covers for routine bore inspections during testing, as well as independent control of the engine oil sump temperature by removing the oil cooler from the engine water jacket. Changes made to the engine had no impact on its internal oiling/lubrication.

- Fuel was supplied from bulk storage tanks to an engine "day-tank" that served as a common location for the engine supply and return lines. The engine's fuel consumption was monitored by a coriolis flow meter for measuring the make-up fuel required to maintain the day tank at a constant volume.

- Inlet fuel temperature was controlled by a heater control loop to maintain steady inlet temperature throughout testing. The control loop maintained a reservoir of a glycol-water solution at a specified temperature, and was then used as a heat source to elevate the temperature of incoming fuel to the desired set point through a liquid-liquid heat exchanger.

- Engine inlet air was drawn past a chilled (process water) water core to lower intake air temperatures prior to the engine air filtering system. Air was filtered through an OEM-style air filter housing with an adjusting valve to vary intake air restriction prior to the turbocharger inlet.

- Engine exhaust gases were ducted into an exhaust ventilation system integrated into the engine laboratory building. Back-pressure was controlled via a butterfly valve located in the exhaust stack between the engine and the buildings common exhaust header before exiting the test cell.

- Engine blow-by gases were ducted into a drum to capture any entrained oil, and then vented through a hot-wire flow meter to monitor engine blow-by rates. Waste gasses were then ducted to the buildings exhaust ventilation system at ambient pressure (to not effect crankcase pressure) to expel blow-by gasses from the test cell.
- Engine coolant was a 60/40 blend of ethylene glycol and de-ionized water.
- Fuel used during testing was JP-8 blended at location from commercially available Jet A with a double max-treat rate of lubricity enhancer DCI-4A. (Appendix I)

### 3.3.2 Test Cycle Operation

The test cycle used for 2-cycle compatibility evaluations was based on procedures outlined in Federal Test Method Standard No. 791C, Method 355, Performance of Engine Lubricating Oils in a Two-Cycle Diesel Engine Under Cyclic, Turbo-Supercharged Conditions [11]. Some modifications were made to selected operating conditions as the engine output and torque characteristics of the current 6V53T model have changed since the original establishment of the test method. Despite this, the general operation of the engine test cycle remained unchanged. The test cycle included cyclic modes of 0.5 hours at idle, 2 hours at max power, 0.5 hours at idle, and 2 hours at max torque. This was repeated 4 times daily for a total of 20 hours runtime, accumulating 240 hours over a 12 day test. Daily operation was followed by a 4 hour engine off soak prior to the next day's running to allow thermal cycling of the lubricant. Similar to the GEP 6.5L(T), the cycle called out in this Federal Test Method was based off of work reported under CRC Report No. 406, Development of Military Fuel/Lubricant/Engine Compatibility Test [9]. As with the tactical wheeled vehicle cycle, the report also outlined a 240 hour tracked vehicle cycle that was correlated at the time of its publishing to 4,000 miles of actual military tracked vehicle proving ground operation.

Prior to the start of testing, and upon completion of every 60 hours an engine airbox inspection was completed to assess the condition of the piston skirts, ring faces, and cylinder liner. This allowed a quasi real time monitoring of the oils performance in protecting critical engine components throughout the test duration. Bore inspections were completed by passing a borescope through the engines airbox and liner intake ports and rating the condition of the liner surface. Per the procedure, if any single liner experienced greater than 30% scuffing while other liners remained in good condition, a single cylinder kit could be replaced and testing continued. This could only be completed once during the test cycle, otherwise testing was to be terminated. If at any time multiple liners experience severe scuffing, and was deemed progressive in nature, the test was to be terminated. Severe scuffing could potentially lead to failure of the liner O-ring and cause catastrophic engine damage.

During testing, engine oil sump and coolant temperatures were controlled to ensure test consistency and severity for each lubricant tested. No engine oil changes were made during the test cycle, and testing was continued until the completed 240 hours, or upon the occurrence of major oil degradation or liner scuffing. Table 11 below shows the operation conditions for the 6V53T testing.

**Table 11. DDC 6V53T Operating Conditions**

| Parameter | Max Power | Max Torque | Idle |
|---|---|---|---|
| Engine Speed [RPM] | 2800 +/- 25 | 1600 +/- 25 | 950 +/- 25 |
| Water Jacket Out [°F] | 170 +/- 5 | 170 +/- 5 | 170+/- 5 |
| Oil Sump [°F] | 245+/- 5 | 230 +/- 5 | 220 +/- 5 |

Used engine oil samples were collected every 20 hours for analysis. These samples were used to assess the condition of the lubricant and to determine test termination if necessary. Extreme liner scuffing could also be identified by sharp changes in iron accumulation rates in the used oil. Tests conducted on daily samples are outlined below in Table 12. Engine oil level was replenished daily after sampling to restore its capacity. All engine oil additions and samples were weighed throughout testing to track engine oil consumption.

**Table 12. Used Oil Analysis Tests**

| Test Method | Description |
|---|---|
| ASTM D445 | Kinematic Viscosity @ 100 °C |
| ASTM D4739 | Total Base Number |
| ASTM D664 | Total Acid Number |
| ASTM D5185 | Wear Metals by ICP |

### 3.3.3 Engine Metrology and Ratings

Each lubricant was evaluated using the same DDC 6V53T engine after completing an "in-frame" rebuild. The primary item of focus for 2-cycle compatibility was the engines liner and piston, commonly referred to as the cylinder kit. Each cylinder kit underwent a metrology process before use to fully document its starting condition prior to build up. The pre-test metrology process included measurements of the cylinder kit, as well as other critical engine parameters to ensure integrity of the engine.

Pre-test metrology included:

- Piston ring clearances (end gap & side clearance, all)
- Top, second, and third ring radial thickness
- Piston ring mass, all
- Upper oil control ring and expander tension (reference only measurement)
- Piston skirt diameter
- Liner bore (free standing, T/AT & F/B) at:
    - 13 mm from top
    - 25 mm above ports
    - 25 mm below ports
    - 13mm from bottom
- Liner surface finish (single pass above ports)
- Engine block bore (top & bottom, T/AT & F/B)
- Slipper bushing tin plate thickness (reference only measurement)
- Slipper bushing mass
- Connecting rod bearing mass
- Connecting rod bearing to crank journal clearance
- Exhaust valve recession
- Crankshaft endplay

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After the inspection and metrology process was completed, the engine was reassembled according to factory specifications. As with the 6.5L(T) testing, any parts requiring lubrication during assembly were lubricated using an additive free lubricant in order to remove any bias on subsequent lubricant test data.

At the completion of each test, the engine was again disassembled and inspected. This allowed for documentation of wear experienced over the test duration, and assessment of the piston skirt, rings, and liner condition. Similar to pretest metrology, post-test metrology procedures included measurements of:

- Piston ring clearances (end gap only, all)
- Top, second, and third ring radial thickness
- Piston ring mass, all
- Piston skirt diameter
- Liner bore (free standing, T/AT & F/B) at:
  - 13mm from top
  - 25mm above ports
  - 25mm below ports
  - 13mm from bottom
- Slipper bushing mass
- Connecting rod bearing mass

In addition to metrology, critical engine components received post-test ratings to quantify the amount and location of carbonaceous and lacquer type deposits present, and wear experienced during testing. Like the 6.5L(T) testing, this process was completed following industry standardized ASTM ratings procedures [10]. Ratings included piston deposits, ring face distress, piston skirt and liner ratings, intake port plugging, and slipper bushing exposed copper.

### 3.3.4 MIL-PRF-2104H and Revised Candidate Evaluation Results

Each of the MIL-PRF-2104H 15W-40 and revised SCPL candidate tests completed the 240 hours test cycle in the 6V53T without experiencing major oil degradation or severe liner scuffing. Due to the DDC 6V53T's comparatively lower engine oil sump temperatures and higher overall oil consumption compared to that of the GEP 6.5L(T), the used engine oil condition did not exhibit much degradation throughout each test. As a result, used oil analysis comparisons were uneventful, and detailed comparison was excluded from discussion. Full used oil analysis for each test can be reviewed in the respective test reported attached as appendices to this report.

As previously stated, engine metrology was completed during pre and post test activities to document overall engine wear and to assess the oil's ability to protect critical engine components. Table 13 and Table 14 show the average liner bore diameter change and piston to liner clearance change for each of the SCPL revised candidates and the baseline MIL-PRF-2014H 15W-40 evaluation. Average liner bore diameter changes from start to end of testing were within two-ten thousands (0.0002″) of an inch for all tests. Similarly, the piston to liner clearance remained within four-ten thousands (0.0004″) of an inch. Overall, the SCPL candidates provided comparable piston and liner protection as the current MIL-PRF-2104H products in 2-cycle applications. (Note- For candidate LO268869, liner 3L was inadvertently split for ratings prior to the post-test liner bore diameter measurements, thus measurements were not made).

**Table 13. DDC 6V53T Average LinerBore Diameter Changes, Baseline & SCPL Revised Candidates.**

| MIL-PRF-2104H 15W40 | | |
|---|---|---|
| Cylinder | Avg Bore DIA Change | Out of Round |
| 1L | | 0.0004 |
| | 0.0003 | 0.0004 |
| | | 0.0001 |
| | | 0.0000 |
| | | |
| 2L | | 0.0001 |
| | 0.0002 | 0.0001 |
| | | 0.0001 |
| | | 0.0001 |
| | | |
| 3L | | 0.0004 |
| | 0.0002 | 0.0000 |
| | | 0.0000 |
| | | 0.0005 |
| | | |
| 1R | | 0.0001 |
| | 0.0003 | 0.0001 |
| | | 0.0002 |
| | | 0.0003 |
| | | |
| 2R | | 0.0005 |
| | 0.0003 | 0.0000 |
| | | 0.0002 |
| | | 0.0004 |
| | | |
| 3R | | 0.0003 |
| | 0.0003 | 0.0002 |
| | | 0.0003 |
| | | 0.0006 |
| | | |
| Average All Cylinders | 0.0002 | |

| Candidate LO268869 | | |
|---|---|---|
| Cylinder | Avg Bore DIA Change | Out of Round |
| 1L | | 0.0012 |
| | 0.0004 | 0.0003 |
| | | 0.0001 |
| | | 0.0003 |
| | | |
| 2L | | 0.0005 |
| | 0.0003 | 0.0002 |
| | | 0.0000 |
| | | 0.0003 |
| | | |
| 3L | | N/A |
| | N/A | N/A |
| | | N/A |
| | | N/A |
| | | |
| 1R | | 0.0006 |
| | 0.0003 | 0.0001 |
| | | 0.0000 |
| | | 0.0003 |
| | | |
| 2R | | 0.0002 |
| | 0.0002 | 0.0002 |
| | | 0.0003 |
| | | 0.0002 |
| | | |
| 3R | | 0.0004 |
| | 0.0002 | 0.0001 |
| | | 0.0002 |
| | | 0.0001 |
| | | |
| Average All Cylinders | 0.0003 | |

| Candidate LO271510 | | |
|---|---|---|
| Cylinder | Avg Bore DIA Change | Out of Round |
| 1L | | 0.0003 |
| | 0.0002 | 0.0004 |
| | | 0.0004 |
| | | 0.0001 |
| | | |
| 2L | | 0.0002 |
| | 0.0002 | 0.0001 |
| | | 0.0000 |
| | | 0.0001 |
| | | |
| 3L | | 0.0002 |
| | 0.0003 | 0.0001 |
| | | 0.0001 |
| | | 0.0003 |
| | | |
| 1R | | 0.0004 |
| | 0.0002 | 0.0003 |
| | | 0.0002 |
| | | 0.0001 |
| | | |
| 2R | | 0.0000 |
| | 0.0002 | 0.0000 |
| | | 0.0000 |
| | | 0.0003 |
| | | |
| 3R | | 0.0003 |
| | 0.0003 | 0.0001 |
| | | 0.0001 |
| | | 0.0000 |
| | | |
| Average All Cylinders | 0.0002 | |

**Table 14. DDC 6V53T Piston to Liner Clearance Changes, Baseline & SCPL Revised Candidates**

| MIL-PRF-2104H 15W40 | | | |
|---|---|---|---|
| | Cylinder | Piston to Liner Clearance | |
| Pre - Test | 1 | 0.0058 | |
| | 2 | 0.0060 | |
| | 3 | 0.0059 | |
| | 4 | 0.0058 | |
| | 5 | 0.0059 | |
| | 6 | 0.0059 | |
| | | | Change |
| Post - Test | 1 | 0.0059 | 0.0002 |
| | 2 | 0.0071 | 0.0010 |
| | 3 | 0.0073 | 0.0015 |
| | 4 | 0.0068 | 0.0011 |
| | 5 | 0.0064 | 0.0005 |
| | 6 | 0.0070 | 0.0010 |

| | |
|---|---|
| Average | 0.0009 |
| Max | 0.0015 |

| Candidate LO268869 | | | |
|---|---|---|---|
| | Cylinder | Piston to Liner Clearance | |
| Pre - Test | 1 | 0.0056 | |
| | 2 | 0.0046 | |
| | 3 | 0.0048 | |
| | 4 | 0.0067 | |
| | 5 | 0.0058 | |
| | 6 | 0.0063 | |
| | | | Change |
| Post - Test | 1 | 0.0068 | 0.0013 |
| | 2 | 0.0065 | 0.0019 |
| | 3 | N/A | N/A |
| | 4 | 0.0078 | 0.0011 |
| | 5 | 0.0072 | 0.0014 |
| | 6 | 0.0069 | 0.0006 |

| | |
|---|---|
| Average | 0.0012 |
| Max | 0.0019 |

| Candidate LO271510 | | | |
|---|---|---|---|
| | Cylinder | Piston to Liner Clearance | |
| Pre - Test | 1 | 0.0052 | |
| | 2 | 0.0046 | |
| | 3 | 0.0057 | |
| | 4 | 0.0046 | |
| | 5 | 0.0055 | |
| | 6 | 0.0058 | |
| | | | Change |
| Post - Test | 1 | 0.0063 | 0.0011 |
| | 2 | 0.0059 | 0.0013 |
| | 3 | 0.0068 | 0.0012 |
| | 4 | 0.0063 | 0.0017 |
| | 5 | 0.0065 | 0.0011 |
| | 6 | 0.0074 | 0.0016 |

| | |
|---|---|
| Average | 0.0013 |
| Max | 0.0017 |

The piston and liner metrology findings were in agreement with the ratings of these components. Table 15 shows the liner surface ratings. Each liner was rated to assess surface condition after being cut in half at the end of testing. Specifically, each liner was rated to quantify the percent area of polish or scuffing present. As seen below, each test had average values below 15% polish, and below 25% polish on any single liner. The revised SCPL candidates did show a slightly higher average polished area than that seen during the baseline 15W-40 test, but still remained relatively low. None of the post-test liners showed scuffing on their surfaces which supports that the revised candidate SCPL's are compatible for use in two-cycle diesel engine applications, and are providing comparable protection as the current MIL-PRF-2104H 15W-40.

**Table 15. DDC 6V53T Cylinder Liner Ratings**

| | | Cylinder Liner Ratings | | | |
|---|---|---|---|---|---|
| | | % Polish | | Total % Area Polished | |
| | | T | AT | | |
| MIL-PRF-2104H 15W40 | 1L | 8 | 3 | 11 | |
| | 2L | 0 | 10 | 10 | |
| | 3L | 7 | 4 | 11 | |
| | 1R | 2 | 4 | 6 | |
| | 2R | 3 | 5 | 8 | Average |
| | 3R | 6 | 4 | 10 | 9.3 |
| | | % Polish | | Total % Area Polished | |
| | | T | AT | | |
| Candidate LO268869 | 1L | 15 | 4 | 19 | |
| | 2L | 10 | 12 | 22 | |
| | 3L | 5 | 2 | 7 | |
| | 1R | 5 | 2 | 7 | |
| | 2R | 2 | 7 | 9 | Average |
| | 3R | 4 | 2 | 6 | 11.7 |
| | | % Polish | | Total % Area Polished | |
| | | T | AT | | |
| Candidate LO271510 | 1L | 10 | 8 | 18 | |
| | 2L | 0 | 3 | 3 | |
| | 3L | 2 | 4 | 6 | |
| | 1R | 16 | 2 | 18 | |
| | 2R | 2 | 18 | 20 | Average |
| | 3R | 1 | 14 | 15 | 13.3 |
| | Percent of total ring travel area | | | | |

Table 16 shows the piston skirt surface ratings. Only minor scuffing (<5%) was present on any single piston, which is in line with the ratings seen from the liner surfaces. Remaining defects noted on the piston skirts included only light or trace scratches.

**Table 16. DDC 6V53T Piston Skirt Ratings**

| | | Piston Skirt Ratings | |
|---|---|---|---|
| | | **Thrust** | **Anti-Thrust** |
| MIL-PRF-2104H 15W40 | 1L | Few Light Scratches, 1% Scuffing | Few Light Scratches, 2% Scuffing |
| | 2L | Few Light Scratches | Few Light Scratches |
| | 3L | Few Light Scratches | Few Light Scratches |
| | 1R | Few Light Scratches | Few Light Scratches |
| | 2R | Few Light Scratches | Few Light Scratches |
| | 3R | Numerous Light Scratches | Few Light Scratches |
| | | **Thrust** | **Anti-Thrust** |
| Candidate LO268869 | 1L | Few Light Scratches & 1% Scuffing | Few Light Scratches |
| | 2L | Few Light Scratches | Few Light Scratches |
| | 3L | Few Light Scratches | Few Very Light Scratches |
| | 1R | Few Light Scratches | Few Light Scratches & 1% Scuffing |
| | 2R | Few Light Scratches | Few Light Scratches & 1% Scuffing |
| | 3R | Few Very Light Scratches | Few Light Scraches & 1% Scuffing |
| | | **Thrust** | **Anti-Thrust** |
| Candidate LO271510 | 1L | 5% Light Scratches | Trace Scratches |
| | 2L | Trace Scratches | Trace Scratches |
| | 3L | 15% Light Scratches | Trace Scratches |
| | 1R | 8% Light Scratches | Trace Scratches |
| | 2R | Trace to Light Scratches | Trace Scratches |
| | 3R | 10% Light Scratches | Trace Scratches |

As previously mentioned in the GEP 6.5L(T) metrology section, ring mass and radial thickness changes can give insight into the low viscosity oils ability to provide adequate film thickness and protect from excessive ring pack wear. Table 17 and Table 18 show the ring mass and ring radial thickness changes for the 6V53T tests, respectively. From the ring mass measurements, we can again see similar weight loss trends with the low viscosity SCPL candidates compared to the MIL-PRF-2104 15W-40 evaluation as tested during Part 1. Although small, each of the SCPL candidate tests experienced an increased ring pack weight loss compared to the baseline 15W-40 test. Likewise, the same trend is seen with the 1$^{st}$, 2$^{nd}$, and 3$^{rd}$ ring radial thickness. Further detailed studies would be required to more definitively quantify the true long term impact of increased wear due to the reduction in oil viscosity. To put this back into military application focus, the correlation initially developed to the 240 hour test was representative of 4,000 miles of proving ground operation, which does represent a significant life span expectation of tracked vehicles. Due to this consideration, and the overall satisfactory operation and performance of the engine during testing, the revised SCPL candidates do cautiously appear to provide adequate protection.

**Table 17. DDC 6V53T Ring Mass Changes, Baseline & SCPL Revised Candidates**

| Cylinder | Ring No. | MIL-PRF-2104H 15W40 | Candidate LO268869 | Candidate LO271510 |
|---|---|---|---|---|
| | | Delta | | |
| 1L | 1 | 0.0145 | 0.0350 | 0.0312 |
| | 2 | 0.1140 | 0.1374 | 0.0983 |
| | 3 | 0.0601 | 0.0736 | 0.0319 |
| | 4 | 0.0169 | 0.0164 | 0.0183 |
| | 5 | 0.0241 | 0.0306 | 0.0240 |
| 2L | 1 | 0.0189 | 0.0241 | 0.0313 |
| | 2 | 0.0404 | 0.0751 | 0.0571 |
| | 3 | 0.0125 | 0.0250 | 0.0193 |
| | 4 | 0.0179 | 0.0222 | 0.0137 |
| | 5 | 0.0177 | 0.0328 | 0.0189 |
| 3L | 1 | 0.0148 | 0.0345 | 0.0191 |
| | 2 | 0.0469 | 0.1102 | 0.0597 |
| | 3 | 0.0197 | 0.0385 | 0.0128 |
| | 4 | 0.0179 | 0.0187 | 0.0134 |
| | 5 | 0.0186 | 0.0280 | 0.0188 |
| 1R | 1 | 0.0111 | 0.0297 | 0.0297 |
| | 2 | 0.0717 | 0.1308 | 0.1008 |
| | 3 | 0.0328 | 0.0584 | 0.0318 |
| | 4 | 0.0202 | 0.0233 | 0.0139 |
| | 5 | 0.0208 | 0.0312 | 0.0204 |
| 2R | 1 | 0.0153 | 0.0226 | 0.0177 |
| | 2 | 0.0539 | 0.0552 | 0.1104 |
| | 3 | 0.0191 | 0.0172 | 0.0544 |
| | 4 | 0.0151 | 0.0214 | 0.0162 |
| | 5 | 0.0190 | 0.0327 | 0.0407 |
| 3R | 1 | 0.0095 | 0.0321 | 0.0328 |
| | 2 | 0.0403 | 0.1072 | 0.0612 |
| | 3 | 0.0110 | 0.0641 | 0.0256 |
| | 4 | 0.0174 | 0.0201 | 0.0175 |
| | 5 | 0.0196 | 0.0463 | 0.0211 |

| | | | |
|---|---|---|---|
| Ring No. 1 max decrease | 0.0189 | 0.0350 | 0.0328 |
| Ring No. 2 max decrease | 0.1140 | 0.1374 | 0.1104 |
| Ring No. 3 max decrease | 0.0601 | 0.0736 | 0.0544 |
| Ring No. 4 max decrease | 0.0202 | 0.0233 | 0.0183 |
| Ring No. 5 max decrease | 0.0241 | 0.0463 | 0.0407 |

| | | | |
|---|---|---|---|
| Ring No. 1 avg decrease | 0.0140 | 0.0297 | 0.0270 |
| Ring No. 2 avg decrease | 0.0612 | 0.1026 | 0.0813 |
| Ring No. 3 avg decrease | 0.0259 | 0.0461 | 0.0293 |
| Ring No. 4 avg decrease | 0.0176 | 0.0203 | 0.0155 |
| Ring No. 5 avg decrease | 0.0200 | 0.0336 | 0.0240 |

**Table 18. DDC 6V53T Top, Second, and Third Ring Radial Thickness, Baseline & SCPL Revised Candidates**

| MIL-PRF-2104H 15W40 | | | | |
|---|---|---|---|---|
| Radial Thickness | | Top Ring | Second Ring | Third Ring |
| Cylinder | Position | Delta | Delta | Delta |
| 1L | 1 | 0.00080 | 0.00095 | 0.00060 |
| | 2 | 0.00020 | 0.00075 | 0.00045 |
| | 3 | 0.00035 | 0.00120 | 0.00085 |
| | 4 | 0.00005 | 0.00115 | 0.00075 |
| | 5 | 0.00075 | 0.00100 | 0.00065 |
| 2L | 1 | 0.00080 | 0.00090 | 0.00025 |
| | 2 | 0.00030 | 0.00040 | 0.00020 |
| | 3 | 0.00020 | 0.00055 | 0.00015 |
| | 4 | 0.00020 | 0.00055 | 0.00015 |
| | 5 | 0.00090 | 0.00060 | 0.00040 |
| 3L | 1 | 0.00080 | 0.00075 | 0.00040 |
| | 2 | 0.00040 | 0.00035 | 0.00030 |
| | 3 | 0.00045 | 0.00070 | 0.00045 |
| | 4 | 0.00040 | 0.00040 | 0.00015 |
| | 5 | 0.00110 | 0.00065 | 0.00040 |
| 1R | 1 | 0.00125 | 0.00100 | 0.00035 |
| | 2 | 0.00000 | 0.00065 | 0.00025 |
| | 3 | 0.00035 | 0.00065 | 0.00025 |
| | 4 | 0.00035 | 0.00070 | 0.00035 |
| | 5 | 0.00160 | 0.00080 | 0.00095 |
| 2R | 1 | 0.00095 | 0.00080 | 0.00030 |
| | 2 | 0.00025 | 0.00060 | 0.00030 |
| | 3 | 0.00060 | 0.00075 | 0.00030 |
| | 4 | 0.00035 | 0.00080 | 0.00030 |
| | 5 | 0.00100 | 0.00060 | 0.00035 |
| 3R | 1 | 0.00050 | 0.00050 | 0.00015 |
| | 2 | 0.00015 | 0.00060 | 0.00035 |
| | 3 | 0.00010 | 0.00255 | 0.00030 |
| | 4 | 0.00025 | 0.00035 | 0.00020 |
| | 5 | 0.00055 | 0.00050 | 0.00025 |
| | Maximum | 0.00160 | 0.00255 | 0.00095 |
| | Average | 0.00053 | 0.00076 | 0.00037 |

| SCPL Candidate LO268869 | | | | |
|---|---|---|---|---|
| Radial Thickness | | Top Ring | Second Ring | Third Ring |
| Cylinder | Position | Delta | Delta | Delta |
| 1L | 1 | 0.00130 | 0.00120 | 0.00075 |
| | 2 | 0.00075 | 0.00115 | 0.00070 |
| | 3 | 0.00080 | 0.00120 | 0.00080 |
| | 4 | 0.00090 | 0.00100 | 0.00050 |
| | 5 | 0.00150 | 0.00105 | 0.00070 |
| 2L | 1 | 0.00085 | 0.00070 | 0.00045 |
| | 2 | 0.00040 | 0.00075 | 0.00050 |
| | 3 | 0.00030 | 0.00085 | 0.00035 |
| | 4 | 0.00035 | 0.00070 | 0.00025 |
| | 5 | 0.00085 | 0.00080 | 0.00040 |
| 3L | 1 | 0.00135 | 0.00110 | 0.00055 |
| | 2 | 0.00060 | 0.00120 | 0.00035 |
| | 3 | 0.00035 | 0.03100 | 0.00040 |
| | 4 | 0.00045 | 0.00090 | 0.00040 |
| | 5 | 0.00140 | 0.00110 | 0.00055 |
| 1R | 1 | 0.00125 | 0.00140 | 0.00085 |
| | 2 | 0.00050 | 0.00090 | 0.00030 |
| | 3 | 0.00050 | 0.00110 | 0.00050 |
| | 4 | 0.00045 | 0.00105 | 0.00060 |
| | 5 | 0.00135 | 0.00155 | 0.00140 |
| 2R | 1 | 0.00100 | 0.00060 | 0.00040 |
| | 2 | 0.00045 | 0.00065 | 0.00025 |
| | 3 | 0.00035 | 0.00080 | 0.00025 |
| | 4 | 0.00040 | 0.00055 | 0.00025 |
| | 5 | 0.00065 | 0.00070 | 0.00035 |
| 3R | 1 | 0.00150 | 0.00100 | 0.00065 |
| | 2 | 0.00085 | 0.00075 | 0.00050 |
| | 3 | 0.00065 | 0.00110 | 0.00065 |
| | 4 | 0.00085 | 0.00100 | 0.00090 |
| | 5 | 0.00040 | 0.00120 | 0.00095 |
| | Maximum | 0.00150 | 0.03100 | 0.00140 |
| | Average | 0.00078 | 0.00197 | 0.00055 |

| SCPL Candidate LO271510 | | | | |
|---|---|---|---|---|
| Radial Thickness | | Top Ring | Second Ring | Third Ring |
| Cylinder | Position | Delta | Delta | Delta |
| 1L | 1 | 0.00090 | 0.00085 | 0.00045 |
| | 2 | 0.00030 | 0.00070 | 0.00045 |
| | 3 | 0.00005 | 0.00095 | 0.00050 |
| | 4 | 0.00050 | 0.00085 | 0.00040 |
| | 5 | 0.00120 | 0.00145 | 0.00070 |
| 2L | 1 | 0.00065 | 0.00065 | 0.00035 |
| | 2 | 0.00060 | 0.00090 | 0.00035 |
| | 3 | 0.00045 | 0.00065 | 0.00050 |
| | 4 | 0.00010 | 0.00065 | 0.00020 |
| | 5 | 0.00065 | 0.00060 | 0.00050 |
| 3L | 1 | 0.00065 | 0.00050 | 0.00025 |
| | 2 | 0.00015 | 0.00080 | 0.00025 |
| | 3 | 0.00035 | 0.00070 | 0.00035 |
| | 4 | 0.00015 | 0.00070 | 0.00015 |
| | 5 | 0.00065 | 0.00075 | 0.00025 |
| 1R | 1 | 0.00115 | 0.00080 | 0.00055 |
| | 2 | 0.00020 | 0.00075 | 0.00020 |
| | 3 | 0.00075 | 0.00145 | 0.00025 |
| | 4 | 0.00040 | 0.00095 | 0.00045 |
| | 5 | 0.00120 | 0.00060 | 0.00050 |
| 2R | 1 | 0.00120 | 0.00095 | 0.00085 |
| | 2 | 0.00050 | 0.00085 | 0.00055 |
| | 3 | 0.00030 | 0.00135 | 0.00050 |
| | 4 | 0.00055 | 0.00065 | 0.00050 |
| | 5 | 0.00150 | 0.00100 | 0.00070 |
| 3R | 1 | 0.00060 | 0.00065 | 0.00030 |
| | 2 | 0.00010 | 0.00060 | 0.00025 |
| | 3 | 0.00005 | 0.00075 | 0.00085 |
| | 4 | 0.00045 | 0.00055 | 0.00040 |
| | 5 | 0.00095 | 0.00050 | 0.00040 |
| | Maximum | 0.00150 | 0.00145 | 0.00085 |
| | Average | 0.00058 | 0.00080 | 0.00043 |

Table 19 shows the slipper bushing weight loss for each of the DDC 6V53T tests. The baseline MIL-PRF-2104H 15W-40 test experienced an average slipper bushing weight loss of 0.11 grams compared to the revised SCPL candidates average of 0.15 grams. This change in weight loss was not immediately alarming, and was reinforced by the slipper bushing visual ratings reported in Table 20.

**Table 19. DDC 6V53T Slipper Bushing Mass Changes, Baseline & SCPL Revised Candidates**

| | Slipper Bushing | Before | After | Change |
|---|---|---|---|---|
| MIL-PRF-2104H 15W40 | 1L | 56.2768 | 56.2085 | 0.0683 |
| | 2L | 55.9443 | 55.8420 | 0.1023 |
| | 3L | 56.2014 | 56.0414 | 0.1600 |
| | 1R | 56.0874 | 56.0086 | 0.0788 |
| | 2R | 56.2125 | 56.1151 | 0.0974 |
| | 3R | 56.1273 | 55.9975 | 0.1298 |

| | |
|---|---|
| Maximum | 0.1600 |
| Average | 0.1061 |

| | Slipper Bushing | Before | After | Change |
|---|---|---|---|---|
| Candidate LO268869 | 1L | 56.1310 | 55.9758 | 0.1552 |
| | 2L | 56.0567 | 55.9313 | 0.1254 |
| | 3L | 56.0873 | 55.9811 | 0.1062 |
| | 1R | 56.0515 | 55.8908 | 0.1607 |
| | 2R | 56.0870 | 55.9288 | 0.1582 |
| | 3R | 55.7503 | 55.5740 | 0.1763 |

| | |
|---|---|
| Maximum | 0.1763 |
| Average | 0.1470 |

| | Slipper Bushing | Before | After | Change |
|---|---|---|---|---|
| Candidate LO271510 | 1L | 56.1116 | 55.9466 | 0.1650 |
| | 2L | 56.3117 | 56.1454 | 0.1663 |
| | 3L | 56.0924 | 55.9997 | 0.0927 |
| | 1R | 56.0745 | 55.9075 | 0.1670 |
| | 2R | 55.9797 | 55.7885 | 0.1912 |
| | 3R | 56.4089 | 56.2706 | 0.1383 |

| | |
|---|---|
| Maximum | 0.1912 |
| Average | 0.1534 |

Table 20 shows the slipper bushing exposed copper ratings. The two revised candidate SCPL tests yielded reduced exposed copper than the baseline 15W-40 test. This again demonstrates that the revised SCPL candidates are providing adequate engine protection. None of the slipper bushings experienced wear that would be considered detrimental to performance. This is noted in the metrology and ratings, as well as a lack of bearing related wear metal accumulation in the used oil.

**Table 20. DDC 6V53T Slipper Bushing Exposed Copper Ratings**

| Slipper Bushing % Exposed Copper | MIL-PRF-2104H 15W-40 | Candidate LO268869 | Candidate LO271510 |
|---|---|---|---|
| 1L | 2 | 1 | 0 |
| 2L | 15 | 1 | 10 |
| 3L | 10 | 2 | 0 |
| 1R | 6 | 2 | 12 |
| 2R | 8 | 1 | 15 |
| 3R | 12 | 2 | 2 |
| **Average** | 8.83 | 1.50 | 6.50 |

Table 21 shows the connecting rod bearing weight loss for each DDC 6V53T test. Like the slipper bushings, a similar trend was also seen here. The revised candidate SCPL evaluations yielded a higher average weight loss than the baseline, with measured averages of 0.014 and 0.011 grams for the revised SCPL candidates, and 0.009 grams for the 15W-40 baseline. As before, this increase was not an alarming result. All of the removed connecting rod bearings appeared to be in good condition upon visual inspection, and low levels of lead and copper wear metals in the engines used oil analysis suggest low overall bearing distress.

**Table 21. DDC 6V53T Connecting Rod Bearing Mass Changes, Baseline & SCPL Revised Candidates**

| | Rod Bearing | Shell | Before | After | Change |
|---|---|---|---|---|---|
| MIL-PRF-2104H 15W40 | 1L | Top | 73.6495 | 73.6297 | 0.0198 |
| | | Bottom | 67.8243 | 67.8210 | 0.0033 |
| | 2L | Top | 73.4362 | 73.4133 | 0.0229 |
| | | Bottom | 67.7831 | 67.7786 | 0.0045 |
| | 3L | Top | 73.4769 | 73.4644 | 0.0125 |
| | | Bottom | 67.8587 | 67.8555 | 0.0032 |
| | 1R | Top | 73.4915 | 73.4771 | 0.0144 |
| | | Bottom | 68.3085 | 68.3036 | 0.0049 |
| | 2R | Top | 73.4822 | 73.4681 | 0.0141 |
| | | Bottom | 68.1717 | 68.1779 | -0 0062 |
| | 3R | Top | 73.2623 | 73.2486 | 0.0137 |
| | | Bottom | 69.3699 | 69.3658 | 0.0041 |

| | |
|---|---|
| Maximum | 0 0229 |
| Average | 0 0093 |

| | Rod | Shell | Before | After | Change |
|---|---|---|---|---|---|
| SCPL Candidate LO268869 | 1L | Top | 73.5096 | 73.4845 | 0.0251 |
| | | Bottom | 68.4050 | 68.3979 | 0.0071 |
| | 2L | Top | 73.5891 | 73.5602 | 0.0289 |
| | | Bottom | 67.9048 | 67.9006 | 0.0042 |
| | 3L | Top | 73.5592 | 73.5377 | 0.0215 |
| | | Bottom | 68.0659 | 68.0599 | 0.0060 |
| | 1R | Top | 73.7570 | 73.7359 | 0.0211 |
| | | Bottom | 67.8936 | 67.8878 | 0.0058 |
| | 2R | Top | 73.5076 | 73.4869 | 0.0207 |
| | | Bottom | 67.9593 | 67.9563 | 0.0030 |
| | 3R | Top | 73.4451 | 73.4258 | 0.0193 |
| | | Bottom | 67.8821 | 67.8766 | 0.0055 |

| | |
|---|---|
| Maximum | 0 0289 |
| Average | 0 0140 |

| | Rod Bearing | Shell | Before | After | Change |
|---|---|---|---|---|---|
| SCPL Candidate LO271510 | 1L | Top | 73.5154 | 73.4940 | 0.0214 |
| | | Bottom | 69.0551 | 69.0506 | 0.0045 |
| | 2L | Top | 73.5056 | 73.4842 | 0.0214 |
| | | Bottom | 68.8418 | 68.8369 | 0.0049 |
| | 3L | Top | 73.6489 | 73.6331 | 0.0158 |
| | | Bottom | 69.0457 | 69.0425 | 0.0032 |
| | 1R | Top | 73.3940 | 73.3765 | 0.0175 |
| | | Bottom | 67.8570 | 67.8504 | 0.0066 |
| | 2R | Top | 73.7199 | 73.7059 | 0.0140 |
| | | Bottom | 68.4373 | 68.4338 | 0.0035 |
| | 3R | Top | 73.7069 | 73.6937 | 0.0132 |
| | | Bottom | 68.1779 | 68.1725 | 0.0054 |

| | |
|---|---|
| Maximum | 0.0214 |
| Average | 0 0109 |

In addition to the metrology, deposit ratings were completed on post test pistons, rings, and liners to assess the ability of each oil to control deposit formation and buildup. Table 22 shows the overall piston deposits accumulated for each test. The two revised candidates had similar overall deposit levels compared to the baseline 15W-40 test. As with the 6.5L(T), none of the deposit levels shown were considered excessive.

**Table 22. DDC 6V53T Post-Test Piston Deposit Ratings**

| | MIL-PRF-2104H 15W40 | Candidate LO268869 | Candidate LO271510 |
|---|---|---|---|
| **Piston Carbon, Average Demerits** | | | |
| No.1 Groove | 60.33 | 62.58 | 58.96 |
| No.2 Groove | 34.54 | 35.13 | 37.00 |
| No.3 Groove | 24.46 | 23.25 | 22.79 |
| No.1 Land | 40.25 | 40.50 | 41.71 |
| No.2 Land | 57.08 | 59.88 | 56.50 |
| No.3 Land | 10.58 | 16.79 | 10.00 |
| No.4 Land | 6.88 | 6.42 | 3.54 |
| **Piston Lacquer, Average Demerits** | | | |
| No.1 Groove | 0.00 | 0.00 | 0.00 |
| No.2 Groove | 0.01 | 0.00 | 0.00 |
| No.3 Groove | 0.08 | 0.31 | 0.23 |
| No.1 Land | 0.26 | 0.00 | 0.00 |
| No.2 Land | 0.09 | 0.00 | 0.00 |
| No.3 Land | 1.93 | 1.52 | 1.78 |
| No.4 Land | 2.50 | 2.57 | 2.64 |
| **Total, Average Demerits** | 238.99 | 248.94 | 235.16 |

| **Miscellanous (Average)** | | | |
|---|---|---|---|
| Top Groove Fill, % | 59.50 | 62.00 | 73.00 |
| Intermediate Groove Fill, % | 60.50 | 58.83 | 66.50 |
| Top Land Heavy Carbon, % | 21.33 | 20.67 | 22.83 |
| Top Lan Flaked Carbon, % | 0.00 | 0.17 | 0.00 |

Table 23 shows deposit ratings for the ring packs only. Interestingly, all of the tests show some propensity to develop deposits on the $2^{nd}$ fire ring. This resulted in a varying amount of cold stuck rings for the post test pistons. From the ratings, it was found that the two revised SCPL candidates showed better overall control of deposit formations resulting in fewer stuck rings. The baseline 15W-40 test showed 5 of the 6 number 2 rings to be cold stuck, varying between 10 to 95% of the ring circumference being unmovable. The two revised candidate SCPL tests only showed two cold stuck rings each, with much lower pinched ring circumferences. Specific carbon ratings of the number two rings were performed to better quantify this carbonaceous accumulation, and the baseline 15W-40 showed nearly twice the heavy carbon buildup as revised candidate LO268869. Unfortunately, the second rings for revised candidate LO271510 were inadvertently cleaned (i.e., carbon removed via abrasive blasting) for metrology measurements prior to the ratings being completed, but based solely off of the ring sticking ratings, it would have likely shown similar rating trends as LO268869.

**Table 23. DDC 6V53T Ring Pack Ratings**

| | Ring Pack Deposit Control | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Ratings | Cylinder Number | | | | | | |
| | | 1L | 2L | 3L | 1R | 2R | 3R | |
| MIL-PRF-2104H 15W40 | **Ring Sticking** (F=Free, CS=Cold Stuck, HS=Hot Stuck, CP=Collapsed Ring, No. Denotes % Of Ring Circumference) | | | | | | | |
| | Top | F | F | F | F | F | F | |
| | Second | 25% CS | F | 40% CS | 10% CS | 95% CS | 90% CS | |
| | Third | F | F | F | F | F | F | |
| | Oil Control Rings | F | F | F | F | F | F | |
| | **2nd Ring Carbon** | | | | | | | **Average** |
| | Heavy Carbon | 26 | 33 | 93 | 70 | 76 | 53 | 59 |
| | Light Carbon | 74 | 67 | 7 | 30 | 20 | 37 | 39 |
| Candidate LO268869 | **Ring Sticking** | | | | | | | |
| | Top | F | F | F | F | F | F | |
| | Second | F | CS 5% | CS 10% | F | F | F | |
| | Third | F | F | F | F | F | F | |
| | Oil Control Rings | F | F | F | F | F | F | |
| | **2nd Ring Carbon** | | | | | | | **Average** |
| | Heavy Carbon | 62 | 10 | 78 | 5 | 4 | 40 | 33 |
| | Light Carbon | 38 | 90 | 22 | 46 | 86 | 60 | 57 |
| Candidate LO271510 | **Ring Sticking** | | | | | | | |
| | Top | F | F | F | F | F | F | |
| | Second | F | F | F | F | CS 20% | CS 15% | |
| | Third | F | F | F | F | F | F | |
| | Oil Control Rings | F | F | F | F | F | F | |
| | **2nd Ring Carbon** | | | | | | | **Average** |
| | Heavy Carbon | - | - | - | - | - | - | - |
| | Light Carbon | - | - | - | - | - | - | - |

Lastly, intake port plugging for each liner was quantified as another form of determining deposit control. Similar to what was seen in the ring pack ratings, the two revised candidates showed less overall intake port buildup than the baseline 15W-40. All of the intake port deposits were considered minor. Intake port deposit levels can be seen in Table 24.

Full DDC 6V53T test report data from each revised candidate test (LO268869 and LO271510) are presented in Appendix B1, and B2 respectively.

Table 24. DDC 6V53T Intake Port Plugging

| Intake Port Plugging | MIL-PRF-2104H 15W40 | Canddiate LO268869 | Candidate LO271510 |
|---|---|---|---|
| 1L | 2.5 | 2 | 3 |
| 2L | 2 | 2 | 3 |
| 3L | 3 | 3 | 2 |
| 1R | 0.5 | 3 | 2 |
| 2R | 1 | 2 | 2 |
| 3R | 25.5 | 3 | 2 |
| **Average** | 5.75 | 2.5 | 2.33 |

### 3.4 6.5L Roller Follower Wear Testing

Each revised SCPL candidate was also evaluated in the ASTM D5966 Roller Follower Wear Test. This procedure, approved for API CJ-4 oil qualification, is used to determine the effects of lubricating oil on camshaft roller follower axle wear. The engine used in testing is the GM 6.5L(NA) V8 diesel engine, which is the base engine the GEP family of V8 diesel engines originate from. The test operates the engine near maximum load at 1000 rpm for a total of 50 hours while controlling engine coolant out and oil galley temperatures at 248 °F. The test is completed without an oil change, with makeup oil being added at the 25 hour point. Once completed, the roller follower assemblies are removed from the engine and disassembled, and the roller axles are measured using a single pass profilometer to determine resulting axle wear. Table 25 on the following page shows the results for the two revised candidates, and the single test MTAC limits set out by the API CJ-4 classification. From the results, we can see that the average axle wear for both revised candidates remains under the maximum average of 0.30 mils allowed by the CJ-4 classification. Revised candidate LO268869 had the higher wear, and resulted just under the MTAC limit at 0.28 mils, while LO271510 had an average wear of 0.15 mils. When comparing the maximum and minimum measurements for all of the follower assemblies, it becomes more clear how variable the wear can be in a single test. The MTAC limits increase to 0.33 mils for a two test qualification, and 0.36 mils for a three test qualification. Both revised candidates passed the CJ-4 requirements, and demonstrate adequate protection of the roller follower assembly.

Full ASTM test reports for each revised candidate can be reviewed in Appendix C1 and C2 for revised candidates LO268869 and LO271510 respectively.

**Table 25. ASTM D5966 Roller Follower Wear Results**

| | Single Test CJ-4 MTAC Limits | SCPL LO268869 | SCPL LO271510 |
|---|---|---|---|
| **Follow Axle Wear, Average [mil]** | 0.30 | 0.28 | 0.15 |
| **Maximum** | N/A | 0.47 | 0.31 |
| **Minimum** | N/A | 0.12 | 0.07 |

## 3.5 TRANSMISSION COMPATIBILITY

As stated in the background and introduction, the SCPL must be capable of being used in military power shift transmission applications in addition to engine crankcase applications. To assess the transmission performance of each revised SCPL candidate, several industry standardized transmission test procedures were completed, including selected: Allison C4, Caterpillar TO-4, and John Deere JDQ test procedures. Many of these industry transmission frictional tests utilize an SAE No. 2 friction testing machine. This machine measures the engagement properties of one friction and reaction plate over a wide range of speeds and application forces. It instantaneously records multiple parameters including load applied, torque transmitted, and plate speed to determine overall torque capacity, dynamic and static coefficients of friction, and slip time. Results are then compared to a baseline fluid which brackets desired performance and determines pass fail of a candidate fluid. Results for the SCPL testing are summarized as follows.

### 3.5.1 Allison C4 Testing

Allison C4 transmission compatibility evaluations for the revised SCPL candidate included frictional testing using paper and graphite materials. Table 26 shows the results from the paper friction testing. Overall, neither of the revised candidates changed their pass/fail results with respect to their initial evaluations. Like initial candidate LO253071, revised candidate LO268869 fell short on the minimum midpoint coefficient of friction at the 100 cycles engagement. This could potentially manifest itself as a greater amount of slip of the friction material during early engagements. Revised candidate LO271510 again passed the paper friction testing.

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# Table 26. Revised SCPL Candidate Evaluations, Allison C4 Paper Friction

## *Initial Candidates*

### ALLISON C- 4 PAPER FRICTION TEST

| | | | |
|---|---|---|---|
| Sponsor Fluid Code: | **LO-253071** | Test Number: | **C2-7-1552** |
| Lab Fluid Code: | **253071** | Fric. Plate Batch: | **Batch 5** |
| Completion Date: | **07/25/2010** | Steel Plate Batch: | **10/9/2008** |

| | Limits | | Results | | | |
|---|---|---|---|---|---|---|
| | Value | % Change | 100 N | 10,000 N | % Change | P/F |
| Slip Time Max. | 0 600 | N/A | 0.540 | 0.450 | -16.67 | **P** |
| Mid-Point Fric. Coeff. Min. | 0 096 | N/A | 0.087 | 0.114 | 31 03 | **F** |
| Static Friction Coeff. | N/A | N/A | 0.161 | 0.125 | -22.36 | |
| Low Speed Peak Fric. Coeff. | N/A | N/A | 0.173 | 0.135 | -21.97 | |
| 0 25 Second Low Speed Coeff. | N/A | N/A | 0.163 | 0.131 | -19.63 | |

### ALLISON C- 4 PAPER FRICTION TEST

| | | | |
|---|---|---|---|
| Sponsor Fluid Code: | **LO-251746** | Test Number: | **C2-6-1551** |
| Lab Fluid Code: | **251746** | Fric. Plate Batch: | **BATCH 5** |
| Completion Date: | **07/23/2010** | Steel Plate Batch: | **10/9/2008** |

| | Limits | | Results | | | |
|---|---|---|---|---|---|---|
| | Value | % Change | 100 N | 10,000 N | % Change | P/F |
| Slip Time Max. | 0 600 | N/A | 0.470 | 0.420 | -10.64 | **P** |
| Mid-Point Fric. Coeff. Min. | 0 096 | N/A | 0.103 | 0.120 | 16 50 | **P** |
| Static Friction Coeff. | N/A | N/A | 0.173 | 0.160 | -7 51 | |
| Low Speed Peak Fric. Coeff. | N/A | N/A | 0.197 | 0.173 | -12.18 | |
| 0 25 Second Low Speed Coeff. | N/A | N/A | 0.182 | 0.165 | -9 34 | |

## *Revised Candidates*

### ALLISON C- 4 PAPER FRICTION TEST

| | | | |
|---|---|---|---|
| Sponsor Fluid Code: | **LO268869** | Test Number: | **C2-3-1573** |
| Lab Fluid Code: | **268869** | Fric. Plate Batch: | **Lot 6** |
| Completion Date: | **10/15/2011** | Steel Plate Batch: | **10/9/2008** |

| | Limits | | Results | | | |
|---|---|---|---|---|---|---|
| | Value | % Change | 100 N | 10,000 N | % Change | P/F |
| Slip Time Max. | 0 600 | N/A | 0.530 | 0.460 | -13.21 | **P** |
| Mid-Point Fric. Coeff. Min. | 0 096 | N/A | 0.093 | 0.111 | 19 35 | **F** |
| Static Friction Coeff. | N/A | N/A | 0.103 | 0.111 | 7.77 | |
| Low Speed Peak Fric. Coeff. | N/A | N/A | 0.102 | 0.115 | 12.75 | |
| 0 25 Second Low Speed Coeff. | N/A | N/A | 0.095 | 0.111 | 16 84 | |

### ALLISON C- 4 PAPER FRICTION TEST

| | | | |
|---|---|---|---|
| Sponsor Fluid Code: | **LO271510** | Test Number: | **C2-4-1574** |
| Lab Fluid Code: | **271510** | Fric. Plate Batch: | **Lot 6** |
| Completion Date: | **10/17/2011** | Steel Plate Batch: | **10/9/2008** |

| | Limits | | Results | | | |
|---|---|---|---|---|---|---|
| | Value | % Change | 100 N | 10,000 N | % Change | P/F |
| Slip Time Max. | 0 600 | N/A | 0.500 | 0.430 | -14.00 | **P** |
| Mid-Point Fric. Coeff. Min. | 0.085 | N/A | 0.095 | 0.118 | 23.16 | **P** |
| Static Friction Coeff. | N/A | N/A | 0.173 | 0.158 | -8 67 | |
| Low Speed Peak Fric. Coeff. | N/A | N/A | 0.187 | 0.166 | -11.23 | |
| 0 25 Second Low Speed Coeff. | N/A | N/A | 0.171 | 0.163 | -9 94 | |

Table 27 shows the results from the graphite friction testing. Both initial candidates LO253071 and LO251746 did not meet the targets in either slip time or midpoint minimum coefficient of friction. Both candidates performed similarly overall. Each showed a borderline increase in slip time with respect to the maximum allowable for the 5,500 cycles engagement (1,500 cycles engagement OK). For midpoint friction coefficient, each candidate met the minimum at 1,500 cycles engagement but fell below the specification at 5,500 cycles engagement. For revised candidate LO268869, the formulations changes improved the slip time response staying below the maximum allowable time. LO268869 was still below the minimum midpoint coefficient of friction, but would be considered a borderline fail (0.088 versus passing 0.089). Revised candidate LO271510's formulation changes allowed a passing result for both criteria.

Full Allison C4 frictional test report data from each revised candidate test, LO268869, and LO271510 are presented in Appendix D1, and D2 respectively.

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# Table 27. Revised SCPL Candidate Evaluations, Allison C4 Graphite Friction Testing

## *Initial Candidates*

**ALLISON C-4 GRAPHITE FRICTION TEST SUMMARY**

(Torque in Ft-Lbs)

| | | | |
|---|---|---|---|
| Sponsor Fluid Code: | **LO253071** | Test Number: | **C4-8-1286** |
| Lab Fluid Code: | **LO-253071** | Fric. Plate Batch: | **BATCH 44** |
| Completion Date: | **7/22/2010** | Steel Plate Batch: | **10/9/2008** |

| | Limits | | Results | | | |
|---|---|---|---|---|---|---|
| | Max | Max Change | 1,500 N | 5,500 N | % Change | P/F |
| Slip Time Max. | 0.89 | N/A | 0.79 | 0.91 | 15.19 | F |
| 0.2 Second Dynamic Coeff. | N/A | N/A | 0.084 | 0.063 | -25.000 | |
| Mid-Point Fric. Coeff. Min. | 0.089 | N/A | 0.093 | 0.082 | -11.828 | F |
| Static Friction Coeff. | N/A | N/A | 0.129 | 0.112 | -13.178 | |
| Low Speed Peak Fric. Coeff. | N/A | N/A | 0.154 | 0.136 | -11.688 | |
| 0.25 Second Low Speed Coeff. | N/A | N/A | 0.130 | 0.123 | -5.385 | |

**ALLISON C-4 GRAPHITE FRICTION TEST SUMMARY**

(Torque in Ft-Lbs)

| | | | |
|---|---|---|---|
| Sponsor Fluid Code: | **LO251746** | Test Number: | **C4-7-1285** |
| Lab Fluid Code: | **LO-251746** | Fric. Plate Batch: | **Batch 44** |
| Completion Date: | **7/21/2010** | Steel Plate Batch: | **10/9/2008** |

| | Limits | | Results | | | |
|---|---|---|---|---|---|---|
| | Max | Max Change | 1,500 N | 5,500 N | % Change | P/F |
| Slip Time Max. | 0.89 | N/A | 0.81 | 0.90 | 11.11 | F |
| 0.2 Second Dynamic Coeff. | N/A | N/A | 0.072 | 0.048 | -33.333 | |
| Mid-Point Fric. Coeff. Min. | 0.089 | N/A | 0.090 | 0.084 | -6.667 | F |
| Static Friction Coeff. | N/A | N/A | 0.142 | 0.136 | -4.225 | |
| Low Speed Peak Fric. Coeff. | N/A | N/A | 0.160 | 0.153 | -4.375 | |
| 0.25 Second Low Speed Coeff. | N/A | N/A | 0.149 | 0.142 | -4.698 | |

## *Revised Candidates*

**ALLISON C-4 GRAPHITE FRICTION TEST SUMMARY**

(Torque in Ft-Lbs)

| | | | |
|---|---|---|---|
| Sponsor Fluid Code: | **LO268869** | Test Number: | **C4-3-1341** |
| Lab Fluid Code: | **268869** | Fric. Plate Batch: | **Lot 44** |
| Completion Date: | **10/14/2011** | Steel Plate Batch: | **10/9/2008** |

| | Limits | | Results | | | |
|---|---|---|---|---|---|---|
| | Max | Max Change | 1,500 N | 5,500 N | % Change | P/F |
| Slip Time Max. | 0.89 | N/A | 0.75 | 0.86 | 14.67 | P |
| 0.2 Second Dynamic Coeff. | N/A | N/A | 0.090 | 0.067 | -25.556 | |
| Mid-Point Fric. Coeff. Min. | 0.089 | N/A | 0.099 | 0.087 | -12.121 | BL-F |
| Static Friction Coeff. | N/A | N/A | 0.132 | 0.113 | -14.394 | |
| Low Speed Peak Fric. Coeff. | N/A | N/A | 0.138 | 0.123 | -10.870 | |
| 0.25 Second Low Speed Coeff. | N/A | N/A | 0.126 | 0.112 | -11.111 | |

**ALLISON C-4 GRAPHITE FRICTION TEST SUMMARY**

(Torque in Ft-Lbs)

| | | | |
|---|---|---|---|
| Sponsor Fluid Code: | **LO271510** | Test Number: | **C4-4-1342** |
| Lab Fluid Code: | **271510** | Fric. Plate Batch: | **Lot 44** |
| Completion Date: | **10/15/2011** | Steel Plate Batch: | **10/9/2008** |

| | Limits | | Results | | | |
|---|---|---|---|---|---|---|
| | Max | Max Change | 1,500 N | 5,500 N | % Change | P/F |
| Slip Time Max. | 0.89 | N/A | 0.76 | 0.81 | 6.58 | P |
| 0.2 Second Dynamic Coeff. | N/A | N/A | 0.086 | 0.077 | -10.465 | |
| Mid-Point Fric. Coeff. Min. | 0.089 | N/A | 0.097 | 0.094 | -3.093 | P |
| Static Friction Coeff. | N/A | N/A | 0.140 | 0.128 | -8.571 | |
| Low Speed Peak Fric. Coeff. | N/A | N/A | 0.164 | 0.148 | -9.756 | |
| 0.25 Second Low Speed Coeff. | N/A | N/A | 0.147 | 0.140 | -4.762 | |

### 3.5.2 Caterpillar TO-4 Testing

Similar to the Allison C4 transmission compatibility tests, Caterpillar TO-4 standardized tests were completed on each revised candidate to assess potential performance in Caterpillar transmission applications. The Caterpillar TO-4 testing matrix for the SCPL candidates included frictional testing on sintered bronze (Sequence 1220) and wheel brake paper (Sequence 1222).

Table 28 shows a summary of the CAT TO-4 frictional testing. Revised candidate LO268869 showed essentially no change over its initial evaluation (LO253071) by passing the sintered bronze (SEQ1220) and failing the wheel brake paper (SEQ1222) tests. For revised candidate LO271510, the formulation changes improved the sintered bronze (SEQ1220) response and passed the test, but still failed the wheel brake paper (SEQ1222).

Both revised SCPL candidates continue to struggle with the wheel brake paper (SEQ1222) portion of the CAT TO-4 test. From further review, revised candidate LO268869 generally showed lower coefficients of friction (static and dynamic) than the limit lines generated by reference fluids. This would suggest increased slipping and potentially reduced torque capacity in a wet clutch/brake arrangement. Despite this, the coefficient of friction traces remained smooth and predictable throughout testing, not showing any tendencies to rapidly change its frictional properties. This suggests that, although a technical failure, the candidate should not cause catastrophic failure within a transmission, but has room for improvement to ensure proper performance in all scenarios. Upon further review of revised candidate LO271510's wheel brake paper (SEQ1222) results, failures only occurred during the dynamic coefficient friction tests. In general it showed very borderline failures during each of these traces with only 1 to 2 points being below the limit lines of the reference fluid. Figure 6 on the following page shows a plot of one of the borderline dynamic coefficient failures seen during LO271510 testing. This suggest that again, although a technical failure, the candidate should perform as intended in this type application.

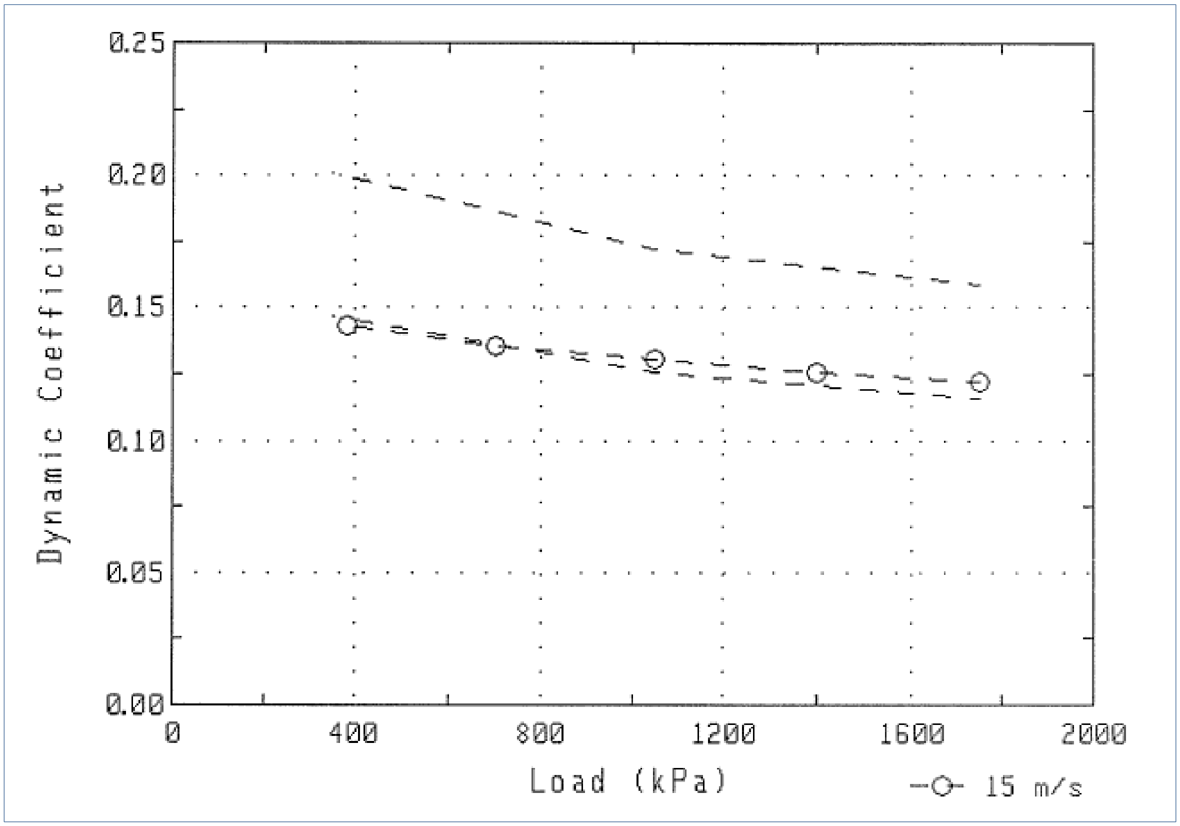


**Figure 6. Revised SCPL Candidate LO271510, CAT TO-4 SEQ1222 Dynamic Coefficient of Friction vs Load Trace**

As before, it is expected that all of these borderline failures for the revised SCPL candidates could be corrected with slight formulation changes. None of the SCPL candidates exhibited behaviors that would be considered catastrophic if used in transmissions, but room for improvement remains for the SCPL oils in regards to Caterpillar TO-4 friction testing. Full Caterpillar TO-4 test report data from each candidate test, LO268869 and LO271510, are presented in Appendix E1, and E2 respectively.

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**Table 28. Revised SCPL Candidate Evaluations, Caterpillar TO-4 Friction Testing**

| CAT TO-4 | LO253071 | LO268869 | LO251746 | LO271510 |
|---|---|---|---|---|
| ***Sequence 1220*** | *initial* | *revised* | *initial* | *revised* |
| Dynamic Coef vs Cycle | Pass | Pass | Fail | Pass |
| Dynamic Coef vs Load | Pass | Pass | Fail | Pass |
| Dynamic Coef vs Speed | Pass | Pass | Fail | Pass |
| Energy Limit | Pass | Pass | Pass | Pass |
| Static Coef vs Load | Pass | Pass | Fail | Pass |
| Static Coef vs Speed | Pass | Pass | Fail | Pass |
| Energy Limit | Pass | Pass | Pass | Pass |
| Total Wear | 0.039 | 0.016 | 0.039 | 0.006 |
| ***Sequence 1222*** | | | | |
| Dynamic Coef vs Cycle | Fail | Fail | Fail | Fail |
| Dynamic Coef vs Load | Fail | Fail | Fail | Fail |
| Dynamic Coef vs Speed | Fail | Fail | Fail | Fail |
| Energy Limit | Pass | Pass | Pass | Pass |
| Static Coef vs Load | Fail | Fail | Fail | FP |
| Static Coef vs Speed | Pass | Fail | Fail | Pass |
| Energy Limit | Pass | Pass | Pass | Pass |
| Total Wear | 0.03 | 0.029 | 0.007 | 0.029 |
| ***Friction Retention*** | | | | |
| | Pass | N/A | Pass | N/A |

### 3.5.3 John Deere JDQ-96 Wet Brake Testing

John Deere JDQ-96 testing assesses lubricant interactions with a submerged wet braking system. Although not a MIL-PRF-2104 spec requirement, this test provides useful information into the frictional properties of the candidate SCPLs combined with different friction materials. As with previous evaluations, an abbreviated 1,000 cycle test was run to get an indication of overall compatibility for the revised SCPL candidates. The two main primary parameters of interest are the relative capacity, and overall torque variation. The relative capacity is a measure of the overall torque capacity of the system with the lubricant being tested, and torque variation is a measure between the peak and valley of the torque trace calculated from high speed torque data acquired across several engagements.

It is important to note here, that direct comparisons between initial and revised candidate testing cannot be made. This is due to a change in the John Deere JDQ-96 test stand. Previously the stand was motored using a fired diesel engine to operate the test axle, whereas the new stand uses a large variable speed drive for powering. This has caused some shifting in results generated between the two stand configurations. In addition, it has been noted by project managers that the JDQ-96 test is sensitive to the actual braking hardware being used. Even from hardware supplied from a single source, the magnitude of torque variation has been found to be highly hardware dependant. To help mitigate these confounding effects, a 1,000 cycle reference was operated using the tested components (piston & backing plate) prior to running the candidate tests, so that baseline data was most relevant to the results.

Table 29 summarizes results for each of the revised SCPL candidates and their respective initial evaluations. All of the candidates provided adequate torque capacity compared to the reference fluid baseline. The overall torque variation for the revised SCPL candidates was again larger than that of the reference fluid, a trend that was consistent with initial SCPL evaluations. This behavior has been noted in previous testing as being typical of engine oils in this type application. This explains each fluid being noted as creating high levels of brake noise. Other than a higher level of audible noise, this increase should not pose adverse effects on overall function and usability of the system.

Full JDQ-96 test report data from each candidate test, LO268869, and LO271510 are presented in Appendix F1 and F2 respectively.

**Table 29. SCPL Revised Candidate Evaluations, JDQ-96 Wet Brake Compatibility**

| John Deere JDQ-96 | | | | |
|---|---|---|---|---|
| Performed using 1400 Series Axle | *initial* | *initial* | *revised* | *revised* |
| Test Number | 10979 | 10739 | 11843 | 111114 |
| Oil Code | **LO253071** | **LO251746** | **LO268869** | **LO271510** |
| EOT Date | 8/2/2010 | 7/31/2010 | 11/23/2011 | 12/1/2011 |
| | | **Current Reference Baseline Average (N*m)** | | |
| Relative Capacity @ 1,000 Cycles | 342,372 | 342,372 | 330,753 | 330,753 |
| Torque Variation @ 1,000 Cycles | 93,746 | 93,746 | 171,228 | 171,228 |
| | | **Results From Test Candidate** | | |
| Relative Capacity @ 1,000 Cycles | 360,738 | 398,534 | 335,125 | 392,229 |
| Torque Variation @ 1,000 Cycles | 164,190 | 253,990 | 206,202 | 264,603 |
| **Notes | This oil created high levels of brake noise. | This oil created high levels of brake noise. | This oil created high levels of brake noise. | This oil created high levels of brake noise. |

## 3.6 ENGINE FUEL CONSUMPTION IMPROVEMENT

To quantify fuel consumption improvements from the use of SCPL candidates, it was desired to develop a "standardized" type test to measure the fuel consumption of a baseline oil compared to each SCPL candidate. The following sections summarize the test stand configuration, cycle development, and procedures used during fuel consumption testing. Results are presented for the revised SCPL candidate evaluations.

### 3.6.1 Stand Configuration and Cycle Development

Similar to Part 1, fuel consumption evaluations were conducted on a test stand configured for the GEP 6.5L(T) engine, similar in many ways to the stand used for endurance evaluations. Variations between the two stands included oil system heat exchanger layout and the inclusion of an inlet air cooler for finer intake air temperature control. Field data from actual HMMWV operation at Ft. Hood, TX was used to create a series of 26 operating modes for testing. After determining which modes had the highest repeatability when conducted in the laboratory setting, a 14-mode cycle was derived. Power output and fuel flow rate (measured by a coriolis mass-flow meter) were used to calculate the engine break-specific fuel consumption (BSFC) for each of the 14 operating modes. After completing all 14 modes, each mode's BSFC value was weighted based upon the corresponding fuel flow rate and then combined to form a cycle BSFC result. For each lubricant evaluation, the 14-mode cycle was repeated seven times for repeatability purposes to verify BSFC changes.

### 3.6.2 Fuel Consumption Test Procedure

Prior to testing each candidate oil, a baseline SAE 40 oil was run to measure and account for engine drift over time. Engine oil was changed in the engine using a double flush method, along with an accompanying filter change. Once fluid levels were set, the engine was started and idled for 60 seconds to stabilize operation and check for system leaks. Next, a 1,500 rpm, half throttle warm-up brought up engine coolant and oil temperatures prior to test cycle initiation. Throughout testing, inlet air was maintained at 75 °F, and fuel temperature at 95 °F. The fuel source used for the evaluations was identical to that used in SCPL endurance testing in the GEP 6.5L(T) engine (Appendix G). Following warm-up, the engine was brought to rated conditions (full load, 3,400 rpm) to set inlet and exhaust restrictions (0.55 psi and 0.27 psi respectively). After the restrictions were set and verified, the engine was then ramped down and controlled to 1,100 rpm and 60 lb-ft for 30 minutes to stabilize temperatures before continuing with the 14-mode cycle shown in Table 30.

**Table 30. GEP 6.5L(T) Fuel Consumption Test Points**

| Point | RPM | Torque, lb-ft | Power, hp | Oil Sump, ˚F | Intake Air, ˚F | Fuel Inlet, ˚F |
|---|---|---|---|---|---|---|
| 1 | 1100 | 59.7 | 12.5 | 165 | 75 | 95 |
| 2 | 2100 | 59.7 | 23.9 | 180 | | |
| 3 | 1100 | 99.6 | 20.9 | | | |
| 4 | 1100 | 179.2 | 37.5 | | | |
| 5 | 1600 | 99.6 | 30.3 | 195 | | |
| 6 | 2100 | 139.4 | 55.7 | | | |
| 7 | 2600 | 99.6 | 49.3 | 215 | | |
| 8 | 2100 | 179.2 | 71.7 | | | |
| 9 | 3100 | 99.6 | 58.8 | | | |
| 10 | 2600 | 139.4 | 69.0 | | | |
| 11 | 3100 | 139.4 | 82.3 | 245 | | |
| 12 | 2600 | 179.2 | 88.7 | | | |
| 13 | 2400 | 302.4 | 138.2 | | | |
| 14 | 2800 | 250.8 | 133.7 | | | |

At the completion of mode 14, the engine would return to the 30 minute stabilization step for the next cycle. This continued until all seven cycles were completed. In the event of a shut-down, the cycle was restarted from the temperature stabilization step.

### 3.6.3 Candidate Results

Results from the revised candidate SCPL's are shown in Table 31 and Table 32. The (4) and (5) associated with the SAE 40 Baseline results reference the order in which that baseline evaluation occurred for the engine installation. Additional baseline evaluations were conducted prior to the SCPL candidate evaluations to ensure engine stability and oil discrimination.

**Table 31. LO271510 Fuel Consumption Improvement**

| **General Engine Products 6.5 Turbo Fuel Consumption** | | **BSFC** |
|---|---|---|
| | **Run** | **FE Cycle** |
| **SAE 40 LO258269 Baseline (4)** | 1 | 0.4989 |
| | 2 | 0.4997 |
| | 3 | 0.4988 |
| | 4 | 0.4983 |
| | 5 | 0.4961 |
| | 6 | 0.4932 |
| | 7 | 0.4968 |
| | Average | 0.49741 |
| | Standard Deviation | 0.00224 |
| | COV | 0.45% |
| **Revised SCPL LO271510 Candidate** | 1 | 0.4854 |
| | 2 | 0.4856 |
| | 3 | 0.4830 |
| | 4 | 0.4848 |
| | 5 | 0.4860 |
| | 6 | 0.4845 |
| | 7 | 0.4836 |
| | Average | 0.48472 |
| | Standard Deviation | 0.00109 |
| | COV | 0.22% |
| | **Percent change:** | **2.55%** |
| | F-Test, two tail | 0.102 |
| | Variance: Equal=2, Unequal=3 | 2 |
| | T-test | $1.29 \times 10^{-08}$ |
| | Statistically significant with 95% CI | Yes |
| | Statistically significant with 99% CI | Yes |

**Table 32. LO268869 Fuel Consumption Improvement**

| General Engine Products 6.5 Turbo Fuel Consumption | | BSFC |
|---|---|---|
| | **Run** | **FE Cycle** |
| **SAE 40 LO258269 Baseline (5)** | 1 | 0.4980 |
| | 2 | 0.4977 |
| | 3 | 0.4974 |
| | 4 | 0.4983 |
| | 5 | 0.4961 |
| | 6 | 0.4969 |
| | 7 | 0.4988 |
| | Average | 0.49760 |
| | Standard Deviation | 0.00090 |
| | COV | 0.18% |
| **Revised SCPL LO268869 Candidate** | 1 | 0.4874 |
| | 2 | 0.4861 |
| | 3 | 0.4857 |
| | 4 | 0.4845 |
| | 5 | 0.4835 |
| | 6 | 0.4842 |
| | 7 | 0.4830 |
| | Average | 0.48490 |
| | Standard Deviation | 0.00157 |
| | COV | 0.32% |
| | **Percent change:** | **2.55%** |
| | F-Test, two tail | 0.205 |
| | Variance: Equal=2, Unequal=3 | 2 |
| | T-test | $3.33 \times 10^{-10}$ |
| | Statistically significant with 95% CI | Yes |
| | Statistically significant with 99% CI | Yes |

Both revised SCPL candidate lubricants showed a statistically significant improvement of 2.55% with respect to the SAE 40 baseline oil. To determine the shift in engine baseline performance, the baseline tests used in each of the candidate lubricant evaluations were compared. This is shown in Table 33.

**Table 33. SAE 40 Baseline Shift**

| **General Engine Products 6.5 Turbo Fuel Consumption** | | **BSFC** |
|---|---|---|
| | **Run** | **FE Cycle** |
| **SAE 40 LO258269 Baseline (4)** | 1 | 0.4989 |
| | 2 | 0.4997 |
| | 3 | 0.4988 |
| | 4 | 0.4983 |
| | 5 | 0.4961 |
| | 6 | 0.4932 |
| | 7 | 0.4968 |
| | Average | 0.49741 |
| | Standard Deviation | 0.00224 |
| | COV | 0.45% |
| **SAE 40 LO258269 Baseline (5)** | 1 | 0.4980 |
| | 2 | 0.4977 |
| | 3 | 0.4974 |
| | 4 | 0.4983 |
| | 5 | 0.4961 |
| | 6 | 0.4969 |
| | 7 | 0.4988 |
| | Average | 0.49760 |
| | Standard Deviation | 0.00090 |
| | COV | 0.18% |
| | **Percent change:** | **-0.04%** |
| | F-Test, two tail | 0.044 |
| | Variance: Equal=2, Unequal=3 | 3 |
| | T-test | $8.44\text{x}10^{-01}$ |
| | Statistically significant with 95% CI | No |
| | Statistically significant with 99% CI | No |

# 4.0 CONCLUSIONS

From testing completed, the revised SCPL candidates provided promising results for the continued development of the SCPL. Overall engine durability and oil degradation testing using the GEP 6.5L(T) engine yielded improved results. Revised candidate LO268869 showed the most improvement in the GEP 6.5L(T) testing, and was capable of operating to the full 210 hour test target while maintaining acceptable used oil condition. Although revised candidate LO271510 did not make the target 210 hours, it ran for 196 hours prior to termination, which is an improvement over its initial evaluation. Both revised candidates demonstrated improved oxidation stability over current military approved oils as tested during Part 1, which reinforces the feasibility aspects of SCPL utilization. In the 2-cycle diesel engine testing using the DDC 6V53T, both revised candidates provided comparable, and in some cases such as deposit control, better performance than that seen during the MIL-PRF-2104H OE/HDO 15W-40 baseline. This suggests that low viscosity SCPL can be successfully used in the military's 2-cycle engines. Lastly, the ASTM D5966 Roller Follower Wear Test demonstrated that each revised candidate provided adequate protection to critical roller follower valve train components.

Transmission testing completed on the revised candidates again confirmed the possibilities of using the SCPL in powershift transmission applications. Some improvements were made over the initial SCPL candidates provided, but further modifications in formulation are desired to improve function and ensure adequate performance during all conditions. Despite this, none of the revised SCPL candidates exhibited any catastrophic incompatibility with typical transmission components they would be expected to come into contact with.

Lastly, fuel consumption improvements were found to be similar for both revised candidate lubricants. Results help confirm that through the use of low viscosity lubricants, potential fuel savings for the military could be realized. The 2.55% improvement over the SAE40 baseline oil translates into an approximate 1.5% improvement over MIL-PRF-2104H 15W-40 diesel engine oils [4]. These savings, combined with goals of extended drain intervals, all help in making an SCPL lubricant potentially cost effective when compared to current products.

## 5.0 RECOMMENDATIONS

It is the recommendation of TFLRF staff that both LO268869 and LO271510 continue to be considered candidates for the SCPL program. Formulation changes need to be made for both candidates to improve transmission performance without negatively impacting engine durability, oil degradation, and 2-cycle compatibility.

Long term considerations for the SCPL program should include:

- High temperature 2–cycle diesel engine compatibility testing
- Aircooled diesel engine compatibility using the AVDS-1790 engine
- Detailed investigation of ring pack wear changes due to lowered viscosities
- Conduct multiple field demonstrations at U.S. Army posts consisting of cold, moderate, and high temperature climate conditions.

## 6.0 REFERENCES


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# APPENDIX – A1
# EVALUATION OF SCPL CANDIDATE
# LO-268869

# EVALUATION OF SCPL CANDIDATE LO-268869

## Project 14734.17

**GEP 6.5L Turbocharged HMMWV Engine**

**Test Lubricant: LO-268869**
**Test Fuel: Jet-A w/DCI-4A**
**Test Number: LO268869-65T1-W-210**
**Start of Test Date: August 22, 2011**
**End of Test Date: September 12, 2011**
**Test Duration: 210 Hours**
**Test Procedure: Tactical Wheeled Vehicle**

***Conducted for***

**U.S. Army TARDEC**
**Force Projection Technologies**
**Warren, Michigan**

# Table of Contents

## Introduction

This test was used to determine the performance of Single Common Powertrain Lubricant (SCPL) candidate LO-268869 when used in the General Engine Products (GEP) 6.5L turbocharged engine by the procedures outlined in the Tactical Wheeled Vehicle Cycle (CRC Report No.406, Development of Military Fuel/Lubricant/Engine Compatibility Test). This work was completed in support of Project 14734.17, Single Common Powertrain Lubricants for Combat/Tactical Equipment.

## Test Engine

The oil was evaluated in the General Engine Products 6.5L turbocharged diesel engine, representative of engines currently fielded in High Mobility Multipurpose Wheeled Vehicles (HMMWV). Prior to testing, the engine was disassembled and measured for pre-test wear. Engine clearances and specifications were verified, and the engine was reassembled following standard assembly procedures.

## Test Stand Configuration

The engine was mounted in a test stand specifically configured for GEP engine testing. Engine monitoring, control, and data acquisition was supplied by Southwest Research Institute (SwRI) developed PRISM software. An appropriately sized absorption dynamometer was used to supply engine loading. Engine oil and coolant temperatures were controlled with the use of liquid-to-liquid heat exchangers. Engine intake air was supplied at ambient conditions, and inlet fuel temperatures were controlled through an auxiliary fuel heater loop.

## Engine Run-in

Prior to testing, the engine was run-in following procedures outlined below. Cyclic modes were repeated for a total of 24 cycles. Total runtime for engine run-in was approximately 6 hours.

| Time, min | Mode | Speed, RPM | Torque, lb*ft | Coolant Out, °F | Oil Galley, °F |
|---|---|---|---|---|---|
| 10 | Steady State | 1500 | 10 | 215 | 220 |
| 10 | Steady State | 1600 | 109 | 215 | 220 |
| 10 | Steady State | 2400 | 145 | 215 | 220 |
| 10 | Steady State | 3200 | 165 | 215 | 220 |
| 1 | Cyclic | 900 | 0 | 215 | 220 |
| 2 | Cyclic | 2600 | 50% | 215 | 220 |
| 2 | Cyclic | 1800 | 1% | 215 | 220 |
| 2 | Cyclic | 1200 | 25% | 215 | 220 |
| 2 | Cyclic | 1800 | 50% | 215 | 220 |
| 2 | Cyclic | 3200 | 5% | 215 | 220 |
| 2 | Cyclic | 2200 | 50% | 215 | 220 |

**Figure A1-1: Test Engine Run-In Procedure**

## Pre-Test Engine Performance Check

After completion of engine run-in, a full load powercurve was completed from 1000 rpm to rated engine speed (3400 rpm) to determine pre-test engine performance. The pre-test engine performance check was completed using the same oil charge used during the engine run-in segment. Powercurve plots can be seen in the Engine Performance Curves section.

## Test Cycle

The test cycle followed during oil evaluation was the standard 210 hr Tactical Wheeled Vehicle cycle as outlined in CRC Report No. 406, Development of Military Fuel/Lubricant/Engine Compatibility Test. Test termination would occur at 210 hrs or upon major oil degradation, which ever occurred first. The test cycle consisted of cyclic modes alternating between 2 hr rated speed conditions and 1 hr idle soaks. Total daily run-time was 14 hrs, 10 hrs at rated and 4 hrs at idle, with a 10 hr soak overnight before resuming the next day's testing. Engine oil temperatures were elevated to simulate conditions consistent with high ambient temperature typical of desert operations. Engine operating parameters were controlled throughout testing as specified below in Figure A1-2.

| Parameter | Rated Speed | Idle |
|---|---|---|
| Engine Speed, RPM | 3400 +/- 25 | 900 +/- 25 |
| Water Jacket Out, °F | 204 +/- 5 | 100 +/- 5 |
| Oil Sump, °F | 260 +/- 5 | 125 +/- 5 |

**Figure A2-2. Test Cycle Operating Parameters**

Engine coolant was a 60/40 blend of ethylene glycol antifreeze and deionized water. Test fuel was JP-8 blended onsite from Jet A with double the max treat rate of corrosion inhibitor/lubricity enhancer DCI-4A.

## Oil Sampling

Four ounces of engine oil was sampled every 14 hrs for used oil analysis. Engine oil analysis consisted of the following tests: (Note – at every 70 hr interval, two additional tests were completed on the used oil as shown below). All oil samples were weighed and logged to take into account during calculations of total engine oil consumption for the test duration.

| *Every 14hrs* | | |
|---|---|---|
| **ASTM** | **D4739** | Total Base Number |
| **ASTM** | **D664** | Total Acid Number |
| **ASTM** | **D445** | Kinematic Viscosity @ 100°C |
| **ASTM** | **API Gravity** | API Gravity |
| **ASTM** | **D4052** | Density |
| **ASTM** | **TGA SOOT** | TGA Soot |
| **ASTM** | **E168** | Oxidation |
| **ASTM** | **E168** | Nitration |
| **ASTM** | **D5185** | Wear Metals by ICP |

| *Every 70hrs* | | |
|---|---|---|
| **ASTM** | **D445** | Kinematic Viscosity @ 40°C |
| **ASTM** | **D2270** | Kinematic Viscosity Index |

**Figure A1-3. Used Oil Analysis Procedures**

Used oil analysis results can be seen in the engine oil analysis and engine oil analysis trends section of the report.

## Oil Level Checks

Engine oil level was checked daily and replenished as needed to restore oil level to full mark. This process occurred after the completion of the 10hr soak, prior to restarting the test. All oil additions were weighed and logged to take into account during calculation of total engine oil consumption for the test duration.

## Post-Test Engine Performance Check

After completion of testing, a full load powercurve was completed from 1000 rpm to rated engine speed (3400 rpm) to determine post-test engine performance. The post-test engine performance check was completed using the same oil charge used during the testing segment. Powercurve plots can be seen in the Engine Performance Curves section.

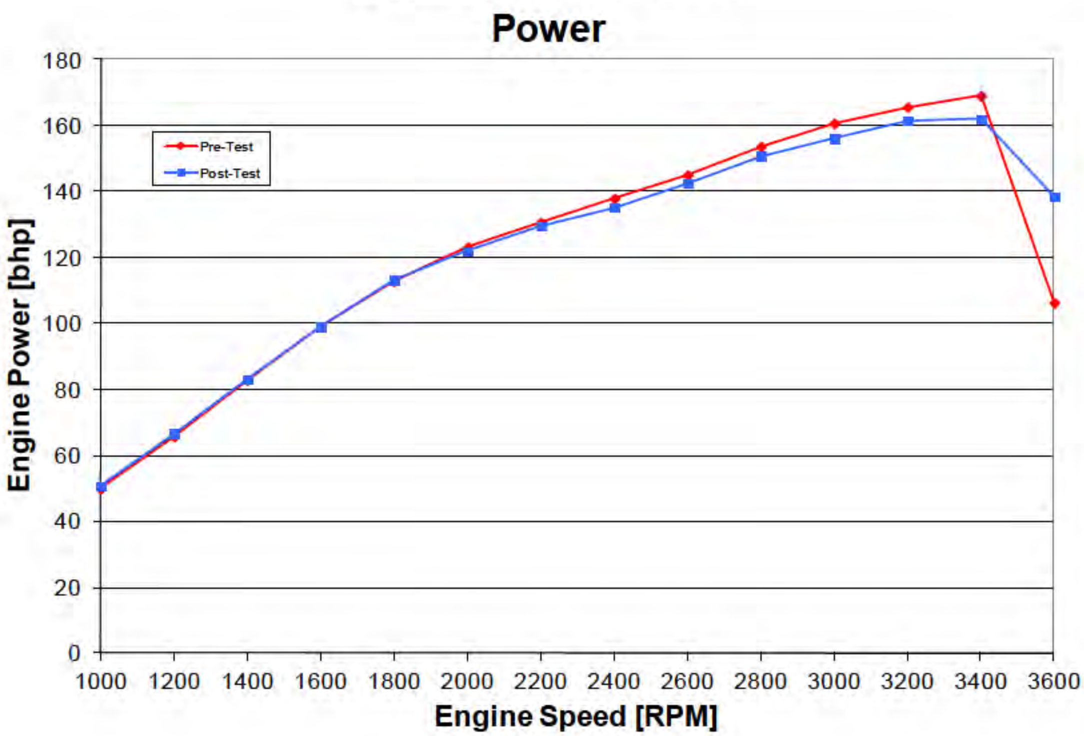
## Engine Operating Conditions Summary

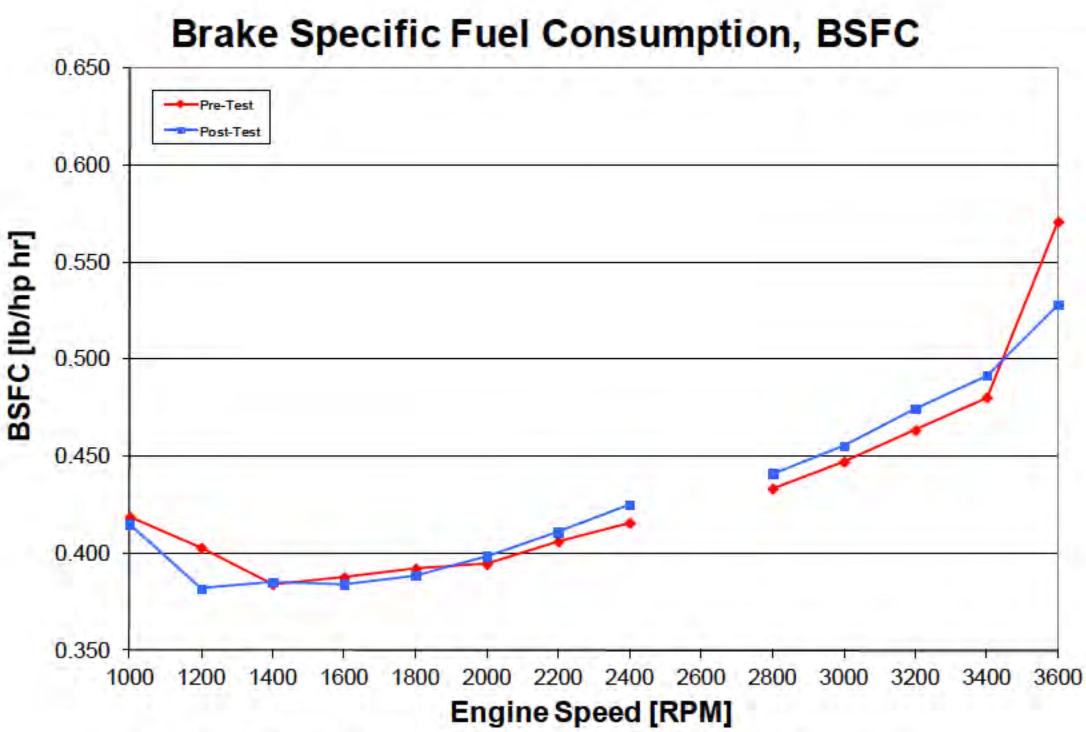
Below is a summary of the engine operating conditions over the test duration. The tested lubricant completed the full 210hr test schedule with satisfactory performance.

| | | Rated Conditions (3400 RPM) | | Idle Conditions (900 RPM) | |
|---|---|---|---|---|---|
| **Perameter:** | **Units:** | **Average** | **Std. Dev.** | **Average** | **Std. Dev.** |
| Engine Speed | RPM | 3400.01 | 0.73 | 900.21 | 2.73 |
| Torque* | ft*lb | 253.98 | 2.61 | 21.78 | 1.95 |
| Fuel Flow | lb/hr | 79.24 | 0.79 | 5.54 | 0.19 |
| Power* | bhp | 164.42 | 1.68 | 3.73 | 0.33 |
| BSFC* | lb/bhp*hr | 0.482 | 0.007 | 1.493 | 0.103 |
| **Temperatures:** | | | | | |
| Coolant In | °F | 190.06 | 1.09 | 91.96 | 0.89 |
| Coolant Out | °F | 205.00 | 1.01 | 99.97 | 0.79 |
| Oil Sump | °F | 260.05 | 0.44 | 125.61 | 1.81 |
| Fuel In | °F | 95.02 | 0.31 | 94.99 | 0.32 |
| Intake Air | °F | 74.94 | 3.62 | 72.25 | 3.25 |
| Cylinder 1 Exhaust | °F | 1136.32 | 15.48 | 194.86 | 5.21 |
| Cylinder 2 Exhaust | °F | 1204.35 | 10.67 | 199.40 | 6.03 |
| Cylinder 3 Exhaust | °F | 1186.67 | 14.53 | 211.52 | 7.07 |
| Cylinder 4 Exhaust | °F | 1141.38 | 14.00 | 201.10 | 7.13 |
| Cylinder 5 Exhaust | °F | 1152.53 | 16.09 | 195.86 | 8.32 |
| Cylinder 6 Exhaust | °F | 1162.03 | 13.27 | 197.34 | 6.78 |
| Cylinder 7 Exhaust | °F | 1150.77 | 14.52 | 190.82 | 4.81 |
| Cylinder 8 Exhaust | °F | 1147.97 | 11.32 | 191.63 | 5.31 |
| **Pressures:** | | | | | |
| Oil Galley | psi | 35.94 | 0.56 | 37.11 | 3.25 |
| Ambient Pressure | psiA | 14.26 | 0.05 | 14.25 | 0.05 |
| Boost Pressure | psi | 4.32 | 0.08 | -0.17 | 0.05 |

* Non-corrected Values

## Engine Performance Curves



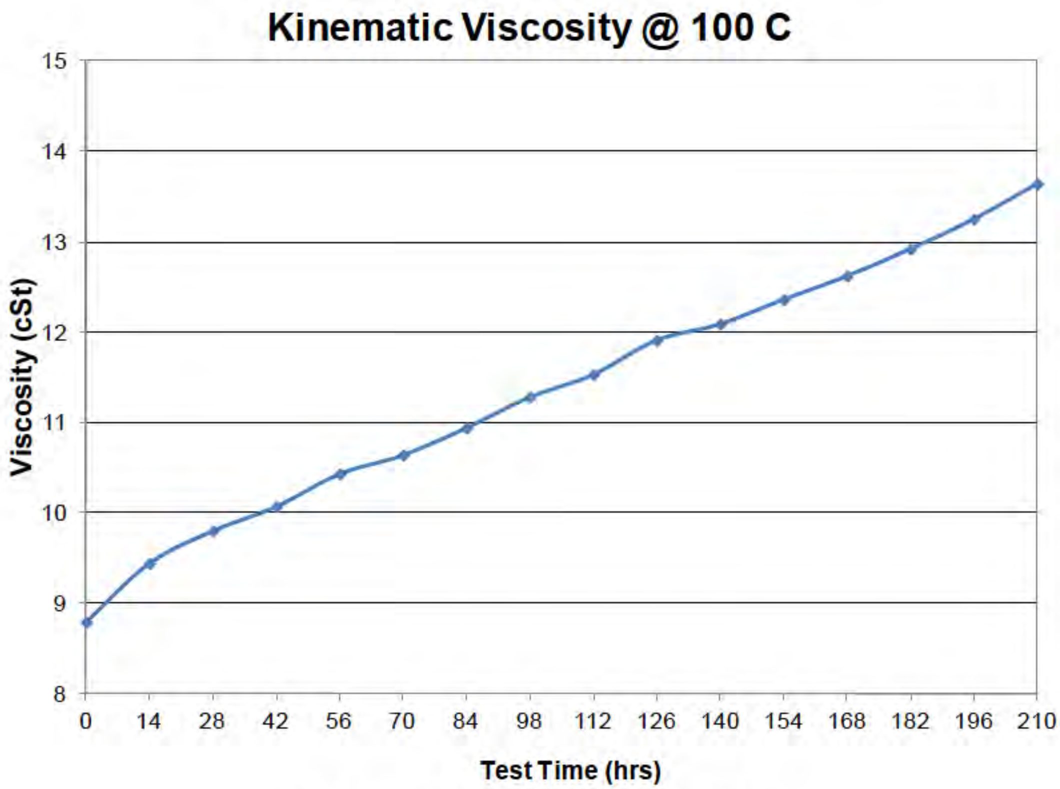



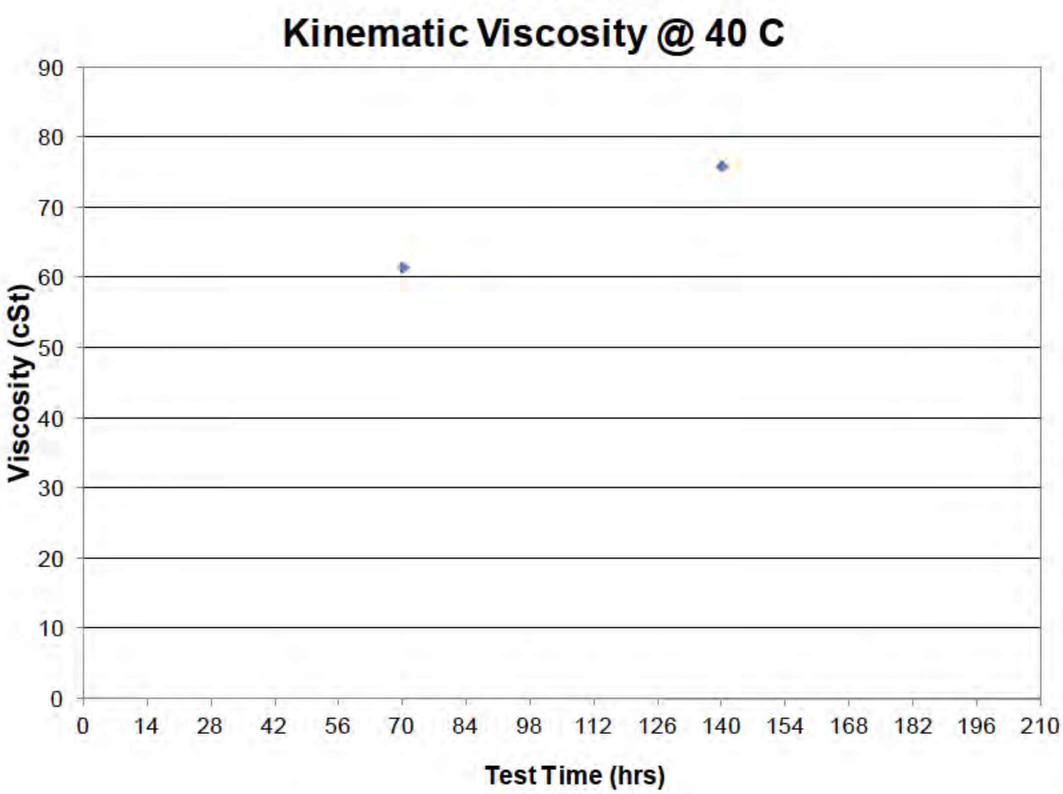

*Note – Breaks in BSFC plot due to invalid values for engine fuel flow during powercurve.

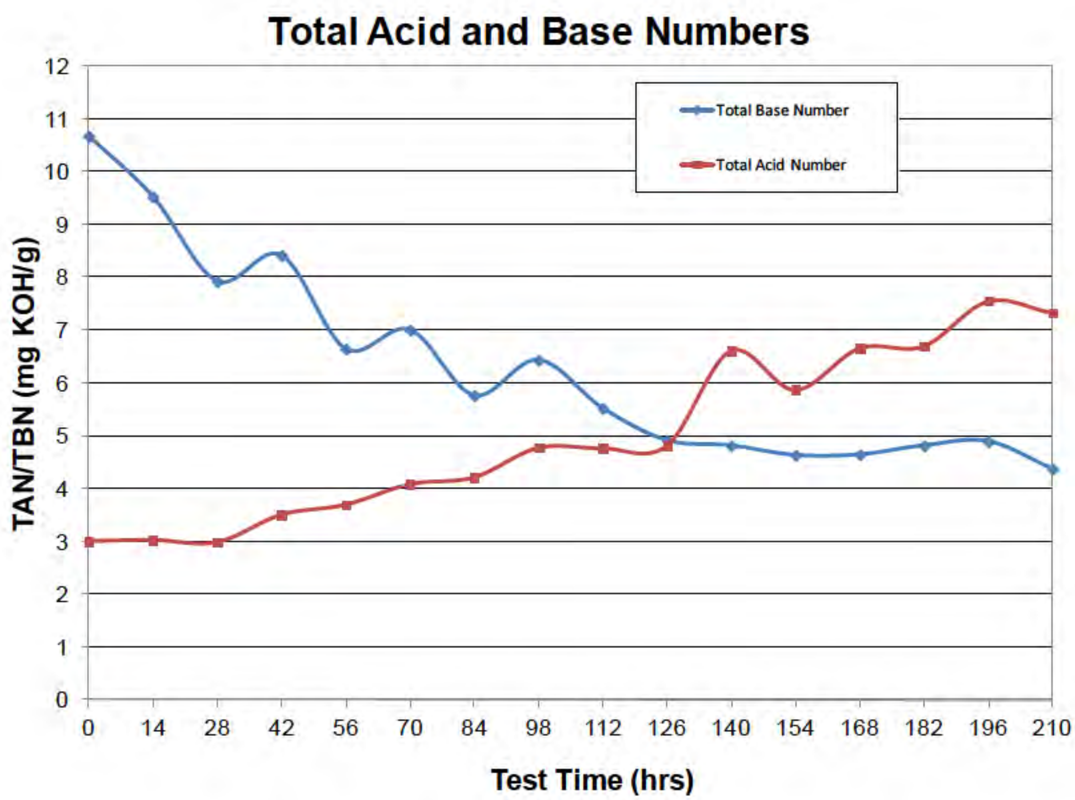
# Engine Oil Analysis

| Property | ASTM Test | Test Hours | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 14 | 28 | 42 | 56 | 70 | 84 | 98 | 112 | 126 | 140 | 154 | 168 | 182 | 196 | 210 |
| Density | D4052 | 0.8562 | 0.8593 | 0.8594 | 0.8625 | 0.863 | 0.8662 | 0.8671 | 0.8692 | 0.8721 | 0.8738 | 0.8758 | 0.8783 | 0.8803 | 0.8822 | 0.8847 | 0.8874 |
| Viscosity @ 100°C (cSt) | D445 | 8.8 | 9.4 | 9.8 | 10.1 | 10.4 | 10.6 | 10.9 | 11.3 | 11.5 | 11.9 | 12.1 | 12.4 | 12.6 | 12.9 | 13.3 | 13.6 |
| Viscosity @ 40°C (cSt) | D445 | | | | | | 61.5 | | | | | 76.0 | | | | | 93.5 |
| Viscosity Index (dyne/cm) | D2270 | | | | | | 164.0 | | | | | 156.0 | | | | | 148.0 |
| Total Base Number (mg KOH/g) | D4739 | 10.7 | 9.5 | 7.9 | 8.4 | 6.6 | 7.0 | 5.8 | 6.4 | 5.5 | 4.9 | 4.8 | 4.6 | 4.6 | 4.8 | 4.9 | 4.4 |
| Total Acid Number (mg KOH/g) | D664 | 3.0 | 3.0 | 3.0 | 3.5 | 3.7 | 4.1 | 4.2 | 4.8 | 4.8 | 4.8 | 6.6 | 5.9 | 6.7 | 6.7 | 7.6 | 7.3 |
| Oxidation (Abs./cm) | E168 FTNG | 0.0 | 1.2 | 5.4 | 9.6 | 13.7 | 18.1 | 22.5 | 26.6 | 30.8 | 35.0 | 39.9 | 45.2 | 50.3 | 55.3 | 63.8 | 68.8 |
| Nitration (Abs./cm) | E168 FTNG | 0.0 | 4.1 | 5.3 | 5.2 | 4.6 | 4.9 | 5.4 | 7.0 | 8.3 | 9.8 | 13.2 | 15.7 | 17.5 | 19.9 | 23.1 | 26.0 |
| Soot | Soot | 0.2 | 0.3 | 0.5 | 0.6 | 0.8 | 0.9 | 0.9 | 1.1 | 1.3 | 1.5 | 1.5 | 1.8 | 1.9 | 1.8 | 2.1 | 2.1 |
| Wear Metals (ppm) | D5185 | | | | | | | | | | | | | | | | |
| Al | | 6 | 7 | 7 | 7 | 8 | 8 | 8 | 9 | 9 | 9 | 10 | 10 | 10 | 11 | 11 | 11 |
| Sb | | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Ba | | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| B | | <1 | 1 | 2 | 3 | 2 | 3 | 5 | 4 | 4 | 3 | 3 | <1 | 5 | 3 | 3 | 3 |
| Ca | | 3524 | 3693 | 3874 | 3918 | 4085 | 4166 | 4267 | 4409 | 4599 | 4662 | 4996 | 4945 | 5003 | 5242 | 5363 | 5393 |
| Cr | | <1 | 1 | 2 | 3 | 4 | 5 | 5 | 6 | 6 | 7 | 8 | 8 | 8 | 9 | 9 | 10 |
| Cu | | <1 | 28 | 29 | 29 | 34 | 36 | 38 | 38 | 38 | 38 | 39 | 41 | 40 | 41 | 43 | 47 |
| Fe | | 2 | 46 | 82 | 113 | 144 | 168 | 198 | 223 | 257 | 288 | 328 | 359 | 373 | 400 | 422 | 447 |
| Pb | | <1 | 15 | 17 | 18 | 21 | 24 | 27 | 31 | 34 | 40 | 46 | 52 | 58 | 67 | 78 | 92 |
| Mg | | 11 | 20 | 16 | 16 | 17 | 19 | 18 | 19 | 19 | 19 | 22 | 21 | 22 | 22 | 21 | 21 |
| Mn | | <1 | 2 | 2 | 3 | 4 | 4 | 4 | 5 | 5 | 6 | 6 | 6 | 6 | 6 | 7 | 7 |
| Mo | | <1 | 10 | 14 | 18 | 21 | 23 | 26 | 27 | 29 | 30 | 32 | 32 | 31 | 32 | 32 | 32 |
| Ni | | <1 | 2 | 3 | 4 | 5 | 5 | 6 | 6 | 7 | 7 | 7 | 8 | 8 | 8 | 8 | 8 |
| P | | 1309 | 1234 | 1218 | 1212 | 1225 | 1246 | 1244 | 1297 | 1364 | 1377 | 1464 | 1498 | 1463 | 1560 | 1592 | 1607 |
| Si | | 2 | 47 | 55 | 56 | 57 | 54 | 57 | 55 | 54 | 52 | 51 | 52 | 49 | 48 | 46 | 46 |
| Ag | | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Na | | 7 | 6 | 6 | 6 | 6 | 7 | 7 | 7 | 8 | 8 | 10 | 8 | 8 | 10 | 10 | 10 |
| Sn | | <1 | 8 | 10 | 10 | 11 | 12 | 13 | 13 | 14 | 15 | 15 | 17 | 16 | 17 | 17 | 18 |
| Zn | | 1873 | 1874 | 1932 | 1897 | 2043 | 2078 | 2119 | 2236 | 2274 | 2342 | 2449 | 2603 | 2547 | 2621 | 2652 | 2747 |
| K | | 7 | 7 | 7 | 8 | 8 | 8 | 9 | 8 | 9 | 9 | 10 | 9 | 10 | 10 | 11 | 10 |
| Sr | | 1 | 2 | 1 | <1 | 2 | 1 | 1 | 2 | 1 | 1 | <1 | 2 | 2 | 1 | <1 | 2 |
| V | | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Ti | | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Cd | | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |

## Engine Oil Analysis Trends

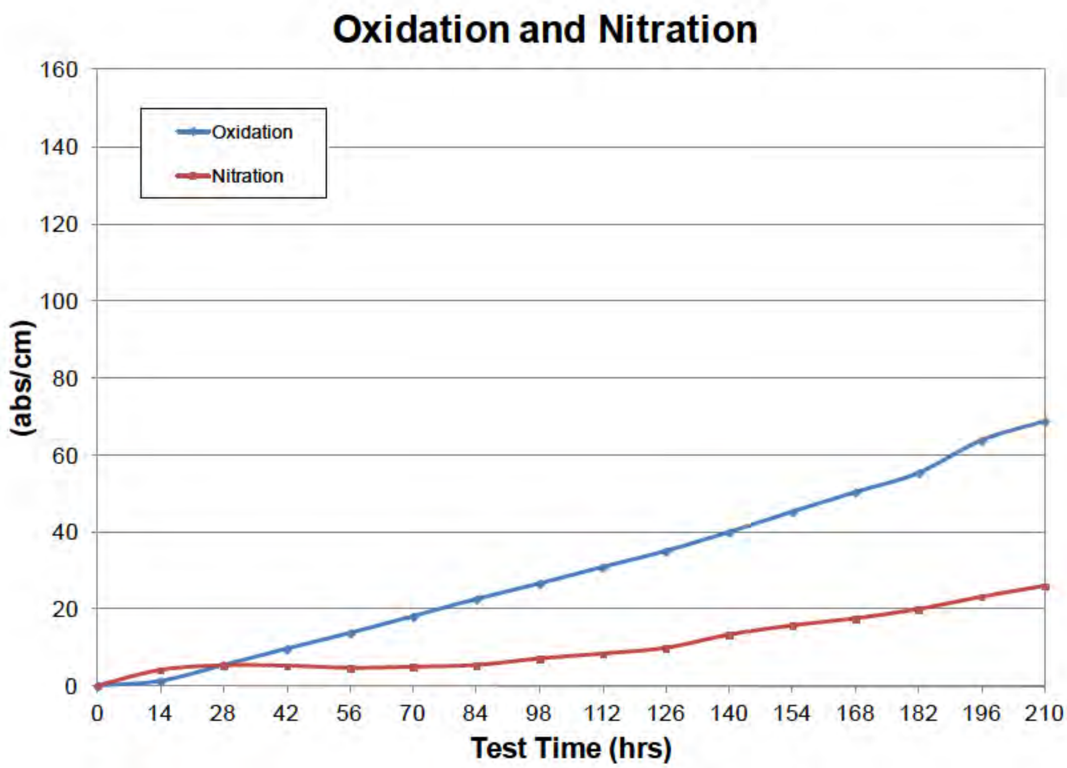


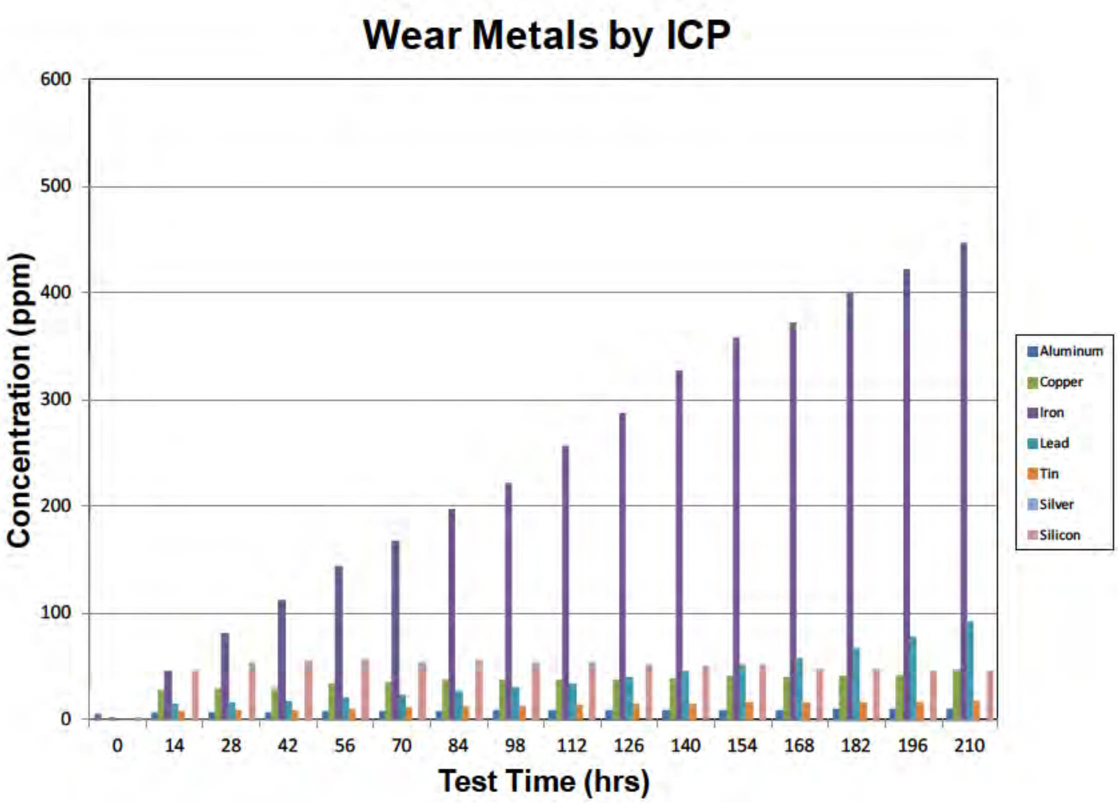





Total Acid and Base Numbers
Total Base Number
Total Acid Number
TAN/TBN (mg KOH/g)
0
1
2
3
4
5
6
7
8
9
10
11
12
0 14 28 42 56 70 84 98 112 126 140 154 168 182 196 210
Test Time (hrs)


Soot
(wt%)
0.0
0.5
1.0
1.5
2.0
2.5
0 14 28 42 56 70 84 98 112 126 140 154 168 182 196 210
Test Time (hrs)


Oxidation and Nitration
Oxidation
Nitration
(abs/cm)
Test Time (hrs)
0
20
40
60
80
100
120
140
160
0 14 28 42 56 70 84 98 112 126 140 154 168 182 196 210


Wear Metals by ICP
Concentration (ppm)
Test Time (hrs)
Aluminum
Copper
Iron
Lead
Tin
Silver
Silicon
0
100
200
300
400
500
600
0 14 28 42 56 70 84 98 112 126 140 154 168 182 196 210

## <u>Oil Consumption Data</u>

Average oil consumption per test hour was 0.081 lbs/hr.

| | Additions (lbs) | Samples (lbs) | Consumption (lbs) | Consumption Accumulated |
|---|---|---|---|---|
| **14 -hr** | 1.38 | 0.25 | 1.13 | 1.13 |
| **28 -hr** | 1.43 | 0.24 | 1.19 | 2.32 |
| **42 -hr** | 1.46 | 0.22 | 1.24 | 3.56 |
| **56 -hr** | 1.46 | 0.23 | 1.23 | 4.79 |
| **70 -hr** | 1.4 | 0.24 | 1.16 | 5.95 |
| **84 -hr** | 1.56 | 0.25 | 1.31 | 7.26 |
| **98 -hr** | 1.49 | 0.25 | 1.24 | 8.5 |
| **112 -hr** | 1.42 | 0.24 | 1.18 | 9.68 |
| **126 -hr** | 1.56 | 0.25 | 1.31 | 10.99 |
| **140 -hr** | 1.39 | 0.26 | 1.13 | 12.12 |
| **154 -hr** | 1.48 | 0.25 | 1.23 | 13.35 |
| **168 -hr** | 1.69 | 0.25 | 1.44 | 14.79 |
| **182 -hr** | 1.71 | 0.25 | 1.46 | 16.25 |
| **196 -hr** | 1.73 | 0.245 | 1.485 | 17.735 |
| **210 -hr** | 2 | 0.25 | 1.75 | 19.485 |
| | **Initial Fill** | 13.31 | **Total Additions** | 23.16 |
| | **EOT Drain** | 15.85 | **Total Samples** | 3.675 |

| | |
|---|---|
| (Initial Fill + Additions) | 36.47 |
| (EOT Drain + Samples) | 19.525 |
| **Total Oil Consumption** | 16.945 |

## Post Test Engine Ratings

| Ratings | Cylinder Number | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Avg |
| **Ring Sticking** | | | | | | | | | |
| Ring No.1 | NO | NO | NO | NO | NO | NO | NO | NO | -- |
| Ring No.2 | NO | NO | NO | NO | NO | NO | NO | NO | -- |
| Ring No.3 | NO | NO | NO | NO | NO | NO | NO | NO | -- |
| **Scuffing % Area** | | | | | | | | | |
| Ring No.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Ring No.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Ring No.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Piston Crown | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Piston Skirt | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Cylinder Liner, % | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| **Piston Carbon, Demerits** | | | | | | | | | |
| No.1 Groove | 47.75 | 80.50 | 68.75 | 37.50 | 78.00 | 42.50 | 72.00 | 57.75 | 60.59 |
| No.2 Groove | 0.05 | 0.00 | 10.50 | 0.00 | 0.00 | 0.50 | 0.50 | 13.25 | 3.10 |
| No.3 Groove | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| No.1 Land | 38.00 | 30.25 | 42.00 | 45.25 | 45.50 | 38.25 | 54.50 | 61.25 | 44.38 |
| No.2 Land | 2.50 | 3.25 | 24.00 | 3.75 | 12.00 | 6.50 | 20.00 | 30.00 | 12.75 |
| No.3 Land | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.75 | 0.34 |
| Upper Skirt | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Under Crown | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Front Pin Bore | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Rear Pin Bore | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Piston Lacquer, Demerits** | | | | | | | | | |
| No.1 Groove | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.18 | 0.00 | 0.02 |
| No.2 Groove | 2.53 | 3.53 | 2.82 | 3.12 | 3.20 | 3.12 | 4.03 | 1.46 | 2.98 |
| No.3 Groove | 1.50 | 2.00 | 1.50 | 1.50 | 1.61 | 2.33 | 1.50 | 1.74 | 1.71 |
| No.1 Land | 0.02 | 0.13 | 0.02 | 0.30 | 0.01 | 0.02 | 0.04 | 0.02 | 0.07 |
| No.2 Land | 2.11 | 2.73 | 0.74 | 2.43 | 1.53 | 3.25 | 0.89 | 0.48 | 1.77 |
| No.3 Land | 1.73 | 2.99 | 1.72 | 2.33 | 1.68 | 2.27 | 1.84 | 2.07 | 2.08 |
| Upper Skirt | 0.66 | 0.66 | 0.86 | 0.73 | 0.33 | 0.66 | 0.39 | 0.77 | 0.63 |
| Under Crown | 2.70 | 3.40 | 3.85 | 3.10 | 5.02 | 3.55 | 2.98 | 4.52 | 3.64 |
| Front Pin Bore | 1.40 | 1.33 | 1.40 | 1.40 | 1.13 | 1.40 | 1.50 | 1.40 | 1.37 |
| Rear Pin Bore | 1.40 | 1.40 | 1.67 | 1.40 | 1.40 | 1.67 | 1.40 | 1.40 | 1.47 |
| **Total, Demerits** | 102.35 | 132.17 | 159.83 | 102.81 | 151.41 | 106.02 | 161.75 | 178.86 | 136.90 |
| | | | | | | | | | |
| **Miscellanous** | | | | | | | | | |
| Top Groove Fill, % | 44 | 75 | 69 | 29 | 65 | 42 | 73 | 56 | 56.63 |
| Intermediate Groove Fill, % | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 14 | 2.38 |
| Top Land Heavy Carbon, % | 18 | 10 | 24 | 29 | 28 | 19 | 40 | 49 | 27.13 |
| Top Lan Flaked Carbon, % | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| | | | | | | | | | |
| **Valve Tulip Deposits, Merits** | | | | | | | | | |
| Exahust | 9.0 | 9.3 | 9.2 | 9.0 | 9.5 | 9.5 | 9.0 | 9.0 | 9.19 |
| Intake | 7.8 | 8.7 | 7.1 | 8.0 | 7.1 | 6.2 | 6.0 | 7.3 | 7.28 |

# Engine Measurement Changes

## Engine Rebuild Measurements, inches

| Cylinder Bore | Minimum | Maximum | Average | Spec: |
|---|---|---|---|---|
| Inside Diameter | 4.0547 | 4.0555 | 4.0550 | Cylinder 1 thru 6 ID 4.054"-4.075" |
| Out of Round | 0.0001 | 0.0007 | 0.0004 | Cylinder 7 thru 8 ID 4.055"-Maximum 0.008" |
| Taper | 0.0001 | 0.0005 | 0.0003 | |
| **Piston Skirt Diameter** | 4.0496 | 4.0499 | 4.0497 | |
| Piston Skirt to Cylinder Bore Clearance | 0.0050 | 0.0058 | 0.0053 | Cylinder 1 thru 7 0.003"-0.004"<br>Cylinder 7 thru 8 0.004"-0.005" |
| **Piston Ring End Gaps** | | | | |
| Top Ring | 0.012 | 0.016 | 0.014 | |
| Second Ring | 0.033 | 0.038 | 0.035 | |
| Oil Control Ring | 0.012 | 0.016 | 0.014 | |
| **Ring To Groove Clearance** | | | | |
| Second Ring | 0.0020 | 0.0020 | 0.0020 | 0.0015"-0.003" |
| Oil Control Ring | 0.0016 | 0.0020 | 0.0019 | 0.0015"-0.0035" |
| **Piston Pin** | | | | |
| Piston Pin Diameter | 1.2205 | 1.2205 | 1.2205 | 1.2203"-1.2206" |
| Pin Bore Diameter (Piston) | 1.2215 | 1.2216 | 1.2216 | 1.2207"-1.2212" |
| Piston Pin Clearance | 0.0010 | 0.0011 | 0.0011 | 0.0003"-0.0012" |
| Piston Pin Diameter | 1.2205 | 1.2205 | 1.2205 | 1.2203"-1.2206" |
| Pin Bore Diameter (Rod) | 1.2215 | 1.2216 | 1.2215 | 1.2207"-1.2212" |
| Piston Pin Clearance | 0.0010 | 0.0011 | 0.0010 | 0.0003"-0.0012" |
| **Bearing Clerances** | | | | |
| Connecting Rod to Journal | 0.0025 | 0.0030 | 0.0027 | 0.0017"-0.0039" |
| Main Bearing to Journa | 0.0020 | 0.0030 | 0.0022 | 0.001"-0.005" |
| **Crankshaft Endplay** | | | | |
| Crankshaft Endplay | N/A | N/A | 0.006 | 0.004-0.010" |
| Rod Side Clearance | 0.008 | 0.009 | 0.009 | 0.007-0.024" |

*Note: Referenced specifications are to 1994 General Motors Light Duty Truck guidelines. Some variation in engine specifications are expected between updated versions of the GEP 6.5L(T) engines used by the military and those used previously by General Motors. GEP engine specifications are not public infomrmation. GM specifications serve only as guielines to acess the pre-test engine condition for fit for purpose.*

## Pre-Test Cylinder Bore Measurements, inches

| Cylinder | Depth | Tranverse (TD) | Longitude (LD) | Avg Bore Dia. (ABD), (TD@MID + TD@BOT)/2 | Out of Round |
|---|---|---|---|---|---|
| **1** | Top | 4.0549 | 4.0547 | | 0.0002 |
| | Middle | 4.0548 | 4.0544 | 4.0548 | 0.0004 |
| | Bottom | 4.0548 | 4.0546 | | 0.0002 |
| | Taper | 0.0001 | 0.0003 | | |
| **2** | Top | 4.0548 | 4.0547 | | 0.0001 |
| | Middle | 4.0547 | 4.0543 | 4.0547 | 0.0004 |
| | Bottom | 4.0546 | 4.0545 | | 0.0001 |
| | Taper | 0.0002 | 0.0004 | | |
| **3** | Top | 4.0552 | 4.0545 | | 0.0007 |
| | Middle | 4.0549 | 4.0542 | 4.0549 | 0.0007 |
| | Bottom | 4.0548 | 4.0545 | | 0.0003 |
| | Taper | 0.0004 | 0.0003 | | |
| **4** | Top | 4.0549 | 4.0545 | | 0.0004 |
| | Middle | 4.0548 | 4.0542 | 4.0548 | 0.0006 |
| | Bottom | 4.0547 | 4.0545 | | 0.0002 |
| | Taper | 0.0002 | 0.0003 | | |
| **5** | Top | 4.0552 | 4.0546 | | 0.0006 |
| | Middle | 4.0550 | 4.0543 | 4.0550 | 0.0007 |
| | Bottom | 4.0549 | 4.0547 | | 0.0002 |
| | Taper | 0.0003 | 0.0004 | | |
| **6** | Top | 4.0551 | 4.0546 | | 0.0005 |
| | Middle | 4.0548 | 4.0543 | 4.0548 | 0.0005 |
| | Bottom | 4.0547 | 4.0546 | | 0.0001 |
| | Taper | 0.0004 | 0.0003 | | |
| **7** | Top | 4.0556 | 4.0555 | | 0.0001 |
| | Middle | 4.0555 | 4.0550 | 4.0555 | 0.0005 |
| | Bottom | 4.0555 | 4.0551 | | 0.0004 |
| | Taper | 0.0001 | 0.0005 | | |
| **8** | Top | 4.0556 | 4.0553 | | 0.0003 |
| | Middle | 4.0555 | 4.0548 | 4.0555 | 0.0007 |
| | Bottom | 4.0554 | 4.0550 | | 0.0004 |
| | Taper | 0.0002 | 0.0005 | | |

## Post-Test Cylinder Bore Measurements, in

| Cylinder | Depth | Tranverse (TD) | Longitude (LD) | Avg Bore Dia. (ABD), (TD@MID + TD@BOT)/2 | Out of Round |
|---|---|---|---|---|---|
| 1 | Top | 4.0551 | 4.0547 | | 0.0004 |
| | Middle | 4.0548 | 4.0544 | 4.0548 | 0.0004 |
| | Bottom | 4.0547 | 4.0547 | | 0.0000 |
| | Taper | 0.0004 | 0.0003 | | |
| 2 | Top | 4.0552 | 4.0547 | | 0.0005 |
| | Middle | 4.0551 | 4.0544 | 4.0550 | 0.0007 |
| | Bottom | 4.0549 | 4.0547 | | 0.0002 |
| | Taper | 0.0003 | 0.0003 | | |
| 3 | Top | 4.0555 | 4.0545 | | 0.0010 |
| | Middle | 4.0550 | 4.0542 | 4.0549 | 0.0008 |
| | Bottom | 4.0548 | 4.0545 | | 0.0003 |
| | Taper | 0.0007 | 0.0003 | | |
| 4 | Top | 4.0551 | 4.0547 | | 0.0004 |
| | Middle | 4.0550 | 4.0543 | 4.0550 | 0.0007 |
| | Bottom | 4.0549 | 4.0547 | | 0.0002 |
| | Taper | 0.0002 | 0.0004 | | |
| 5 | Top | 4.0554 | 4.0547 | | 0.0007 |
| | Middle | 4.0550 | 4.0543 | 4.0550 | 0.0007 |
| | Bottom | 4.0549 | 4.0548 | | 0.0001 |
| | Taper | 0.0005 | 0.0005 | | |
| 6 | Top | 4.0557 | 4.0546 | | 0.0011 |
| | Middle | 4.0552 | 4.0543 | 4.0551 | 0.0009 |
| | Bottom | 4.0549 | 4.0547 | | 0.0002 |
| | Taper | 0.0008 | 0.0004 | | |
| 7 | Top | 4.0558 | 4.0555 | | 0.0003 |
| | Middle | 4.0555 | 4.0550 | 4.0555 | 0.0005 |
| | Bottom | 4.0554 | 4.0552 | | 0.0002 |
| | Taper | 0.0004 | 0.0005 | | |
| 8 | Top | 4.0559 | 4.0553 | | 0.0006 |
| | Middle | 4.0558 | 4.0548 | 4.0557 | 0.0010 |
| | Bottom | 4.0555 | 4.0553 | | 0.0002 |
| | Taper | 0.0004 | 0.0005 | | |

## Cylinder Bore Diameter Changes, in

| Cylinder | Depth | Tranverse (TD) | Longitude (LD) | Avg Bore Dia. Change (TD@MID + TD@BOT)/2 |
|---|---|---|---|---|
| 1 | Top | 0.0002 | 0.0000 | |
| | Middle | 0.0000 | 0.0000 | 0.0000 |
| | Bottom | 0.0001 | 0.0001 | |
| | | | | |
| 2 | Top | 0.0004 | 0.0000 | |
| | Middle | 0.0004 | 0.0001 | 0.0004 |
| | Bottom | 0.0003 | 0.0002 | |
| | | | | |
| 3 | Top | 0.0003 | 0.0000 | |
| | Middle | 0.0001 | 0.0000 | 0.0000 |
| | Bottom | 0.0000 | 0.0000 | |
| | | | | |
| 4 | Top | 0.0002 | 0.0002 | |
| | Middle | 0.0002 | 0.0001 | 0.0002 |
| | Bottom | 0.0002 | 0.0002 | |
| | | | | |
| 5 | Top | 0.0002 | 0.0001 | |
| | Middle | 0.0000 | 0.0000 | 0.0000 |
| | Bottom | 0.0000 | 0.0001 | |
| | | | | |
| 6 | Top | 0.0006 | 0.0000 | |
| | Middle | 0.0004 | 0.0000 | 0.0003 |
| | Bottom | 0.0002 | 0.0001 | |
| | | | | |
| 7 | Top | 0.0002 | 0.0000 | |
| | Middle | 0.0000 | 0.0000 | 0.0001 |
| | Bottom | 0.0001 | 0.0001 | |
| | | | | |
| 8 | Top | 0.0003 | 0.0000 | |
| | Middle | 0.0003 | 0.0000 | 0.0002 |
| | Bottom | 0.0001 | 0.0003 | |
| | | | | |
| Avgerage All Cylinders | Top | 0.0003 | 0.0000 | |
| | Middle | 0.0002 | 0.0000 | |
| | Bottom | 0.0001 | 0.0001 | |
| | | | | |

## Valve Guide Measurement Changes, in

| | Valve Guide Diameter Intake | | | Valve Guide Diameter Exahust | | |
|---|---|---|---|---|---|---|
| Cylinder | Before | After | Change | Before | After | Change |
| 1 | 0.3424 | 0.4240 | 0.0816 | 0.3726 | 0.3728 | 0.0002 |
| 2 | 0.3425 | 0.3425 | 0.0000 | 0.3725 | 0.3728 | 0.0003 |
| 3 | 0.3425 | 0.3424 | -0.0001 | 0.3726 | 0.3728 | 0.0002 |
| 4 | 0.3424 | 0.3424 | 0.0000 | 0.3726 | 0.3729 | 0.0003 |
| 5 | 0.3424 | 0.3424 | 0.0000 | 0.3726 | 0.3728 | 0.0002 |
| 6 | 0.3425 | 0.3425 | 0.0000 | 0.3725 | 0.3729 | 0.0004 |
| 7 | 0.3425 | 0.3425 | 0.0000 | 0.3726 | 0.3728 | 0.0002 |
| 8 | 0.3424 | 0.3424 | 0.0000 | 0.3726 | 0.3728 | 0.0002 |

| | | | |
|---|---|---|---|
| Maximum | 0.0816 | Maximum | 0.0004 |
| Average | 0.0102 | Average | 0.0003 |

## Valve Stem Measurement Changes, in

| | Valve Stem Diameter Intake | | | Valve Stem Diameter Exahust | | |
|---|---|---|---|---|---|---|
| Cylinder | Before | After | Change | Before | After | Change |
| 1 | 0.3414 | 0.3411 | 0.0003 | 0.3711 | 0.3710 | 0.0001 |
| 2 | 0.3414 | 0.3410 | 0.0004 | 0.3712 | 0.3710 | 0.0002 |
| 3 | 0.3414 | 0.3412 | 0.0002 | 0.3712 | 0.3706 | 0.0006 |
| 4 | 0.3413 | 0.3409 | 0.0004 | 0.3712 | 0.3709 | 0.0003 |
| 5 | 0.3413 | 0.3411 | 0.0002 | 0.3712 | 0.3711 | 0.0001 |
| 6 | 0.3414 | 0.3410 | 0.0004 | 0.3711 | 0.3711 | 0.0000 |
| 7 | 0.3414 | 0.3411 | 0.0003 | 0.3711 | 0.3710 | 0.0001 |
| 8 | 0.3414 | 0.3410 | 0.0004 | 0.3712 | 0.3709 | 0.0003 |

| | | | |
|---|---|---|---|
| Maximum | 0.0004 | Maximum | 0.0006 |
| Average | 0.0003 | Average | 0.0002 |

## Valve Stem to Guide Clearance Changes, in

| | Stem/Guide Clearance Intake | | | Stem Guide Clearance Exahust | | |
|---|---|---|---|---|---|---|
| Cylinder | Before | After | Change | Before | After | Change |
| 1 | 0.0010 | 0.0829 | 0.0819 | 0.0015 | 0.0018 | 0.0003 |
| 2 | 0.0011 | 0.0015 | 0.0004 | 0.0013 | 0.0018 | 0.0005 |
| 3 | 0.0011 | 0.0012 | 0.0001 | 0.0014 | 0.0022 | 0.0008 |
| 4 | 0.0011 | 0.0015 | 0.0004 | 0.0014 | 0.0020 | 0.0006 |
| 5 | 0.0011 | 0.0013 | 0.0002 | 0.0014 | 0.0017 | 0.0003 |
| 6 | 0.0011 | 0.0015 | 0.0004 | 0.0014 | 0.0018 | 0.0004 |
| 7 | 0.0011 | 0.0014 | 0.0003 | 0.0015 | 0.0018 | 0.0003 |
| 8 | 0.0010 | 0.0014 | 0.0004 | 0.0014 | 0.0019 | 0.0005 |

| | |
|---|---|
| Maximum | 0.0819 |
| Average | 0.0105 |

| | |
|---|---|
| Maximum | 0.0008 |
| Average | 0.0005 |

## Valve Recession Measurement Changes, in

| | Valve Recession Intake | | | Valve Recession Exahust | | |
|---|---|---|---|---|---|---|
| Cylinder | Before | After | Change | Before | After | Change |
| 1 | 0.024 | 0.062 | 0.038 | 0.027 | 0.037 | 0.010 |
| 2 | 0.025 | 0.065 | 0.040 | 0.026 | 0.028 | 0.002 |
| 3 | 0.025 | 0.055 | 0.030 | 0.027 | 0.029 | 0.002 |
| 4 | 0.024 | 0.042 | 0.018 | 0.027 | 0.027 | 0.000 |
| 5 | 0.024 | 0.062 | 0.038 | 0.028 | 0.036 | 0.008 |
| 6 | 0.025 | 0.040 | 0.015 | 0.027 | 0.027 | 0.000 |
| 7 | 0.022 | 0.043 | 0.021 | 0.025 | 0.029 | 0.004 |
| 8 | 0.024 | 0.048 | 0.024 | 0.026 | 0.030 | 0.004 |

| | |
|---|---|
| Maximum | 0.040 |
| Average | 0.028 |

| | |
|---|---|
| Maximum | 0.010 |
| Average | 0.004 |

## Post-Test Cam Lobe Profile, in

| Cam Lobe | Waviness Parameter [µm] |
|---|---|
| 1 | 1.73 |
| 2 | 1.24 |
| 3 | 1.47 |
| 4 | 1.17 |
| 5 | 1.66 |
| 6 | 2.21 |
| 7 | 1.82 |
| 8 | 1.31 |
| 9 | 2.24 |
| 10 | 1.43 |
| 11 | 0.91 |
| 12 | 1.24 |
| 13 | 2.06 |
| 14 | 2.98 |
| 15 | 1.59 |
| 16 | 1.42 |

| | |
|---|---|
| Maximum | 2.98 |
| Average | 1.66 |

## Piston Skirt to Bore Clearance, in

| | Cylinder | Average Bore Diameter | Piston Skirt Diameter | Clearance |
|---|---|---|---|---|
| Pre - Test | 1 | 4.0548 | 4.0497 | 0.0051 |
| | 2 | 4.0547 | 4.0497 | 0.0050 |
| | 3 | 4.0549 | 4.0497 | 0.0052 |
| | 4 | 4.0548 | 4.0497 | 0.0051 |
| | 5 | 4.0550 | 4.0499 | 0.0050 |
| | 6 | 4.0548 | 4.0496 | 0.0052 |
| | 7 | 4.0555 | 4.0497 | 0.0058 |
| | 8 | 4.0555 | 4.0497 | 0.0058 |
| | | | | |
| Post - Test | 1 | 4.0548 | 4.0493 | 0.0055 |
| | 2 | 4.0550 | 4.0492 | 0.0058 |
| | 3 | 4.0549 | 4.0493 | 0.0056 |
| | 4 | 4.0550 | 4.0491 | 0.0058 |
| | 5 | 4.0550 | 4.0493 | 0.0057 |
| | 6 | 4.0551 | 4.0491 | 0.0059 |
| | 7 | 4.0555 | 4.0494 | 0.0061 |
| | 8 | 4.0557 | 4.0493 | 0.0064 |

# Top and Second Ring Radial Wear, in

| Top Ring | | | | |
|---|---|---|---|---|
| Cylinder | Position | Before | After | Delta |
| 1 | 1 | 0.17780 | 0.17705 | 0.00075 |
| | 2 | 0.17770 | 0.17695 | 0.00075 |
| | 3 | 0.17650 | 0.17595 | 0.00055 |
| | 4 | 0.17750 | 0.17710 | 0.00040 |
| | 5 | 0.17740 | 0.17690 | 0.00050 |
| 2 | 1 | 0.17830 | 0.17770 | 0.00060 |
| | 2 | 0.17855 | 0.17800 | 0.00055 |
| | 3 | 0.17880 | 0.17815 | 0.00065 |
| | 4 | 0.17835 | 0.17795 | 0.00040 |
| | 5 | 0.17780 | 0.17730 | 0.00050 |
| 3 | 1 | 0.17855 | 0.17815 | 0.00040 |
| | 2 | 0.17925 | 0.17885 | 0.00040 |
| | 3 | 0.17840 | 0.17790 | 0.00050 |
| | 4 | 0.17815 | 0.17755 | 0.00060 |
| | 5 | 0.17830 | 0.17780 | 0.00050 |
| 4 | 1 | 0.17905 | 0.17865 | 0.00040 |
| | 2 | 0.17975 | 0.17952 | 0.00023 |
| | 3 | 0.17875 | 0.17845 | 0.00030 |
| | 4 | 0.17825 | 0.17760 | 0.00065 |
| | 5 | 0.17845 | 0.17805 | 0.00040 |
| 5 | 1 | 0.17865 | 0.17815 | 0.00050 |
| | 2 | 0.18005 | 0.17940 | 0.00065 |
| | 3 | 0.18015 | 0.17960 | 0.00055 |
| | 4 | 0.17970 | 0.17895 | 0.00075 |
| | 5 | 0.17870 | 0.17830 | 0.00040 |
| 6 | 1 | 0.17955 | 0.17905 | 0.00050 |
| | 2 | 0.17795 | 0.17745 | 0.00050 |
| | 3 | 0.17895 | 0.17815 | 0.00080 |
| | 4 | 0.17990 | 0.17925 | 0.00065 |
| | 5 | 0.17970 | 0.17920 | 0.00050 |
| 7 | 1 | 0.17890 | 0.17850 | 0.00040 |
| | 2 | 0.17870 | 0.17825 | 0.00045 |
| | 3 | 0.17890 | 0.17835 | 0.00055 |
| | 4 | 0.17875 | 0.17845 | 0.00030 |
| | 5 | 0.17905 | 0.17855 | 0.00050 |
| 8 | 1 | 0.17790 | 0.17725 | 0.00065 |
| | 2 | 0.17750 | 0.17700 | 0.00050 |
| | 3 | 0.17805 | 0.17745 | 0.00060 |
| | 4 | 0.17880 | 0.17835 | 0.00045 |
| | 5 | 0.17800 | 0.17735 | 0.00065 |
| *Note - Measurements with a negitive delta value, shown in italics, are considered pre-test measurements error | | | | |

| | |
|---|---|
| Maximum | 0.00080 |
| Average | 0.00052 |

| Second Ring | | | | |
|---|---|---|---|---|
| Cylinder | Position | Before | After | Delta |
| 1 | 1 | 0.16210 | 0.16150 | 0.00060 |
| | 2 | 0.16200 | 0.16155 | 0.00045 |
| | 3 | 0.15990 | 0.15950 | 0.00040 |
| | 4 | 0.15920 | 0.15885 | 0.00035 |
| | 5 | 0.16105 | 0.16070 | 0.00035 |
| 2 | 1 | 0.16165 | 0.16120 | 0.00045 |
| | 2 | 0.16290 | 0.16225 | 0.00065 |
| | 3 | 0.16030 | 0.15985 | 0.00045 |
| | 4 | 0.16010 | 0.15960 | 0.00050 |
| | 5 | 0.16125 | 0.16080 | 0.00045 |
| 3 | 1 | 0.16155 | 0.16080 | 0.00075 |
| | 2 | 0.16075 | 0.16020 | 0.00055 |
| | 3 | 0.16040 | 0.15970 | 0.00070 |
| | 4 | 0.16185 | 0.16150 | 0.00035 |
| | 5 | 0.16150 | 0.16100 | 0.00050 |
| 4 | 1 | 0.16190 | 0.16125 | 0.00065 |
| | 2 | 0.16140 | 0.16085 | 0.00055 |
| | 3 | 0.16070 | 0.15985 | 0.00085 |
| | 4 | 0.16100 | 0.16040 | 0.00060 |
| | 5 | 0.16175 | 0.16130 | 0.00045 |
| 5 | 1 | 0.16230 | 0.16185 | 0.00045 |
| | 2 | 0.16315 | 0.16245 | 0.00070 |
| | 3 | 0.16145 | 0.16080 | 0.00065 |
| | 4 | 0.16120 | 0.16055 | 0.00065 |
| | 5 | 0.16175 | 0.16120 | 0.00055 |
| 6 | 1 | 0.16200 | 0.16140 | 0.00060 |
| | 2 | 0.16230 | 0.16205 | 0.00025 |
| | 3 | 0.16020 | 0.15970 | 0.00050 |
| | 4 | 0.16075 | 0.16010 | 0.00065 |
| | 5 | 0.16220 | 0.16145 | 0.00075 |
| 7 | 1 | 0.16215 | 0.16145 | 0.00070 |
| | 2 | 0.16227 | 0.16205 | 0.00022 |
| | 3 | 0.16155 | 0.16105 | 0.00050 |
| | 4 | 0.16075 | 0.16025 | 0.00050 |
| | 5 | 0.16215 | 0.16165 | 0.00050 |
| 8 | 1 | 0.16125 | 0.16085 | 0.00040 |
| | 2 | 0.16190 | 0.16165 | 0.00025 |
| | 3 | 0.16025 | 0.15990 | 0.00035 |
| | 4 | 0.16160 | 0.16120 | 0.00040 |
| | 5 | 0.16115 | 0.16100 | 0.00015 |
| *Note - Measurements with a negitive delta value, shown in italics, are considered pre-test measurements error | | | | |

| | |
|---|---|
| Maximum | 0.00085 |
| Average | 0.00051 |

## Piston Ring Gap Measurements, in

| Cylinder | Ring No. | Before | After | Delta |
|---|---|---|---|---|
| 1 | 1 | 0.013 | 0.016 | 0.003 |
| | 2 | 0.033 | 0.037 | 0.004 |
| | 3 | 0.013 | 0.015 | 0.002 |
| 2 | 1 | 0.013 | 0.016 | 0.003 |
| | 2 | 0.033 | 0.038 | 0.005 |
| | 3 | 0.013 | 0.015 | 0.002 |
| 3 | 1 | 0.012 | 0.016 | 0.004 |
| | 2 | 0.035 | 0.037 | 0.002 |
| | 3 | 0.013 | 0.016 | 0.003 |
| 4 | 1 | 0.013 | 0.017 | 0.004 |
| | 2 | 0.034 | 0.038 | 0.004 |
| | 3 | 0.013 | 0.016 | 0.003 |
| 5 | 1 | 0.013 | 0.015 | 0.002 |
| | 2 | 0.038 | 0.042 | 0.004 |
| | 3 | 0.014 | 0.016 | 0.002 |
| 6 | 1 | 0.013 | 0.020 | 0.007 |
| | 2 | 0.035 | 0.036 | 0.001 |
| | 3 | 0.014 | 0.017 | 0.003 |
| 7 | 1 | 0.016 | 0.018 | 0.002 |
| | 2 | 0.038 | 0.041 | 0.003 |
| | 3 | 0.016 | 0.018 | 0.002 |
| 8 | 1 | 0.016 | 0.020 | 0.004 |
| | 2 | 0.034 | 0.039 | 0.005 |
| | 3 | 0.012 | 0.017 | 0.005 |

| | |
|---|---|
| Ring No. 1 max increase | 0.007 |
| Ring No. 2 max increase | 0.005 |
| Ring No. 3 max increase | 0.005 |

| | |
|---|---|
| Ring No. 1 avg increase | 0.004 |
| Ring No. 2 avg increase | 0.004 |
| Ring No. 3 avg increase | 0.003 |

## Piston Ring Mass, grams

| Cylinder | Ring No. | Before | After | Delta |
|---|---|---|---|---|
| **1** | 1 | 22.7541 | 22.6533 | 0.1008 |
| | 2 | 17.0669 | 17.0356 | 0.0313 |
| | 3 | 15.2482 | 15.2357 | 0.0125 |
| **2** | 1 | 22.8106 | 22.7119 | 0.0987 |
| | 2 | 17.0748 | 17.0382 | 0.0366 |
| | 3 | 14.9461 | 14.9318 | 0.0143 |
| **3** | 1 | 22.8003 | 22.7104 | 0.0899 |
| | 2 | 17.0292 | 16.9901 | 0.0391 |
| | 3 | 15.3226 | 15.3044 | 0.0182 |
| **4** | 1 | 22.8790 | 22.7945 | 0.0845 |
| | 2 | 17.0481 | 17.0143 | 0.0338 |
| | 3 | 14.9637 | 14.9467 | 0.0170 |
| **5** | 1 | 22.8445 | 22.7391 | 0.1054 |
| | 2 | 17.1074 | 17.0637 | 0.0437 |
| | 3 | 15.3087 | 15.2923 | 0.0164 |
| **6** | 1 | 22.8318 | 22.7400 | 0.0918 |
| | 2 | 17.0351 | 16.9959 | 0.0392 |
| | 3 | 15.0681 | 15.0518 | 0.0163 |
| **7** | 1 | 22.8722 | 22.7913 | 0.0809 |
| | 2 | 17.0542 | 17.0209 | 0.0333 |
| | 3 | 15.2659 | 15.2512 | 0.0147 |
| **8** | 1 | 22.8376 | 22.7511 | 0.0865 |
| | 2 | 17.0606 | 17.0295 | 0.0311 |
| | 3 | 15.3035 | 15.2847 | 0.0188 |

| | |
|---|---|
| Ring No. 1 max decrease | 0.1054 |
| Ring No. 2 max decrease | 0.0437 |
| Ring No. 3 max decrease | 0.0188 |

| | |
|---|---|
| Ring No. 1 avg decrease | 0.0923 |
| Ring No. 2 avg decrease | 0.0360 |
| Ring No. 3 avg decrease | 0.0160 |

## Connecting Rod Bearing Weight Loss, grams

| Rod Bearing | Shell | Before | After | Change |
|---|---|---|---|---|
| 1 | Top | 27.5997 | 27.5758 | 0.0239 |
| | Bottom | 27.5825 | 27.5719 | 0.0106 |
| 2 | Top | 27.5555 | 27.5383 | 0.0172 |
| | Bottom | 27.5790 | 27.5702 | 0.0088 |
| 3 | Top | 27.6239 | 27.5766 | 0.0473 |
| | Bottom | 27.5660 | 27.5299 | 0.0361 |
| 4 | Top | 27.5801 | 27.5626 | 0.0175 |
| | Bottom | 27.6037 | 27.5913 | 0.0124 |
| 5 | Top | 27.5768 | 27.5493 | 0.0275 |
| | Bottom | 27.5344 | 27.5210 | 0.0134 |
| 6 | Top | 27.4884 | 27.4620 | 0.0264 |
| | Bottom | 27.6483 | 27.6330 | 0.0153 |
| 7 | Top | 27.5598 | 27.5348 | 0.0250 |
| | Bottom | 27.6727 | 27.6538 | 0.0189 |
| 8 | Top | 27.6420 | 27.6278 | 0.0142 |
| | Bottom | 27.6912 | 27.6782 | 0.0130 |

| | |
|---|---|
| Maximum | 0.0473 |
| Average | 0.0205 |

## Main Bearing Weight Loss, grams

| Main Bearing | Shell | Before | After | Change |
|---|---|---|---|---|
| 1 | Top | 48.1879 | 48.1408 | 0.0471 |
| | Bottom | 51.7463 | 51.6480 | 0.0983 |
| 2 | Top | 48.0748 | 48.0425 | 0.0323 |
| | Bottom | 51.5846 | 51.3740 | 0.2106 |
| 3 | Top | 97.7533 | 97.4820 | 0.2713 |
| | Bottom | 103.4375 | 103.0981 | 0.3394 |
| 4 | Top | 47.9910 | 47.9638 | 0.0272 |
| | Bottom | 51.5284 | 51.3870 | 0.1414 |
| 5 | Top | 69.0709 | 69.0106 | 0.0603 |
| | Bottom | 72.9269 | 72.8335 | 0.0934 |

| | |
|---|---|
| Maximum | 0.3394 |
| Average | 0.1321 |

## Stanadyne Injection Pump Calibration/Evaluation

# Stanadyne Pump Calibration / Evaluation

| | |
|---|---|
| **Pump Type : DB2831-5079 (arctic)** | **SN: 15714947** |
| **Test condition :** | **AL:** |

| ***PUMP RPM*** | ***Description*** | ***Spec.*** | ***Before*** | ***After*** | ***Change*** |
|---|---|---|---|---|---|
| 1000 | Transfer pump psi. | 60-62 psi | 62 | 61 | 1 |
| | Return Fuel | 225-375 cc | 260 | 270 | 10 |
| 350 | Low Idle | 12-16 cc | 15 | 7.5 | 7.5 |
| | Housing psi. | 8-12 psi | 10 | 11 | 1 |
| | Advance | 3.5 deg. min | 2.5 | 2.98 | 0.48 |
| | Cold Advance Solenoid | 0-1 psi. | 0 | 0 | 0 |
| 750 | Shut-Off | 4 cc max. | 0 | 0 | 0 |
| 900 | Fuel Delivery | 66.5 - 69.5cc | 66 | 66 | 0 |
| 1600 | WOT Fuel delivery | 59.5 min. | 64 | 64 | 0 |
| | WOT Advance | 2.5 - 3.5 deg. | 3.03 | 3.2 | 0.17 |
| | Face Cam Fuel delivery | 21.5 - 23.5 | 22 | 22 | 0 |
| | Face Cam Advance | 5.25 - 7.25 deg. | 6.15 | 6.1 | 0.05 |
| | Low Idle | 11 - 12 deg. | 11.03 | 11.01 | 0.02 |
| 1825 | Fuel Delivery | 33 cc min. | 38 | 39 | 1 |
| 1950 | High Idle | 15 cc max. | 2 | 2 | 0 |
| | Transfer pump psi. | 125 psi max. | 112 | 111 | 1 |
| 200 | WOT Fuel Delivery | 58 cc min. | 60 | 60 | 0 |
| | WOT Shut-Off | 4 cc max. | 0 | 0 | 0 |
| 75 | Low Idle Fuel Delivery | 37 cc min. | 48 | 48 | 0 |
| | Transfer pump psi. | 16 psi min. | 24 | 22 | 2 |
| | Housing psi. | 0 -12 psi | 10 | 10 | 0 |
| | Air Timing | -.5 deg.(+/-.5 deg) | -0.5 | -0.5 | 0 |

*Pump calibration data to be used for reference only

# PHOTOGRAPHS

GEP 6.5 - Wheeled Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO268869 | **EOT Date:** | 9-12-11 |
| **Test No.:** | LO268869-65T1-W-210 | **Test Length:** | 210 |

**Piston Skirt Thrust - Best    Cyl 1**

**Piston Skirt Anti-thrust - Best    Cyl 1**

GEP 6.5 - Wheeled Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO268869 | **EOT Date:** | 9-12-11 |
| **Test No.:** | LO268869-65T1-W-210 | **Test Length:** | 210 |

**Piston Skirt Thrust - Worst Cyl 8**

**Piston Skirt Anti-thrust - Worst Cyl 8**

GEP 6.5 - Wheeled Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO268869 | **EOT Date:** | 9-12-11 |
| **Test No.:** | LO268869-65T1-W-210 | **Test Length:** | 210 |

**Piston Rings - Best Cyl 7**

**Piston Rings - Worst Cyl 5**

GEP 6.5 - Wheeled Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO268869 | **EOT Date:** | 9-12-11 |
| **Test No.:** | LO268869-65T1-W-210 | **Test Length:** | 210 |

**Piston Undercrown - Best Cyl 1**

**Piston Undercrown - Worst Cyl 8**

GEP 6.5 - Wheeled Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO268869 | **EOT Date:** | 9-12-11 |
| **Test No.:** | LO268869-65T1-W-210 | **Test Length:** | 210 |

**Engine Block Cylinder Bore - Best Cyl 5**

**Engine Block Cylinder Bore - Worst Cyl 8**

**GEP 6.5 - Wheeled Vehicle Cycle**

| | | | |
|---|---|---|---|
| **Oil Code:** | LO268869 | **EOT Date:** | 9-12-11 |
| **Test No.:** | LO268869-65T1-W-210 | **Test Length:** | 210 |

**Exhaust and Intake Valve - Best Cyl 2**

GEP 6.5 - Wheeled Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO268869 | **EOT Date:** | 9-12-11 |
| **Test No.:** | LO268869-65T1-W-210 | **Test Length:** | 210 |

**Exhaust and Intake Valve - Worst Cyl 7**

GEP 6.5 - Wheeled Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO268869 | **EOT Date:** | 9-12-11 |
| **Test No.:** | LO268869-65T1-W-210 | **Test Length:** | 210 |

**Rod Bearings**

| | | | |
|---|---|---|---|
| **Oil Code:** | LO268869 | **EOT Date:** | 9-12-11 |
| **Test No.:** | LO268869-65T1-W-210 | **Test Length:** | 210 |

**Main Bearings**

**APPENDIX – A2**

**EVALUATION OF SCPL CANDIDATE**

**LO-271510**

# EVALUATION OF SCPL CANDIDATE LO-271510

## Project 14734.01

**GEP 6.5L Turbocharged HMMWV Engine**

**Test Lubricant: LO-271510**
**Test Fuel: Jet-A w/DCI-4A**
**Test Number: LO271510-65T1-W-210**
**Start of Test Date: October 11, 2011**
**End of Test Date: October 31, 2011**
**Test Duration: 196 Hours**
**Test Procedure: Tactical Wheeled Vehicle**

*Conducted for*

**U.S. Army TARDEC**
**Force Projection Technologies**
**Warren, Michigan**

# Table of Contents

## Introduction

This test was used to determine the performance of Single Common Powertrain Lubricant (SCPL) candidate LO-271510 when used in the General Engine Products (GEP) 6.5L turbocharged engine by the procedures outlined in the Tactical Wheeled Vehicle Cycle (CRC Report No.406, Development of Military Fuel/Lubricant/Engine Compatibility Test). This work was completed in support of Project 14734.01, Single Common Powertrain Lubricants for Combat/Tactical Equipment.

## Test Engine

The oil was evaluated in the General Engine Products 6.5L turbocharged diesel engine, representative of engines currently fielded in High Mobility Multipurpose Wheeled Vehicles (HMMWV). Prior to testing, the engine was disassembled and measured for pre-test wear. Engine clearances and specifications were verified, and the engine was reassembled following standard assembly procedures.

## Test Stand Configuration

The engine was mounted in a test stand specifically configured for GEP engine testing. Engine monitoring, control, and data acquisition was supplied by Southwest Research Institute (SwRI) developed PRISM software. An appropriately sized absorption dynamometer was used to supply engine loading. Engine oil and coolant temperatures were controlled with the use of liquid-to-liquid heat exchangers. Engine intake air was supplied at ambient conditions, and inlet fuel temperatures were controlled through an auxiliary fuel heater loop.

## Engine Run-in

Prior to testing, the engine was run-in following procedures outlined below. Cyclic modes were repeated for a total of 24 cycles. Total runtime for engine run-in was approximately 6 hours.

| Time, min | Mode | Speed, RPM | Torque, lb*ft | Coolant Out, °F | Oil Galley, °F |
|---|---|---|---|---|---|
| 10 | Steady State | 1500 | 10 | 215 | 220 |
| 10 | Steady State | 1600 | 109 | 215 | 220 |
| 10 | Steady State | 2400 | 145 | 215 | 220 |
| 10 | Steady State | 3200 | 165 | 215 | 220 |
| 1 | Cyclic | 900 | 0 | 215 | 220 |
| 2 | Cyclic | 2600 | 50% | 215 | 220 |
| 2 | Cyclic | 1800 | 1% | 215 | 220 |
| 2 | Cyclic | 1200 | 25% | 215 | 220 |
| 2 | Cyclic | 1800 | 50% | 215 | 220 |
| 2 | Cyclic | 3200 | 5% | 215 | 220 |
| 2 | Cyclic | 2200 | 50% | 215 | 220 |

**Figure 1 - Test Engine Run-In Procedure**

## Pre-Test Engine Performance Check

After completion of engine run-in, a full load powercurve was completed from 1000 rpm to rated engine speed (3400 rpm) to determine pre-test engine performance. The pre-test engine performance check was completed using the same oil charge used during the engine run-in segment. Powercurve plots can be seen in the Engine Performance Curves section.

## Test Cycle

The test cycle followed during oil evaluation was the standard 210 hr Tactical Wheeled Vehicle cycle as outlined in CRC Report No. 406, Development of Military Fuel/Lubricant/Engine Compatibility Test. Test termination would occur at 210 hrs or upon major oil degradation, which ever occurred first. The test cycle consists of cyclic modes alternating between 2 hr rated speed conditions and 1 hr idle soaks. Total daily run-time was 14 hrs, 10 hrs at rated and 4 hrs at idle, with a 10 hr soak overnight before resuming the next days testing. Engine oil temperatures were elevated to simulate conditions consistent with high ambient temperature typical of desert operations. Engine operating parameters were controlled throughout testing as specified in the table below.

| Parameter | Rated Speed | Idle |
|---|---|---|
| Engine Speed, RPM | 3400 +/- 25 | 900 +/- 25 |
| Water Jacket Out, °F | 204 +/- 5 | 100 +/- 5 |
| Oil Sump, °F | 260 +/- 5 | 125 +/- 5 |

**Figure 2 - Test Cycle Operating Parameters**

Engine coolant was a 60/40 blend of ethylene glycol antifreeze and deionized water. Test fuel was JP8 blended onsite from Jet-A with double the max treat rate of corrosion inhibitor/lubricity enhancer DCI-4A.

## Oil Sampling

Four ounces of engine oil was sampled every 14 hrs for used oil analysis. Engine oil analysis consisted of the following tests: (Note – at every 70 hr interval, two additional tests were completed on the used oil as shown below). All oil samples were weighed and logged to take into account during calculations of total engine oil consumption for the test duration.

| *Every 14hrs* | | |
|---|---|---|
| **ASTM** | **D4739** | Total Base Number |
| **ASTM** | **D664** | Total Acid Number |
| **ASTM** | **D445** | Kinematic Viscosity @ 100°C |
| **ASTM** | **API Gravity** | API Gravity |
| **ASTM** | **D4052** | Density |
| **ASTM** | **TGA SOOT** | TGA Soot |
| **ASTM** | **E168** | Oxidation |
| **ASTM** | **E168** | Nitration |
| **ASTM** | **D5185** | Wear Metals by ICP |

| *Every 70hrs* | | |
|---|---|---|
| **ASTM** | **D445** | Kinematic Viscosity @ 40°C |
| **ASTM** | **D2270** | Kinematic Viscosity Index |

**Figure 3 - Used Oil Analysis Procedures**

Used oil analysis results can be seen in the engine oil analysis and engine oil analysis trends section of the report.

## Oil Level Checks

Engine oil level was checked daily and replenished as needed to restore oil level to full mark. This process occurred after the completion of the 10hr soak, prior to restarting the test. All oil additions were weighed and logged to take into account during calculation of total engine oil consumption for the test duration.

## Post-Test Engine Performance Check

After completion of testing, a full load powercurve was completed from 1000 rpm to rated engine speed (3400 rpm) to determine post-test engine performance. The post-test engine performance check was completed using the same oil charge used during the testing segment. Powercurve plots can be seen in the Engine Performance Curves section.

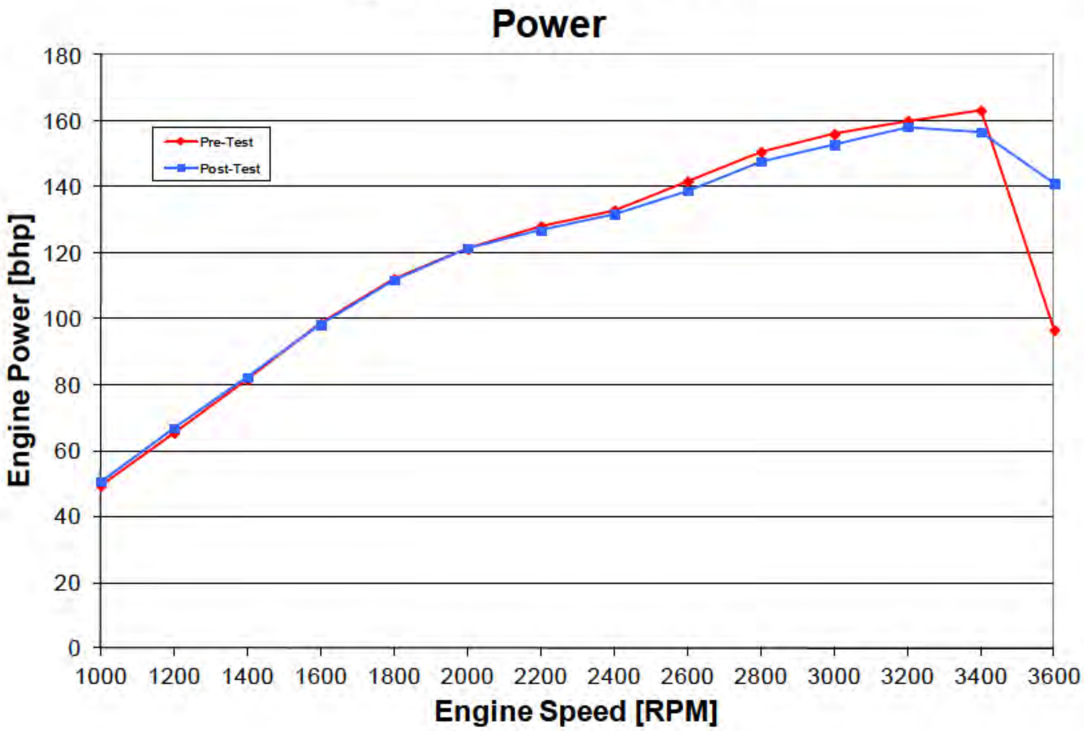
## Engine Operating Conditions Summary

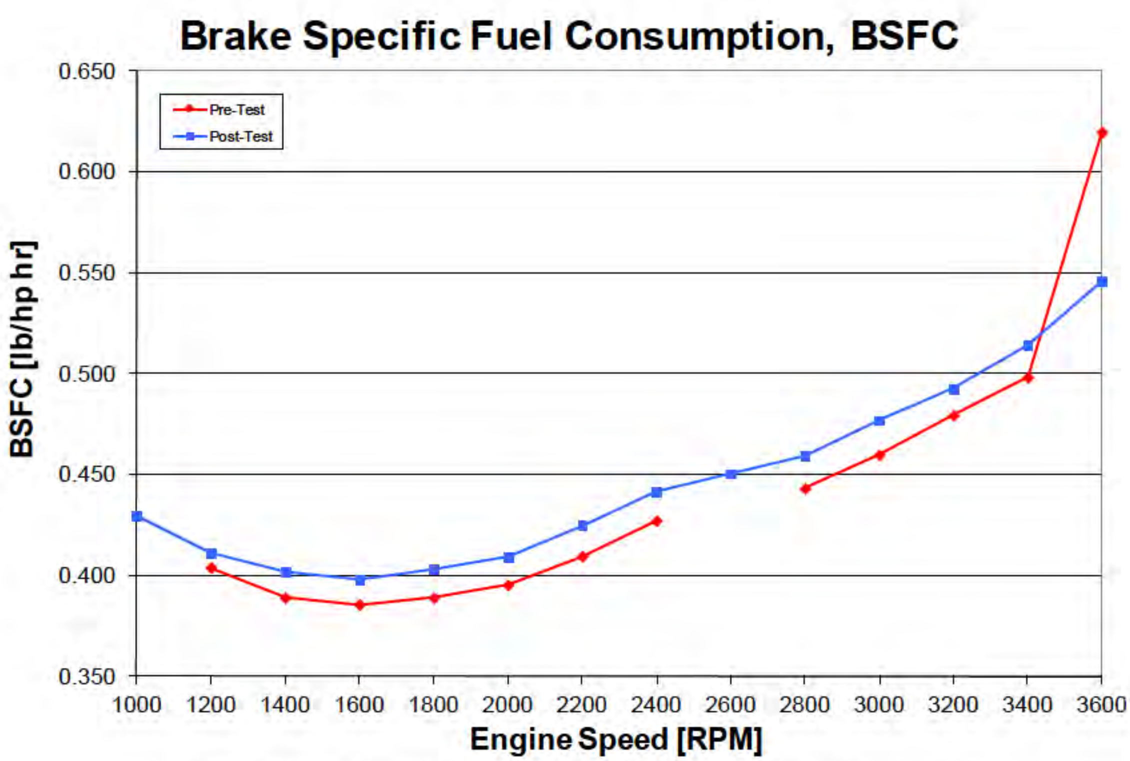
Below is a summary of the engine operating conditions over the test duration. The tested lubricant completed 196hrs of the scheduled 210hr test before being stopped due to oil degradation.

| | | Rated Conditions (3400 RPM) | | Idle Conditions (900 RPM) | |
|---|---|---|---|---|---|
| **Perameter:** | **Units:** | **Average** | **Std. Dev.** | **Average** | **Std. Dev.** |
| Engine Speed | RPM | 3400.01 | 0.76 | 900.58 | 5.12 |
| Torque* | ft*lb | 254.23 | 2.88 | 26.49 | 1.94 |
| Fuel Flow | lb/hr | 80.52 | 0.83 | 5.79 | 6.54 |
| Power* | bhp | 164.58 | 1.86 | 4.55 | 0.33 |
| BSFC* | lb/bhp*hr | 0.489 | 0.006 | 1.282 | 1.453 |
| **Temperatures:** | | | | | |
| Coolant In | °F | 190.40 | 0.92 | 92.28 | 0.93 |
| Coolant Out | °F | 204.99 | 0.84 | 100.00 | 0.80 |
| Oil Sump | °F | 260.05 | 0.50 | 125.59 | 1.94 |
| Fuel In | °F | 95.01 | 0.34 | 94.98 | 0.32 |
| Intake Air | °F | 68.33 | 3.34 | 65.14 | 3.14 |
| Cylinder 1 Exhaust | °F | 1135.40 | 16.16 | 180.81 | 4.02 |
| Cylinder 2 Exhaust | °F | 1205.01 | 13.90 | 181.45 | 4.63 |
| Cylinder 3 Exhaust | °F | 1206.48 | 16.88 | 185.56 | 4.70 |
| Cylinder 4 Exhaust | °F | 1144.29 | 15.49 | 194.32 | 6.49 |
| Cylinder 5 Exhaust | °F | 1162.88 | 14.26 | 187.07 | 4.81 |
| Cylinder 6 Exhaust | °F | 1166.94 | 17.23 | 196.79 | 5.34 |
| Cylinder 7 Exhaust | °F | 1144.28 | 18.44 | 186.20 | 4.77 |
| Cylinder 8 Exhaust | °F | 1164.26 | 13.81 | 186.75 | 4.35 |
| **Pressures:** | | | | | |
| Oil Galley | psi | 36.96 | 1.59 | 40.60 | 5.59 |
| Ambient Pressure | psiA | 14.30 | 0.07 | 14.30 | 0.07 |
| Boost Pressure | psi | 4.84 | 0.12 | -0.14 | 0.06 |

* Non-corrected Values

## Engine Performance Curves



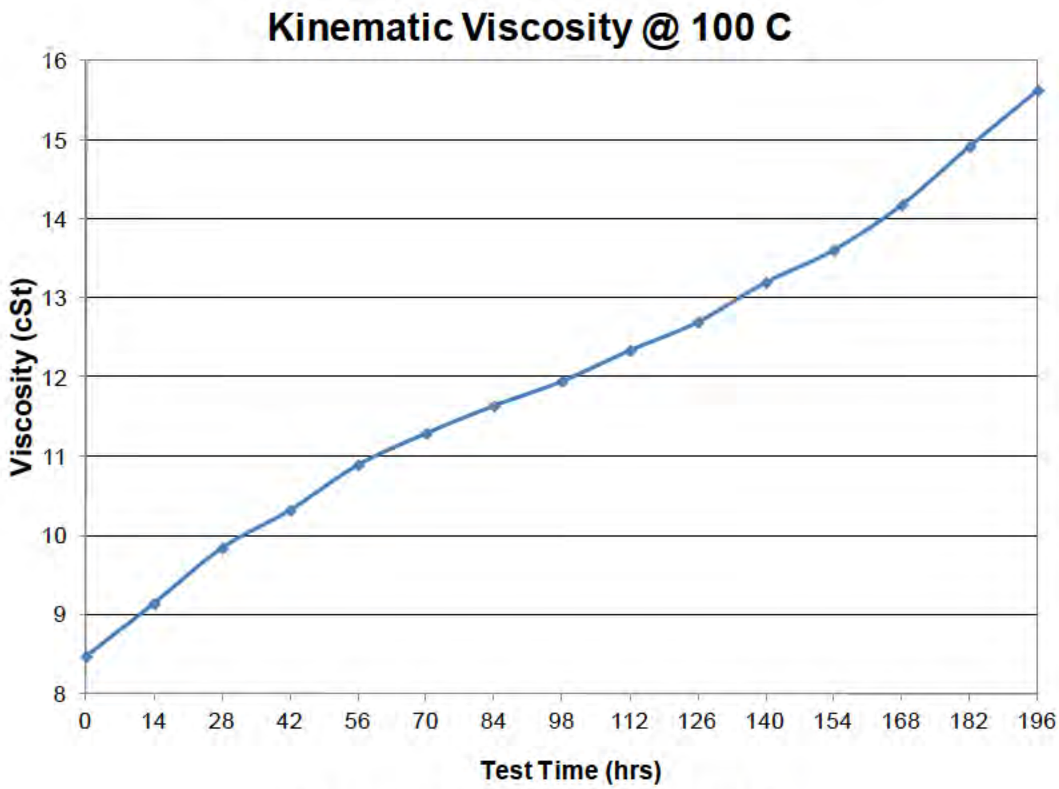



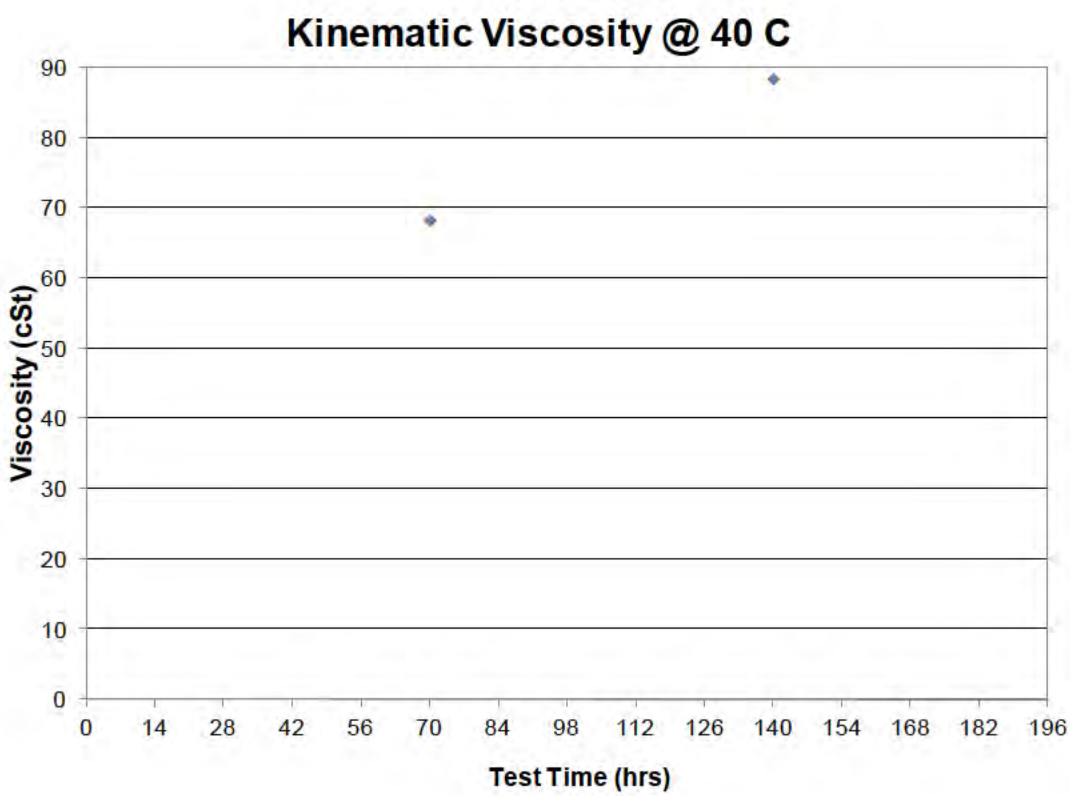

*Note – Breaks in BSFC plot due to invalid values for engine fuel flow during powercurve.

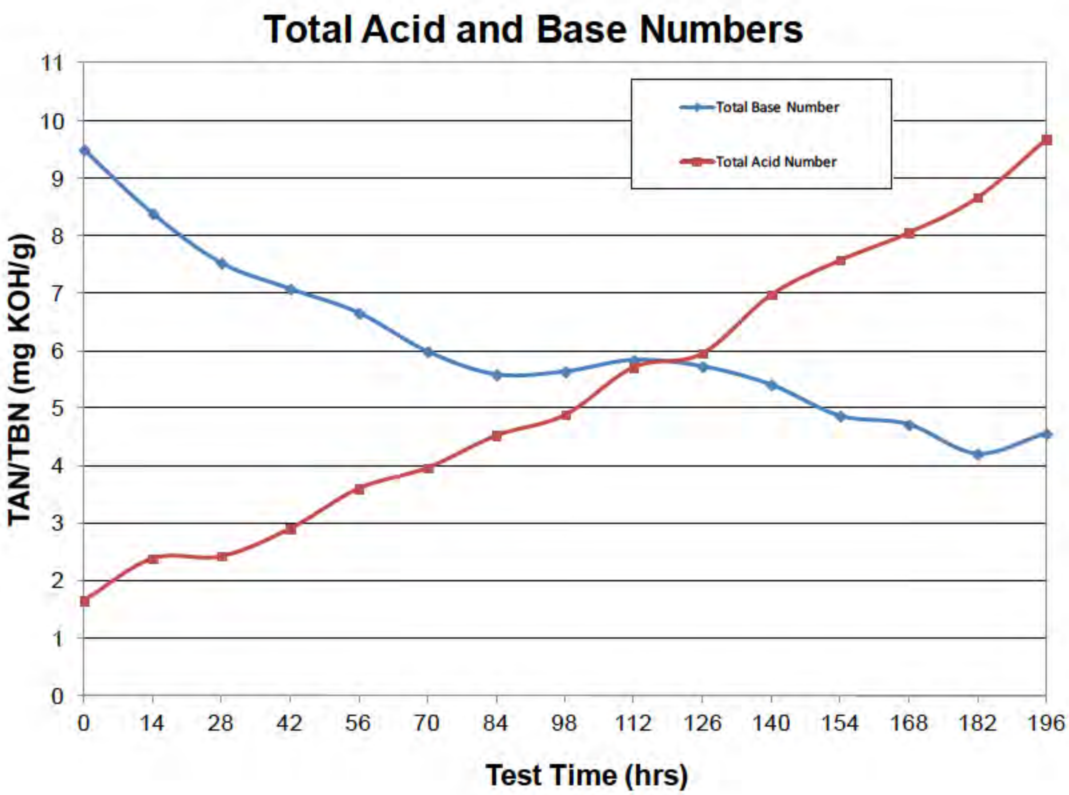
# Engine Oil Analysis

| Property | ASTM Test | Test Hours | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 14 | 28 | 42 | 56 | 70 | 84 | 98 | 112 | 126 | 140 | 154 | 168 | 182 | 196 |
| Density | D4052 | 0.8466 | 0.8512 | 0.8552 | 0.8582 | 0.861 | 0.864 | 0.8667 | 0.8693 | 0.8717 | 0.8752 | 0.8796 | 0.8831 | 0.887 | 0.8908 | 0.894 |
| Viscosity @ 100°C (cSt) | D445 | 8.5 | 9.1 | 9.8 | 10.3 | 10.9 | 11.3 | 11.6 | 12.0 | 12.3 | 12.7 | 13.2 | 13.6 | 14.2 | 14.9 | 15.6 |
| Viscosity @ 40°C (cSt) | D445 | | | | | | 68.3 | | | | | 88.4 | | | | |
| Viscosity Index (dyne/cm) | D2270 | | | | | | 159.0 | | | | | 150.0 | | | | |
| Total Base Number (mg KOH/g) | D4739 | 9.5 | 8.4 | 7.5 | 7.1 | 6.7 | 6.0 | 5.6 | 5.6 | 5.8 | 5.7 | 5.4 | 4.9 | 4.7 | 4.2 | 4.6 |
| Total Acid Number (mg KOH/g) | D664 | 1.7 | 2.4 | 2.4 | 2.9 | 3.6 | 4.0 | 4.5 | 4.9 | 5.7 | 6.0 | 7.0 | 7.6 | 8.1 | 8.7 | 9.7 |
| Oxidation (Abs./cm) | E168 FTNG | 0.0 | 6.9 | 13.3 | 18.7 | 24.2 | 31.5 | 37.3 | 43.7 | 50.3 | 58.8 | 69.6 | 80.4 | 91.3 | 103.0 | 111.7 |
| Nitration (Abs./cm) | E168 FTNG | 0.0 | 5.6 | 6.2 | 7.3 | 9.8 | 15.0 | 18.2 | 21.8 | 26.6 | 33.7 | 39.7 | 44.1 | 48.0 | 51.2 | 52.0 |
| Soot | Soot | 0.2 | 0.4 | 0.6 | 0.8 | 1.0 | 1.1 | 1.3 | 1.4 | 1.6 | 1.7 | 1.8 | 2.2 | 2.3 | 2.4 | 2.6 |
| Wear Metals (ppm) | D5185 | | | | | | | | | | | | | | | |
| Al | | 2 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 5 |
| Sb | | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Ba | | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| B | | 14 | 14 | 16 | 15 | 18 | 16 | 17 | 17 | 17 | 17 | 18 | 17 | 18 | 19 | 22 |
| Ca | | 902 | 1012 | 1013 | 1080 | 1081 | 1172 | 1206 | 1204 | 1254 | 1291 | 1312 | 1355 | 1422 | 1436 | 1469 |
| Cr | | <1 | 2 | 2 | 3 | 4 | 4 | 4 | 5 | 5 | 5 | 6 | 5 | 6 | 6 | 6 |
| Cu | | <1 | 33 | 36 | 36 | 37 | 39 | 40 | 39 | 39 | 40 | 42 | 43 | 47 | 52 | 61 |
| Fe | | 1 | 54 | 85 | 112 | 136 | 173 | 200 | 217 | 239 | 270 | 297 | 323 | 366 | 398 | 452 |
| Pb | | <1 | 19 | 24 | 27 | 29 | 34 | 38 | 41 | 45 | 56 | 74 | 94 | 128 | 174 | 232 |
| Mg | | 1259 | 1330 | 1392 | 1453 | 1485 | 1583 | 1617 | 1644 | 1700 | 1756 | 1806 | 1841 | 1915 | 1926 | 1995 |
| Mn | | <1 | 2 | 2 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 6 | 6 |
| Mo | | 64 | 78 | 88 | 96 | 98 | 105 | 110 | 111 | 110 | 120 | 122 | 120 | 128 | 130 | 132 |
| Ni | | <1 | 3 | 4 | 5 | 6 | 6 | 7 | 7 | 7 | 8 | 8 | 8 | 8 | 8 | 9 |
| P | | 1079 | 1083 | 1076 | 1104 | 1079 | 1169 | 1207 | 1214 | 1223 | 1304 | 1350 | 1336 | 1463 | 1474 | 1476 |
| Si | | 5 | 53 | 64 | 69 | 67 | 71 | 71 | 68 | 63 | 65 | 63 | 59 | 57 | 55 | 56 |
| Ag | | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Na | | <5 | <5 | <5 | 5 | 5 | 6 | 7 | 6 | 7 | 7 | 8 | 8 | 9 | 10 | 9 |
| Sn | | <1 | 8 | 10 | 10 | 11 | 12 | 12 | 12 | 12 | 13 | 14 | 14 | 13 | 14 | 15 |
| Zn | | 1265 | 1324 | 1379 | 1453 | 1506 | 1564 | 1611 | 1648 | 1691 | 1752 | 1812 | 1867 | 1876 | 1878 | 1979 |
| K | | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 |
| Sr | | <1 | <1 | <1 | <1 | 1 | 1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| V | | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Ti | | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Cd | | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |

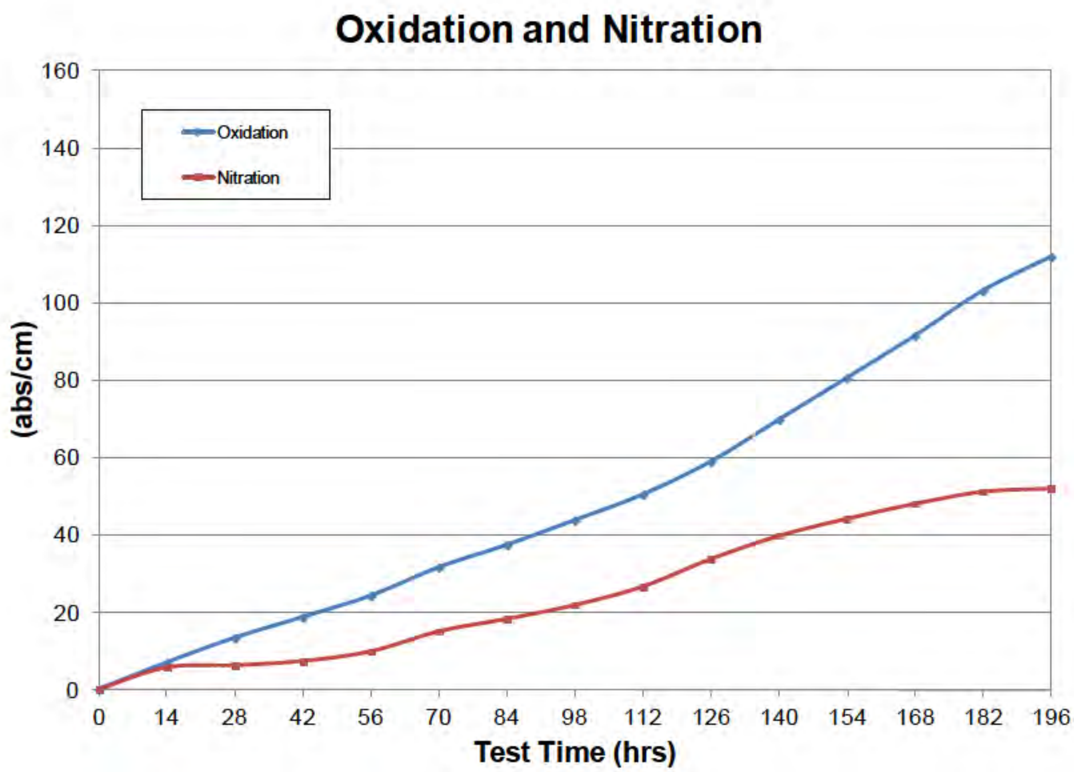
## Engine Oil Analysis Trends



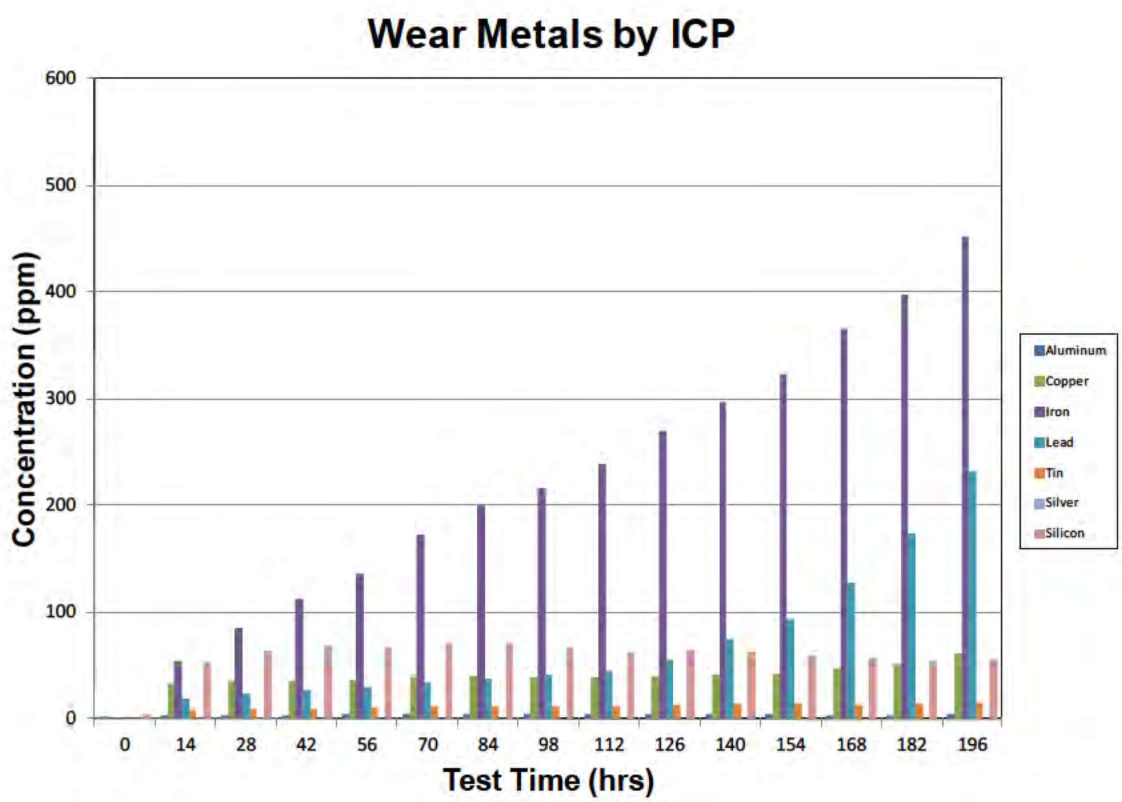




Total Acid and Base Numbers
TAN/TBN (mg KOH/g)
Total Base Number
Total Acid Number
0
1
2
3
4
5
6
7
8
9
10
11
0 14 28 42 56 70 84 98 112 126 140 154 168 182 196
Test Time (hrs)


Soot
(wt%)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0 14 28 42 56 70 84 98 112 126 140 154 168 182 196
Test Time (hrs)



Oxidation and Nitration
Oxidation
Nitration
(abs/cm)
160
140
120
100
80
60
40
20
0
0 14 28 42 56 70 84 98 112 126 140 154 168 182 196
Test Time (hrs)

Wear Metals by ICP
Concentration (ppm)
600
500
400
300
200
100
0
0 14 28 42 56 70 84 98 112 126 140 154 168 182 196
Test Time (hrs)
Aluminum
Copper
Iron
Lead
Tin
Silver
Silicon

## Oil Consumption Data

Average oil consumption per test hour was 0.084 lbs/hr.

| | Additions (lbs) | Samples (lbs) | Consumption (lbs) | Consumption Accumulated |
|---|---|---|---|---|
| **14 -hr** | 1.24 | 0.235 | 1.005 | 1.005 |
| **28 -hr** | 1.63 | 0.22 | 1.41 | 2.415 |
| **42 -hr** | 1.61 | 0.21 | 1.4 | 3.815 |
| **56 -hr** | 1.2 | 0.22 | 0.98 | 4.795 |
| **70 -hr** | 1.64 | 0.21 | 1.43 | 6.225 |
| **84 -hr** | 1.61 | 0.23 | 1.38 | 7.605 |
| **98 -hr** | 1.62 | 0.23 | 1.39 | 8.995 |
| **112 -hr** | 1.44 | 0.22 | 1.22 | 10.215 |
| **126 -hr** | 1.57 | 0.25 | 1.32 | 11.535 |
| **140 -hr** | 1.65 | 0.26 | 1.39 | 12.925 |
| **154 -hr** | 1.7 | 0.26 | 1.44 | 14.365 |
| **168 -hr** | 1.61 | 0.26 | 1.35 | 15.715 |
| **182 -hr** | 1.69 | 0.235 | 1.455 | 17.17 |
| **196 -hr** | 1.61 | 0.25 | 1.36 | 18.53 |
| | **Initial Fill** | 13.33 | **Total Additions** | 21.82 |
| | **EOT Drain** | 15.36 | **Total Samples** | 3.29 |

| | |
|---|---|
| (Initial Fill + Additions) | 35.15 |
| (EOT Drain + Samples) | 18.65 |
| **Total Oil Consumption** | 16.5 |

## Post Test Engine Ratings

| Ratings | Cylinder Number | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Avg |
| **Ring Sticking** | | | | | | | | | |
| Ring No.1 | NO | NO | NO | NO | NO | NO | NO | NO | -- |
| Ring No.2 | NO | NO | NO | NO | NO | NO | NO | NO | -- |
| Ring No.3 | NO | NO | NO | NO | NO | NO | NO | NO | -- |
| **Scuffing % Area** | | | | | | | | | |
| Ring No.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Ring No.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Ring No.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Piston Crown | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Piston Skirt | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Cylinder Liner, % | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| **Piston Carbon, Demerits** | | | | | | | | | |
| No.1 Groove | 44.75 | 47.50 | 65.75 | 59.50 | 35.50 | 52.25 | 33.25 | 51.25 | 48.72 |
| No.2 Groove | 0.00 | 0.50 | 10.00 | 1.25 | 2.25 | 5.25 | 0.00 | 10.00 | 3.66 |
| No.3 Groove | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| No.1 Land | 30.00 | 28.75 | 40.50 | 35.75 | 39.50 | 36.50 | 27.25 | 38.75 | 34.63 |
| No.2 Land | 7.25 | 11.25 | 13.50 | 2.25 | 17.25 | 15.00 | 6.75 | 22.00 | 11.91 |
| No.3 Land | 0.00 | 0.00 | 0.50 | 0.00 | 1.00 | 1.25 | 0.00 | 0.50 | 0.41 |
| Upper Skirt | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Under Crown | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 12.50 | 1.56 |
| Front Pin Bore | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Rear Pin Bore | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Piston Lacquer, Demerits** | | | | | | | | | |
| No.1 Groove | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| No.2 Groove | 3.67 | 2.09 | 2.59 | 2.93 | 1.98 | 2.14 | 3.00 | 1.84 | 2.53 |
| No.3 Groove | 2.10 | 1.60 | 1.90 | 1.84 | 1.20 | 1.99 | 1.80 | 2.20 | 1.83 |
| No.1 Land | 0.04 | 0.03 | 0.02 | 0.01 | 0.01 | 0.02 | 0.06 | 0.01 | 0.03 |
| No.2 Land | 1.96 | 1.13 | 0.92 | 1.74 | 0.92 | 1.47 | 1.63 | 0.64 | 1.30 |
| No.3 Land | 1.24 | 1.69 | 1.96 | 1.52 | 1.70 | 2.37 | 1.50 | 2.34 | 1.79 |
| Upper Skirt | 0.33 | 0.68 | 0.64 | 0.70 | 0.50 | 0.77 | 0.55 | 0.99 | 0.65 |
| Under Crown | 5.13 | 4.13 | 4.87 | 3.06 | 3.11 | 4.44 | 4.07 | 2.10 | 3.86 |
| Front Pin Bore | 1.36 | 1.36 | 1.36 | 1.40 | 1.78 | 1.36 | 1.36 | 1.78 | 1.47 |
| Rear Pin Bore | 1.78 | 1.36 | 1.10 | 1.10 | 1.36 | 1.78 | 1.36 | 1.36 | 1.40 |
| **Total, Demerits** | 99.61 | 102.07 | 145.61 | 113.05 | 108.06 | 126.59 | 82.58 | 148.26 | 115.73 |
| | | | | | | | | | |
| **Miscellanous** | | | | | | | | | |
| Top Groove Fill, % | 41 | 40 | 65 | 41 | 29 | 40 | 22 | 43 | 40.13 |
| Intermediate Groove Fill, % | 0 | 0 | 7 | 0 | 0 | 1 | 0 | 4 | 1.50 |
| Top Land Heavy Carbon, % | 8 | 7 | 22 | 15 | 20 | 17 | 7 | 19 | 14.38 |
| Top Lan Flaked Carbon, % | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| | | | | | | | | | |
| **Valve Tulip Deposits, Merits** | | | | | | | | | |
| Exahust | 9.0 | 9.1 | 9.1 | 9.0 | 9.0 | 9.0 | 9.0 | 9.1 | 9.04 |
| Intake | 7.0 | 7.6 | 7.7 | 6.8 | 6.8 | 8.7 | 7.1 | 7.0 | 7.34 |

# Engine Measurement Changes

## Engine Rebuild Measurements, inches

| Cylinder Bore | Minimum | Maximum | Average | Spec: |
|---|---|---|---|---|
| Inside Diameter | 4.0546 | 4.0555 | 4.0549 | Cylinder 1 thru 6 ID 4.054"-4.075" |
| Out of Round | 0.0001 | 0.0045 | 0.0006 | Cylinder 7 thru 8 ID 4.055"-Maximum 0.008" |
| Taper | 0.0001 | 0.0042 | 0.0005 | |
| **Piston Skirt Diameter** | 4.0499 | 4.0504 | 4.0502 | |
| Piston Skirt to Cylinder Bore Clearance | 0.0044 | 0.0051 | 0.0047 | Cylinder 1 thru 7 0.003"-0.004" Cylinder 7 thru 8 0.004"-0.005" |
| **Piston Ring End Gaps** | | | | |
| Top Ring | 0.013 | 0.016 | 0.015 | |
| Second Ring | 0.032 | 0.039 | 0.035 | |
| Oil Control Ring | 0.013 | 0.015 | 0.014 | |
| **Ring To Groove Clearance** | | | | |
| Second Ring | 0.0020 | 0.0020 | 0.0020 | 0.0015"-0.003" |
| Oil Control Ring | 0.0016 | 0.0020 | 0.0019 | 0.0015"-0.0035" |
| **Piston Pin** | | | | |
| Piston Pin Diameter | 1.2205 | 1.2205 | 1.2205 | 1.2203"-1.2206" |
| Pin Bore Diameter (Piston) | 1.2216 | 1.2218 | 1.2217 | 1.2207"-1.2212" |
| Piston Pin Clearance | 0.0011 | 0.0013 | 0.0012 | 0.0003"-0.0012" |
| Piston Pin Diameter | 1.2205 | 1.2205 | 1.2205 | 1.2203"-1.2206" |
| Pin Bore Diameter (Rod) | 1.2217 | 1.2218 | 1.2218 | 1.2207"-1.2212" |
| Piston Pin Clearance | 0.0012 | 0.0013 | 0.0013 | 0.0003"-0.0012" |
| **Bearing Clearances** | | | | |
| Connecting Rod to Journal | 0.0025 | 0.0030 | 0.0028 | 0.0017"-0.0039" |
| Main Bearing to Journa | 0.0020 | 0.0030 | 0.0022 | 0.001"-0.005" |
| **Crankshaft Endplay** | | | | |
| Crankshaft Endplay | N/A | N/A | 0.007 | 0.004-0.010" |
| Rod Side Clearance | 0.009 | 0.010 | 0.010 | 0.007-0.024" |

*Note: Referenced specifications are to 1994 General Motors Light Duty Truck guidelines. Some variation in engine specifications are expected between updated versions of the GEP 6.5L(T) engines used by the military and those used previously by General Motors. GEP engine specifications are not public infomrmation. GM specifications serve only as guielines to acess the pre-test engine condition for fit for purpose.*

## Pre-Test Cylinder Bore Measurements, inches

| Cylinder | Depth | Tranverse (TD) | Longitude (LD) | Avg Bore Dia. (ABD), (TD@MID + TD@BOT)/2 | Out of Round |
|---|---|---|---|---|---|
| 1 | Top | 4.0549 | 4.0546 | | 0.0003 |
| | Middle | 4.0548 | 4.0543 | 4.0548 | 0.0005 |
| | Bottom | 4.0547 | 4.0546 | | 0.0001 |
| | Taper | 0.0002 | 0.0003 | | |
| 2 | Top | 4.0548 | 4.0545 | | 0.0003 |
| | Middle | 4.0547 | 4.0541 | 4.0547 | 0.0006 |
| | Bottom | 4.0547 | 4.0544 | | 0.0003 |
| | Taper | 0.0001 | 0.0004 | | |
| 3 | Top | 4.0550 | 4.0545 | | 0.0005 |
| | Middle | 4.0548 | 4.0542 | 4.0548 | 0.0006 |
| | Bottom | 4.0547 | 4.0545 | | 0.0002 |
| | Taper | 0.0003 | 0.0003 | | |
| 4 | Top | 4.0548 | 4.0545 | | 0.0003 |
| | Middle | 4.0547 | 4.0541 | 4.0546 | 0.0006 |
| | Bottom | 4.0545 | 4.0544 | | 0.0001 |
| | Taper | 0.0003 | 0.0004 | | |
| 5 | Top | 4.0551 | 4.0545 | | 0.0006 |
| | Middle | 4.0549 | 4.0542 | 4.0549 | 0.0007 |
| | Bottom | 4.0548 | 4.0546 | | 0.0002 |
| | Taper | 0.0003 | 0.0004 | | |
| 6 | Top | 4.0550 | 4.0545 | | 0.0005 |
| | Middle | 4.0548 | 4.0541 | 4.0548 | 0.0007 |
| | Bottom | 4.0547 | 4.0544 | | 0.0003 |
| | Taper | 0.0003 | 0.0004 | | |
| 7 | Top | 4.0556 | 4.0552 | | 0.0004 |
| | Middle | 4.0555 | 4.0548 | 4.0555 | 0.0007 |
| | Bottom | 4.0555 | 4.0510 | | 0.0045 |
| | Taper | 0.0001 | 0.0042 | | |
| 8 | Top | 4.0556 | 4.0551 | | 0.0005 |
| | Middle | 4.0554 | 4.0547 | 4.0554 | 0.0007 |
| | Bottom | 4.0553 | 4.0551 | | 0.0002 |
| | Taper | 0.0003 | 0.0004 | | |

## Post-Test Cylinder Bore Measurements, in

| Cylinder | Depth | Tranverse (TD) | Longitude (LD) | Avg Bore Dia. (ABD), (TD@MID + TD@BOT)/2 | Out of Round |
|---|---|---|---|---|---|
| 1 | Top | 4.0553 | 4.0546 | | 0.0007 |
| | Middle | 4.0549 | 4.0543 | 4.0549 | 0.0006 |
| | Bottom | 4.0548 | 4.0548 | | 0.0000 |
| | Taper | 0.0005 | 0.0005 | | |
| 2 | Top | 4.0555 | 4.0546 | | 0.0009 |
| | Middle | 4.0551 | 4.0541 | 4.0550 | 0.0010 |
| | Bottom | 4.0549 | 4.0546 | | 0.0003 |
| | Taper | 0.0006 | 0.0005 | | |
| 3 | Top | 4.0555 | 4.0545 | | 0.0010 |
| | Middle | 4.0551 | 4.0542 | 4.0549 | 0.0009 |
| | Bottom | 4.0547 | 4.0546 | | 0.0001 |
| | Taper | 0.0008 | 0.0004 | | |
| 4 | Top | 4.0551 | 4.0547 | | 0.0004 |
| | Middle | 4.0550 | 4.0541 | 4.0550 | 0.0009 |
| | Bottom | 4.0549 | 4.0547 | | 0.0002 |
| | Taper | 0.0002 | 0.0006 | | |
| 5 | Top | 4.0554 | 4.0545 | | 0.0009 |
| | Middle | 4.0552 | 4.0543 | 4.0551 | 0.0009 |
| | Bottom | 4.0549 | 4.0548 | | 0.0001 |
| | Taper | 0.0005 | 0.0005 | | |
| 6 | Top | 4.0556 | 4.0545 | | 0.0011 |
| | Middle | 4.0553 | 4.0541 | 4.0551 | 0.0012 |
| | Bottom | 4.0549 | 4.0548 | | 0.0001 |
| | Taper | 0.0007 | 0.0007 | | |
| 7 | Top | 4.0560 | 4.0553 | | 0.0007 |
| | Middle | 4.0557 | 4.0548 | 4.0557 | 0.0009 |
| | Bottom | 4.0557 | 4.0552 | | 0.0005 |
| | Taper | 0.0003 | 0.0005 | | |
| 8 | Top | 4.0560 | 4.0553 | | 0.0007 |
| | Middle | 4.0557 | 4.0547 | 4.0557 | 0.0010 |
| | Bottom | 4.0556 | 4.0552 | | 0.0004 |
| | Taper | 0.0004 | 0.0006 | | |

## Cylinder Bore Diameter Changes, in

| Cylinder | Depth | Tranverse (TD) | Longitude (LD) | Avg Bore Dia. Change (TD@MID + TD@BOT)/2 |
|---|---|---|---|---|
| 1 | Top | 0.0004 | 0.0000 | |
| | Middle | 0.0001 | 0.0000 | 0.0001 |
| | Bottom | 0.0001 | 0.0002 | |
| | | | | |
| 2 | Top | 0.0007 | 0.0001 | |
| | Middle | 0.0004 | 0.0000 | 0.0003 |
| | Bottom | 0.0002 | 0.0002 | |
| | | | | |
| 3 | Top | 0.0005 | 0.0000 | |
| | Middle | 0.0003 | 0.0000 | 0.0002 |
| | Bottom | 0.0000 | 0.0001 | |
| | | | | |
| 4 | Top | 0.0003 | 0.0002 | |
| | Middle | 0.0003 | 0.0000 | 0.0003 |
| | Bottom | 0.0004 | 0.0003 | |
| | | | | |
| 5 | Top | 0.0003 | 0.0000 | |
| | Middle | 0.0003 | 0.0001 | 0.0002 |
| | Bottom | 0.0001 | 0.0002 | |
| | | | | |
| 6 | Top | 0.0006 | 0.0000 | |
| | Middle | 0.0005 | 0.0000 | 0.0003 |
| | Bottom | 0.0002 | 0.0004 | |
| | | | | |
| 7 | Top | 0.0004 | 0.0001 | |
| | Middle | 0.0002 | 0.0000 | 0.0002 |
| | Bottom | 0.0002 | 0.0042 | |
| | | | | |
| 8 | Top | 0.0004 | 0.0002 | |
| | Middle | 0.0003 | 0.0000 | 0.0003 |
| | Bottom | 0.0003 | 0.0001 | |
| | | | | |
| Avgerage All Cylinders | Top | 0.0005 | 0.0001 | |
| | Middle | 0.0003 | 0.0000 | |
| | Bottom | 0.0002 | 0.0007 | |
| | | | | |

## Valve Guide Measurement Changes, in

| | Valve Guide Diameter Intake | | | Valve Guide Diameter Exahust | | |
|---|---|---|---|---|---|---|
| Cylinder | Before | After | Change | Before | After | Change |
| 1 | 0.3424 | 0.3424 | 0.0000 | 0.3726 | 0.3729 | 0.0003 |
| 2 | 0.3425 | 0.3425 | 0.0000 | 0.3726 | 0.3728 | 0.0002 |
| 3 | 0.3424 | 0.3425 | 0.0001 | 0.3725 | 0.3729 | 0.0004 |
| 4 | 0.3424 | 0.3425 | 0.0001 | 0.3725 | 0.3728 | 0.0003 |
| 5 | 0.3425 | 0.3426 | 0.0001 | 0.3726 | 0.3728 | 0.0002 |
| 6 | 0.3425 | 0.3425 | 0.0000 | 0.3725 | 0.3729 | 0.0004 |
| 7 | 0.3425 | 0.3425 | 0.0000 | 0.3725 | 0.3728 | 0.0003 |
| 8 | 0.3425 | 0.3425 | 0.0000 | 0.3726 | 0.3728 | 0.0002 |

| | |
|---|---|
| Maximum | 0.0001 |
| Average | 0.0000 |

| | |
|---|---|
| Maximum | 0.0004 |
| Average | 0.0003 |

## Valve Stem Measurement Changes, in

| | Valve Stem Diameter Intake | | | Valve Stem Diameter Exahust | | |
|---|---|---|---|---|---|---|
| Cylinder | Before | After | Change | Before | After | Change |
| 1 | 0.3414 | 0.3409 | 0.0005 | 0.3711 | 0.3709 | 0.0002 |
| 2 | 0.3414 | 0.3409 | 0.0005 | 0.3712 | 0.3709 | 0.0003 |
| 3 | 0.3414 | 0.3410 | 0.0004 | 0.3712 | 0.3708 | 0.0004 |
| 4 | 0.3414 | 0.3411 | 0.0003 | 0.3711 | 0.3708 | 0.0003 |
| 5 | 0.3414 | 0.3411 | 0.0003 | 0.3712 | 0.3708 | 0.0004 |
| 6 | 0.3414 | 0.3410 | 0.0004 | 0.3711 | 0.3708 | 0.0003 |
| 7 | 0.3414 | 0.3409 | 0.0005 | 0.3711 | 0.3708 | 0.0003 |
| 8 | 0.3414 | 0.3410 | 0.0004 | 0.3712 | 0.3708 | 0.0004 |

| | |
|---|---|
| Maximum | 0.0005 |
| Average | 0.0004 |

| | |
|---|---|
| Maximum | 0.0004 |
| Average | 0.0003 |

## Valve Stem to Guide Clearance Changes, in

| | Stem/Guide Clearance Intake | | | Stem Guide Clearance Exahust | | |
|---|---|---|---|---|---|---|
| Cylinder | Before | After | Change | Before | After | Change |
| 1 | 0.0010 | 0.0015 | 0.0005 | 0.0015 | 0.0020 | 0.0005 |
| 2 | 0.0011 | 0.0016 | 0.0005 | 0.0014 | 0.0019 | 0.0005 |
| 3 | 0.0010 | 0.0015 | 0.0005 | 0.0013 | 0.0021 | 0.0008 |
| 4 | 0.0010 | 0.0014 | 0.0004 | 0.0014 | 0.0020 | 0.0006 |
| 5 | 0.0011 | 0.0015 | 0.0004 | 0.0014 | 0.0020 | 0.0006 |
| 6 | 0.0011 | 0.0015 | 0.0004 | 0.0014 | 0.0021 | 0.0007 |
| 7 | 0.0011 | 0.0016 | 0.0005 | 0.0014 | 0.0020 | 0.0006 |
| 8 | 0.0011 | 0.0015 | 0.0004 | 0.0014 | 0.0020 | 0.0006 |

| | |
|---|---|
| Maximum | 0.0005 |
| Average | 0.0004 |

| | |
|---|---|
| Maximum | 0.0008 |
| Average | 0.0006 |

## Valve Recession Measurement Changes, in

| | Valve Recession Intake | | | Valve Recession Exahust | | |
|---|---|---|---|---|---|---|
| Cylinder | Before | After | Change | Before | After | Change |
| 1 | 0.025 | 0.049 | 0.024 | 0.027 | 0.055 | 0.028 |
| 2 | 0.024 | 0.070 | 0.046 | 0.026 | 0.029 | 0.003 |
| 3 | 0.026 | 0.047 | 0.021 | 0.028 | 0.092 | 0.064 |
| 4 | 0.022 | 0.072 | 0.050 | 0.028 | 0.042 | 0.014 |
| 5 | 0.024 | 0.059 | 0.035 | 0.025 | 0.047 | 0.022 |
| 6 | 0.024 | 0.059 | 0.035 | 0.026 | 0.045 | 0.019 |
| 7 | 0.026 | 0.065 | 0.039 | 0.025 | 0.061 | 0.036 |
| 8 | 0.023 | 0.052 | 0.029 | 0.026 | 0.065 | 0.039 |

| | |
|---|---|
| Maximum | 0.050 |
| Average | 0.035 |

| | |
|---|---|
| Maximum | 0.064 |
| Average | 0.028 |

## Post-Test Cam Lobe Profile, in

| Cam Lobe | Waviness Parameter [µm] |
|---|---|
| 1 | 1.07 |
| 2 | 0.95 |
| 3 | 0.92 |
| 4 | 1.32 |
| 5 | 0.83 |
| 6 | 1.44 |
| 7 | 1.01 |
| 8 | 1.23 |
| 9 | 1.18 |
| 10 | 1.03 |
| 11 | 1.06 |
| 12 | 1.05 |
| 13 | 1.10 |
| 14 | 1.14 |
| 15 | 1.25 |
| 16 | 1.02 |

| | |
|---|---|
| Maximum | 1.44 |
| Average | 1.10 |

## Piston Skirt to Bore Clearance, in

| | Cylinder | Average Bore Diameter | Piston Skirt Diameter | Clearance |
|---|---|---|---|---|
| Pre - Test | 1 | 4.0548 | 4.0500 | 0.0048 |
| | 2 | 4.0547 | 4.0503 | 0.0044 |
| | 3 | 4.0548 | 4.0499 | 0.0049 |
| | 4 | 4.0546 | 4.0501 | 0.0045 |
| | 5 | 4.0549 | 4.0502 | 0.0046 |
| | 6 | 4.0548 | 4.0501 | 0.0047 |
| | 7 | 4.0555 | 4.0504 | 0.0051 |
| | 8 | 4.0554 | 4.0503 | 0.0050 |
| | | | | |
| Post - Test | 1 | 4.0549 | 4.0493 | 0.0056 |
| | 2 | 4.0550 | 4.0491 | 0.0059 |
| | 3 | 4.0549 | 4.0488 | 0.0061 |
| | 4 | 4.0550 | 4.0491 | 0.0058 |
| | 5 | 4.0551 | 4.0493 | 0.0057 |
| | 6 | 4.0551 | 4.0488 | 0.0063 |
| | 7 | 4.0557 | 4.0494 | 0.0063 |
| | 8 | 4.0557 | 4.0495 | 0.0061 |

## Top and Second Ring Radial Wear, in

| Top Ring | | | | |
|---|---|---|---|---|
| **Cylinder** | **Position** | **Before** | **After** | **Delta** |
| **1** | 1 | 0.17790 | 0.17760 | 0.00030 |
| | 2 | 0.17840 | 0.17790 | 0.00050 |
| | 3 | 0.17790 | 0.17765 | 0.00025 |
| | 4 | 0.17687 | 0.17655 | 0.00032 |
| | 5 | 0.17790 | 0.17750 | 0.00040 |
| **2** | 1 | 0.17965 | 0.17925 | 0.00040 |
| | 2 | 0.18005 | 0.17975 | 0.00030 |
| | 3 | 0.17905 | 0.17850 | 0.00055 |
| | 4 | 0.17880 | 0.17840 | 0.00040 |
| | 5 | 0.17895 | 0.17860 | 0.00035 |
| **3** | 1 | 0.17730 | 0.17700 | 0.00030 |
| | 2 | 0.17755 | 0.17680 | 0.00075 |
| | 3 | 0.17675 | 0.17665 | 0.00010 |
| | 4 | 0.17770 | 0.17720 | 0.00050 |
| | 5 | 0.17690 | 0.17655 | 0.00035 |
| **4** | 1 | 0.17775 | 0.17710 | 0.00065 |
| | 2 | 0.17835 | 0.17810 | 0.00025 |
| | 3 | 0.17860 | 0.17795 | 0.00065 |
| | 4 | 0.17745 | 0.17680 | 0.00065 |
| | 5 | 0.17760 | 0.17690 | 0.00070 |
| **5** | 1 | 0.17825 | 0.17770 | 0.00055 |
| | 2 | 0.17815 | 0.17770 | 0.00045 |
| | 3 | 0.17820 | 0.17775 | 0.00045 |
| | 4 | 0.17915 | 0.17865 | 0.00050 |
| | 5 | 0.17875 | 0.17810 | 0.00065 |
| **6** | 1 | 0.17845 | 0.17790 | 0.00055 |
| | 2 | 0.17835 | 0.17785 | 0.00050 |
| | 3 | 0.17855 | 0.17790 | 0.00065 |
| | 4 | 0.17935 | 0.17880 | 0.00055 |
| | 5 | 0.17855 | 0.17815 | 0.00040 |
| **7** | 1 | 0.17805 | 0.17750 | 0.00055 |
| | 2 | 0.17920 | 0.17875 | 0.00045 |
| | 3 | 0.17925 | 0.17860 | 0.00065 |
| | 4 | 0.17875 | 0.17825 | 0.00050 |
| | 5 | 0.17830 | 0.17775 | 0.00055 |
| **8** | 1 | 0.17900 | 0.17850 | 0.00050 |
| | 2 | 0.17855 | 0.17795 | 0.00060 |
| | 3 | 0.17765 | 0.17710 | 0.00055 |
| | 4 | 0.17860 | 0.17795 | 0.00065 |
| | 5 | 0.17820 | 0.17765 | 0.00055 |
| ***Note - Measurements with a negitive delta value, shown in italics, are considered pre-test measurements error** | | | | |

| | |
|---|---|
| Maximum | 0.00075 |
| Average | 0.00049 |

| Second Ring | | | | |
|---|---|---|---|---|
| **Cylinder** | **Position** | **Before** | **After** | **Delta** |
| **1** | 1 | 0.16240 | 0.16180 | 0.00060 |
| | 2 | 0.16145 | 0.16125 | 0.00020 |
| | 3 | 0.16035 | 0.15990 | 0.00045 |
| | 4 | 0.16145 | 0.16105 | 0.00040 |
| | 5 | 0.16245 | 0.16190 | 0.00055 |
| **2** | 1 | 0.16100 | 0.16065 | 0.00035 |
| | 2 | 0.16160 | 0.16140 | 0.00020 |
| | 3 | 0.16035 | 0.16010 | 0.00025 |
| | 4 | 0.16100 | 0.16010 | 0.00090 |
| | 5 | 0.16140 | 0.16105 | 0.00035 |
| **3** | 1 | 0.16200 | 0.16135 | 0.00065 |
| | 2 | 0.16140 | 0.16105 | 0.00035 |
| | 3 | 0.15990 | 0.15945 | 0.00045 |
| | 4 | 0.16055 | 0.16020 | 0.00035 |
| | 5 | 0.16195 | 0.16125 | 0.00070 |
| **4** | 1 | 0.16255 | 0.16180 | 0.00075 |
| | 2 | 0.16225 | 0.16150 | 0.00075 |
| | 3 | 0.16085 | 0.16050 | 0.00035 |
| | 4 | 0.16065 | 0.16015 | 0.00050 |
| | 5 | 0.16160 | 0.16130 | 0.00030 |
| **5** | 1 | 0.16235 | 0.16200 | 0.00035 |
| | 2 | 0.16225 | 0.16190 | 0.00035 |
| | 3 | 0.16200 | 0.16155 | 0.00045 |
| | 4 | 0.16200 | 0.16165 | 0.00035 |
| | 5 | 0.16235 | 0.16210 | 0.00025 |
| **6** | 1 | 0.16200 | 0.16160 | 0.00040 |
| | 2 | 0.16210 | 0.16170 | 0.00040 |
| | 3 | 0.16150 | 0.16105 | 0.00045 |
| | 4 | 0.16230 | 0.16180 | 0.00050 |
| | 5 | 0.16195 | 0.16145 | 0.00050 |
| **7** | 1 | 0.16235 | 0.16165 | 0.00070 |
| | 2 | 0.16215 | 0.16180 | 0.00035 |
| | 3 | 0.16050 | 0.16000 | 0.00050 |
| | 4 | 0.16070 | 0.16020 | 0.00050 |
| | 5 | 0.16165 | 0.16130 | 0.00035 |
| **8** | 1 | 0.16230 | 0.16175 | 0.00055 |
| | 2 | 0.16225 | 0.16185 | 0.00040 |
| | 3 | 0.16155 | 0.16110 | 0.00045 |
| | 4 | 0.16175 | 0.16120 | 0.00055 |
| | 5 | 0.16235 | 0.16165 | 0.00070 |
| ***Note - Measurements with a negitive delta value, shown in italics, are considered pre-test measurements error** | | | | |

| | |
|---|---|
| Maximum | 0.00090 |
| Average | 0.00046 |

## Piston Ring Gap Measurements, in

| Cylinder | Ring No. | Before | After | Delta |
|---|---|---|---|---|
| 1 | 1 | 0.015 | 0.019 | 0.004 |
| | 2 | 0.039 | 0.036 | -0.003 |
| | 3 | 0.014 | 0.017 | 0.003 |
| 2 | 1 | 0.013 | 0.016 | 0.003 |
| | 2 | 0.033 | 0.037 | 0.004 |
| | 3 | 0.013 | 0.014 | 0.001 |
| 3 | 1 | 0.015 | 0.019 | 0.004 |
| | 2 | 0.037 | 0.037 | 0.000 |
| | 3 | 0.013 | 0.015 | 0.002 |
| 4 | 1 | 0.014 | 0.018 | 0.004 |
| | 2 | 0.033 | 0.037 | 0.004 |
| | 3 | 0.013 | 0.014 | 0.001 |
| 5 | 1 | 0.014 | 0.017 | 0.003 |
| | 2 | 0.033 | 0.036 | 0.003 |
| | 3 | 0.014 | 0.015 | 0.001 |
| 6 | 1 | 0.014 | 0.018 | 0.004 |
| | 2 | 0.032 | 0.037 | 0.005 |
| | 3 | 0.013 | 0.015 | 0.002 |
| 7 | 1 | 0.015 | 0.019 | 0.004 |
| | 2 | 0.036 | 0.040 | 0.004 |
| | 3 | 0.015 | 0.019 | 0.004 |
| 8 | 1 | 0.016 | 0.019 | 0.003 |
| | 2 | 0.035 | 0.039 | 0.004 |
| | 3 | 0.013 | 0.016 | 0.003 |

| | |
|---|---|
| Ring No. 1 max increase | 0.004 |
| Ring No. 2 max increase | 0.005 |
| Ring No. 3 max increase | 0.004 |

| | |
|---|---|
| Ring No. 1 avg increase | 0.004 |
| Ring No. 2 avg increase | 0.003 |
| Ring No. 3 avg increase | 0.002 |

**Piston Ring Mass, grams**

| Cylinder | Ring No. | Before | After | Delta |
|---|---|---|---|---|
| 1 | 1 | 22.6275 | 22.5644 | 0.0631 |
| | 2 | 17.0414 | 17.0180 | 0.0234 |
| | 3 | 14.9285 | 14.9164 | 0.0121 |
| 2 | 1 | 22.9259 | 22.8534 | 0.0725 |
| | 2 | 17.0222 | 16.9949 | 0.0273 |
| | 3 | 15.1302 | 15.1187 | 0.0115 |
| 3 | 1 | 22.7588 | 22.6788 | 0.0800 |
| | 2 | 17.0284 | 16.9976 | 0.0308 |
| | 3 | 15.2237 | 15.2099 | 0.0138 |
| 4 | 1 | 22.8261 | 22.7332 | 0.0929 |
| | 2 | 17.0187 | 16.9891 | 0.0296 |
| | 3 | 15.2492 | 15.2365 | 0.0127 |
| 5 | 1 | 22.7028 | 22.6228 | 0.0800 |
| | 2 | 17.1366 | 17.1132 | 0.0234 |
| | 3 | 15.1280 | 15.1164 | 0.0116 |
| 6 | 1 | 22.7503 | 22.6496 | 0.1007 |
| | 2 | 17.1877 | 17.1625 | 0.0252 |
| | 3 | 15.1892 | 15.1769 | 0.0123 |
| 7 | 1 | 22.8320 | 22.7328 | 0.0992 |
| | 2 | 17.0632 | 17.0315 | 0.0317 |
| | 3 | 14.9747 | 14.9616 | 0.0131 |
| 8 | 1 | 22.7414 | 22.6407 | 0.1007 |
| | 2 | 17.1126 | 17.0863 | 0.0263 |
| | 3 | 15.2040 | 15.1918 | 0.0122 |

| | |
|---|---|
| Ring No. 1 max decrease | 0.1007 |
| Ring No. 2 max decrease | 0.0317 |
| Ring No. 3 max decrease | 0.0138 |

| | |
|---|---|
| Ring No. 1 avg decrease | 0.0861 |
| Ring No. 2 avg decrease | 0.0272 |
| Ring No. 3 avg decrease | 0.0124 |

## Connecting Rod Bearing Weight Loss, grams

| Rod Bearing | Shell | Before | After | Change |
|---|---|---|---|---|
| 1 | Top | 27.5345 | 27.5214 | 0.0131 |
| | Bottom | 27.6127 | 27.5962 | 0.0165 |
| 2 | Top | 27.5403 | 27.5246 | 0.0157 |
| | Bottom | 27.5795 | 27.5661 | 0.0134 |
| 3 | Top | 27.5885 | 27.5654 | 0.0231 |
| | Bottom | 27.5954 | 27.5884 | 0.0070 |
| 4 | Top | 27.5868 | 27.5703 | 0.0165 |
| | Bottom | 27.5086 | 27.4981 | 0.0105 |
| 5 | Top | 27.5361 | 27.5225 | 0.0136 |
| | Bottom | 27.5505 | 27.5366 | 0.0139 |
| 6 | Top | 27.6061 | 27.5934 | 0.0127 |
| | Bottom | 27.5823 | 27.5745 | 0.0078 |
| 7 | Top | 27.5794 | 27.5625 | 0.0169 |
| | Bottom | 27.6012 | 27.5834 | 0.0178 |
| 8 | Top | 27.5305 | 27.5141 | 0.0164 |
| | Bottom | 27.6246 | 27.6081 | 0.0165 |

| | |
|---|---|
| Maximum | 0.0231 |
| Average | 0.0145 |

## Main Bearing Weight Loss, grams

| Main Bearing | Shell | Before | After | Change |
|---|---|---|---|---|
| 1 | Top | 48.0311 | 47.9983 | 0.0328 |
| | Bottom | 51.5973 | 51.5392 | 0.0581 |
| 2 | Top | 47.9831 | 47.9512 | 0.0319 |
| | Bottom | 51.6018 | 51.3885 | 0.2133 |
| 3 | Top | 97.8027 | 96.9159 | 0.8868 |
| | Bottom | 103.4064 | 102.1396 | 1.2668 |
| 4 | Top | 47.9791 | 47.9432 | 0.0359 |
| | Bottom | 51.5222 | 51.4074 | 0.1148 |
| 5 | Top | 69.0665 | 69.0102 | 0.0563 |
| | Bottom | 72.7559 | 72.6407 | 0.1152 |

| | |
|---|---|
| Maximum | 1.2668 |
| Average | 0.2812 |

# Stanadyne Injection Pump Calibration/Evaluation

## Stanadyne Pump Calibration / Evaluation

| Pump Type : DB2831-5079 (arctic) | SN: 15684040 |
|---|---|
| Test condition : | AL: |

| PUMP RPM | Description | Spec. | Before | After | Change |
|---|---|---|---|---|---|
| 1000 | Transfer pump psi. | 60-62 psi | 62 | 62 | 0 |
| | Return Fuel | 225-375 cc | 270 | 348 | 78 |
| 350 | Low Idle | 12-16 cc | 16 | 20 | 4 |
| | Housing psi. | 8-12 psi | 10 | 11 | 1 |
| | Advance | 3.5 deg. min | 3.65 | 4.25 | 0.6 |
| | Cold Advance Solenoid | 0-1 psi. | 0 | 0 | 0 |
| 750 | Shut-Off | 4 cc max. | 0 | 0 | 0 |
| 900 | Fuel Delivery | 66.5 - 69.5cc | 68 | 68 | 0 |
| 1600 | WOT Fuel delivery | 59.5 min. | 66 | 65 | 1 |
| | WOT Advance | 2.5 - 3.5 deg. | 2.98 | 3.46 | 0.48 |
| | Face Cam Fuel delivery | 21.5 - 23.5 | 22 | 21 | 1 |
| | Face Cam Advance | 5.25 - 7.25 deg. | 6.41 | 7.2 | 0.79 |
| | Low Idle | 11 - 12 deg. | 10.81 | 10.98 | 0.17 |
| 1825 | Fuel Delivery | 33 cc min. | 37 | 54 | 17 |
| 1950 | High Idle | 15 cc max. | 4 | 2 | 2 |
| | Transfer pump psi. | 125 psi max. | 105 | 107 | 2 |
| 200 | WOT Fuel Delivery | 58 cc min. | 62 | 62 | 0 |
| | WOT Shut-Off | 4 cc max. | 0 | 0 | 0 |
| 75 | Low Idle Fuel Delivery | 37 cc min. | 47 | 47 | 0 |
| | Transfer pump psi. | 16 psi min. | 25 | 30 | 5 |
| | Housing psi. | 0 -12 psi | 9 | 10 | 1 |
| | Air Timing | -.5 deg.(+/-.5 deg) | -0.5 | -0.5 | 0 |

*Pump calibration data to be used for reference only

**PHOTOGRAPHS**

GEP 6.5 - Wheeled Vehicle Cycle

| Oil Code: | LO271510 | EOT Date: | 10-31-11 |
|---|---|---|---|
| Test No.: | LO271510-65T1-W-210 | Test Length: | 196 |

Piston Skirt Thrust - Best Cyl 7

Piston Skirt Anti-thrust - Best Cyl 7

GEP 6.5 - Wheeled Vehicle Cycle

| Oil Code: | LO271510 | EOT Date: | 10-31-11 |
|---|---|---|---|
| Test No.: | LO271510-65T1-W-210 | Test Length: | 196 |

Piston Skirt Thrust - Worst Cyl 8

Piston Skirt Anti-thrust - Worst Cly 8

GEP 6.5 - Wheeled Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO271510 | **EOT Date:** | 10-31-11 |
| **Test No.:** | LO271510-65T1-W-210 | **Test Length:** | 196 |

**Piston Rings - Best Cyl 1**

**Piston Rings - Worst Cyl 7**

**GEP 6.5 - Wheeled Vehicle Cycle**

| Oil Code: | LO271510 | EOT Date: | 10-31-11 |
|---|---|---|---|
| Test No.: | LO271510-65T1-W-210 | Test Length: | 196 |

**Piston Undercrown - Best Cyl 7**

**Piston Undercrown - Worst Cyl 8**

GEP 6.5 - Wheeled Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO271510 | **EOT Date:** | 10-31-11 |
| **Test No.:** | LO271510-65T1-W-210 | **Test Length:** | 196 |

**Engine Block Cylinder Bore - Best Cyl 7**

**Engine Block Cylinder Bore - Worst Cyl 4**

GEP 6.5 - Wheeled Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO271510 | **EOT Date:** | 10-31-11 |
| **Test No.:** | LO271510-65T1-W-210 | **Test Length:** | 196 |

**Exhaust and Intake Valve - Best Cyl 6**

GEP 6.5 - Wheeled Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO271510 | **EOT Date:** | 10-31-11 |
| **Test No.:** | LO271510-65T1-W-210 | **Test Length:** | 196 |

**Exhaust and Intake Valve - Worst Cyl 4**

GEP 6.5 - Wheeled Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO271510 | **EOT Date:** | 10-31-11 |
| **Test No.:** | LO271510-65T1-W-210 | **Test Length:** | 196 |

**Rod Bearings**

GEP 6.5 - Wheeled Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO271510 | **EOT Date:** | 10-31-11 |
| **Test No.:** | LO271510-65T1-W-210 | **Test Length:** | 196 |

**Main Bearings**

# APPENDIX–B1
# EVALUATION OF MIL-PRF-2104H
# LO-257264

# EVALUATION OF MIL-PRF-2104H
# LO-257264

## Project 14734.17

**Detroit Diesel Corporation 6V53T**

**Test Lubricant: LO-257264**
**Test Fuel: Jet-A w/DCI-4A**
**Test Number: LO257264-6V53T1-T-240**
**Start of Test Date: August 25, 2011**
**End of Test Date: September 13, 2011**
**Test Duration: 240 Hours**
**Test Procedure: Tracked Vehicle Engine Cycle**

***Conducted for***

**U.S. Army TARDEC**
**Force Projection Technologies**
**Warren, Michigan**

# Table of Contents

## Introduction

This test was used to determine the performance of MIL-PRF-2104H (LO-257264) when used in the Detroit Diesel Corporation (DDC) 6V53T engine, by the procedures outlined in the Tracked Vehicle Engine Cycle (CRC Report No.406, Development of Military Fuel/Lubricant/Engine Compatibility Test). This work was completed in support of Project 14734.17, Single Common Powertrain Lubricants for Combat/Tactical Equipment.

## Test Engine

The oil was evaluated in the DDC 6V53T turbo-supercharged diesel engine representative of engines currently fielded in the M113 Armored Personnel Carrier (APC). Prior to testing, the engine was rebuilt using premeasured cylinder kits and rod bearings to provide a known starting condition for post test wear measurements. Engine clearances and specifications were verified, and the engine was assembled following standard assembly procedures.

## Test Stand Configuration

The engine was mounted in a test stand specifically configured for DDC engine testing. Engine monitoring, control, and data acquisition was supplied by Southwest Research Institute (SwRI) developed PRISM software. An appropriately sized absorption dynamometer was used to supply engine loading. Engine oil and coolant temperatures were controlled with the use of liquid-to-liquid heat exchangers. Engine intake air was supplied at ambient conditions, and inlet fuel temperature was controlled through an auxiliary fuel heater loop.

### Test Procedure

The procedure outline below is followed in sequential order for each lubricant test in the DDC 6V53T engine.

- Initial Oil Flush:
  -Engine is charged with fresh test oil and a new filter (not weighed).
  -Engine operated at 1200 rpm and 88 lb-ft load until engine and oil temperatures stabilize.
  -Engine shut down and oil charge drained to remove and solvent left from engine rebuild

- Engine Run In:
  -Engine is charged with fresh test oil and a new filter (weighed and recorded)
  -Engine is started and run-in following procedures outline in Table B1-1.
  -Immediately after run-in is complete, a no-load governor check is completed
  (2950-3030 rpm). If engine governed speed is out of spec, adjust and retest.

**Table B1-1. Test Engine Run-In Procedure**

| Engine Speed [RPM] | Load [lb-ft] | Power (Observed) [bhp] | Duration [min] |
|---|---|---|---|
| 1000 | None commanded | -- | 10 |
| 2800 | None commanded | -- | 30 |
| 1800 | 88 | 30 | 15 |
| 2200 | 310 | 130 | 30 |
| 2500 | 420 | 200 | 30 |
| 2800 | 422 | 225 | 30 |

- Engine Shake Down:
  -Engine operated for 5 hrs at 2800 rpm and 390 lb-ft load
  -After shakedown is complete, engine output is checked at max power and torque load points
  -Completed using run-in oil charge

- Pre Test Engine Powercurve:
  -Full load engine power is mapped over entire speed range in 200 rpm increments
  -Completed using run-in oil charge. Once complete, engine oil charge is drained and recorded.

- Testing:
  -Engine is charged with fresh test oil and a new filter (weighed and recorded)
  -Engine is operated on test for 240 hrs. Test termination can be determined early due to severe piston/liner scuffing, or upon major oil degradation.
  -Oil samples collected daily for used oil analysis
  -Airbox inspections take place at 0, 60, 120, and 180 hours.

- Post Test Engine Powercurve:
  -Full load engine power is mapped over entire speed range in 200 rpm increments
  -Completed using test oil charge. Once complete, engine oil charge is drained and recorded.

## Test Cycle

The test cycle followed during oil evaluation was the standard 240 hr Tracked Vehicle Engine Cycle as outlined in CRC Report No. 406, Development of Military Fuel/Lubricant/Engine Compatibility Test. Test termination would occur at the completion of 240 hrs. Early test termination could be called due to severe oil degradation, or upon experiencing major piston and liner scuffing during the test. The test cycle consists of cyclic modes alternating between idle, max power, and max torque load points. Total daily runtime consisted of 20 hrs of operation followed by a 4 hr engine off soak period. The cyclic mode consisted of the following modes repeated 4 times daily: 30 minutes at idle speed, 2 hours at max power, 30 minutes of idle speed, and 2 hours at max torque. Multiple engine parameters were controlled throughout testing to ensure test consistency, and are specified below in Table B1-2.

**Table B1-2. Test Cycle Operating Parameters**

| Parameter | Max Power | Max Torque | Idle |
|---|---|---|---|
| Speed [rpm] | 2800 +/- 25 | 1600 +/- 25 | 950 +/- 25 |
| Water Jacket Out [°F] | 170 +/- 5 | 170 +/- 5 | 170 +/- 5 |
| Inlet Fuel [°F] | 100 +/- 5 | 100 +/- 5 | 100 +/- 5 |
| Oil Sump [°F] | 245 +/- 5 | 230 +/- 5 | NS (190) |

Engine coolant was a 60/40 blend of ethylene glycol antifreeze and deionized water. Test fuel was Jet-A with the max treat rate of corrosion inhibitor/lubricity enhancer DCI-4A.

## Oil Sampling

Four ounces of engine oil was sampled every 20 hrs for used oil analysis. Engine oil analysis consisted of the following tests outlined in Table B1-3. All oil samples were weighed and logged to take into account during calculations of total engine oil consumption for the test duration.

**Table B1-3. Used Oil Analysis Procedures**

| Daily Used Oil Analysis | |
|---|---|
| ASTM D445 | Kinematic Viscosity @ 100°C |
| ASTM D5185 | Wear Metals by ICP |
| ASTM D4739 | Total Base Number |
| ASTM D664 | Total Acid Number |

Used oil analysis results can be seen in the engine oil analysis section of the report.

## Oil Level Checks

Engine oil level was checked daily and replenished as needed to restore oil level to full mark. This process occurred daily after the completion of the 4 hr soak prior to restarting testing. All oil additions were weighed and logged to take into account during calculation of total engine oil consumption for the test duration.

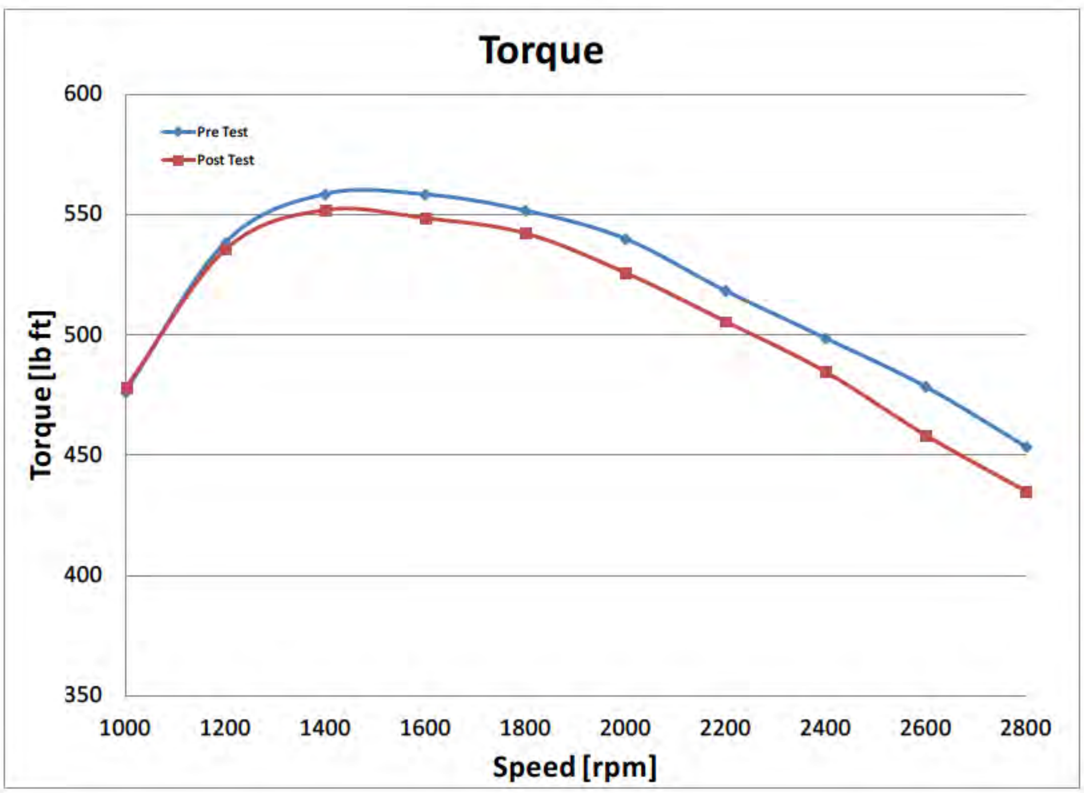
# Engine Operating Conditions Summary

Below is a summary of the engine operating conditions over the test duration. The complete 240hr test schedule was completed by the lubricant.

| | | Peak Power (2800 RPM) | | Peak Torque (1600 RPM) | | Idle Conditions (950 RPM) | |
|---|---|---|---|---|---|---|---|
| **Perameter:** | **Units:** | **Average** | **Std. Dev.** | **Average** | **Std. Dev.** | **Average** | **Std. Dev.** |
| Engine Speed | RPM | 2799.92 | 5.36 | 1600.00 | 4.76 | 942.87 | 5.60 |
| Torque* | ft*lb | 450.00 | 40.08 | 560.92 | 34.58 | - | - |
| Fuel Flow | lb/hr | 94.28 | 1.30 | 64.52 | 0.64 | 2.98 | 0.60 |
| Power* | bhp | 239.86 | 20.92 | 170.85 | 10.04 | - | - |
| BSFC* | lb/bhp*hr | 0.396 | 0.035 | 0.379 | 0.022 | - | - |
| Engine Blowby | acfm | 8.56 | 1.86 | 6.51 | 1.00 | 3.79 | 0.78 |
| Relative Humidity | % | 30.40 | 14.81 | 32.46 | 16.46 | 32.76 | 15.66 |
| **Temperatures:** | | | | | | | |
| Coolant In | °F | 160.61 | 0.88 | 158.74 | 0.93 | 164.81 | 6.41 |
| Coolant Out | °F | 170.00 | 0.77 | 170.00 | 0.80 | 167.49 | 6.62 |
| Oil Galley | °F | 212.51 | 1.43 | 207.66 | 0.82 | 194.12 | 13.05 |
| Oil Sump | °F | 245.00 | 0.40 | 230.00 | 0.40 | 197.45 | 13.52 |
| Fuel In | °F | 100.06 | 0.68 | 100.04 | 0.61 | 99.79 | 1.89 |
| Dry Bulb | °F | 95.80 | 7.65 | 94.04 | 8.54 | 92.58 | 7.60 |
| Intake Air | °F | 82.89 | 4.20 | 80.45 | 3.66 | 78.58 | 2.86 |
| Air After Turbo | °F | 296.31 | 6.23 | 210.18 | 4.40 | 86.26 | 3.36 |
| Air After Supercharger | °F | 279.27 | 4.55 | 201.28 | 3.53 | 143.04 | 10.51 |
| Cylinder 1 Exhaust | °F | 797.60 | 9.97 | 616.65 | 6.41 | 208.22 | 7.80 |
| Cylinder 2 Exhaust | °F | 870.37 | 9.93 | 723.30 | 7.13 | 219.11 | 8.44 |
| Cylinder 3 Exhaust | °F | 826.26 | 10.88 | 702.00 | 7.41 | 208.62 | 9.31 |
| Cylinder 4 Exhaust | °F | 794.12 | 10.04 | 646.46 | 8.68 | 186.53 | 6.23 |
| Cylinder 5 Exhaust | °F | 884.20 | 10.93 | 837.94 | 11.34 | 200.19 | 6.05 |
| Cylinder 6 Exhaust | °F | 855.70 | 8.83 | 803.17 | 13.50 | 179.17 | 5.96 |
| Exhaust Exit Left | °F | 896.36 | 8.84 | 871.51 | 9.68 | 196.48 | 4.38 |
| Exhaust Exit Right | °F | 892.39 | 10.71 | 815.79 | 9.71 | 228.93 | 8.24 |
| Exhaust After Turbo | °F | 689.06 | 8.79 | 686.50 | 9.16 | 220.71 | 18.80 |
| **Pressures:** | | | | | | | |
| Oil Galley | psiG | 55.15 | 0.54 | 41.86 | 0.54 | 25.49 | 3.53 |
| Ambient Pressure | psiA | 14.35 | 0.05 | 14.35 | 0.04 | 14.35 | 0.04 |
| Pressure After Turbo | psiG | 20.70 | 0.35 | 11.33 | 0.24 | 0.11 | 0.05 |
| Pressure After Supercharger | psiG | 22.68 | 0.34 | 10.92 | 0.27 | 0.50 | 0.09 |
| Pressure Exhaust Left | psiG | 19.68 | 0.30 | 10.05 | 0.23 | 0.33 | 0.07 |
| Pressure Exhaust Right | psiG | 18.74 | 0.25 | 9.54 | 0.17 | 0.44 | 0.04 |
| Pressure Exhaust After Turbo | psiG | 0.71 | 0.08 | 0.16 | 0.02 | -0.02 | 0.00 |
| Fuel Pressure | psiG | 28.65 | 2.23 | 11.70 | 1.44 | 5.06 | 0.34 |

* Non-corrected Values

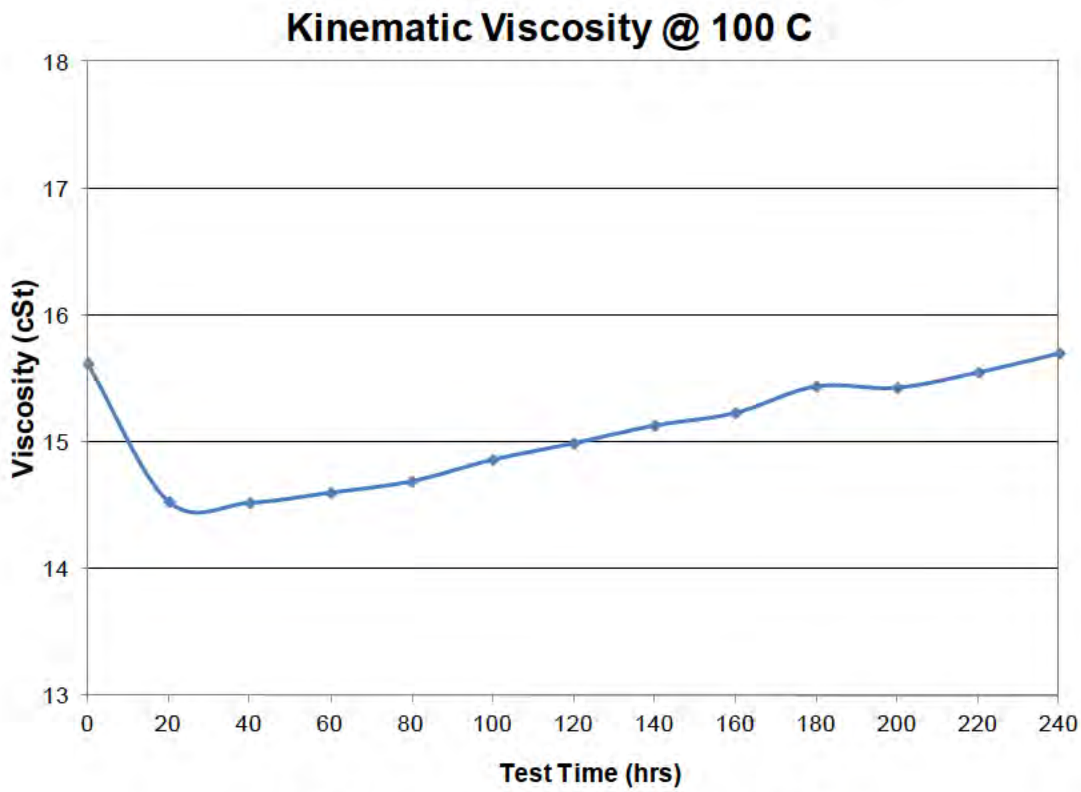
## Engine Performance Curves

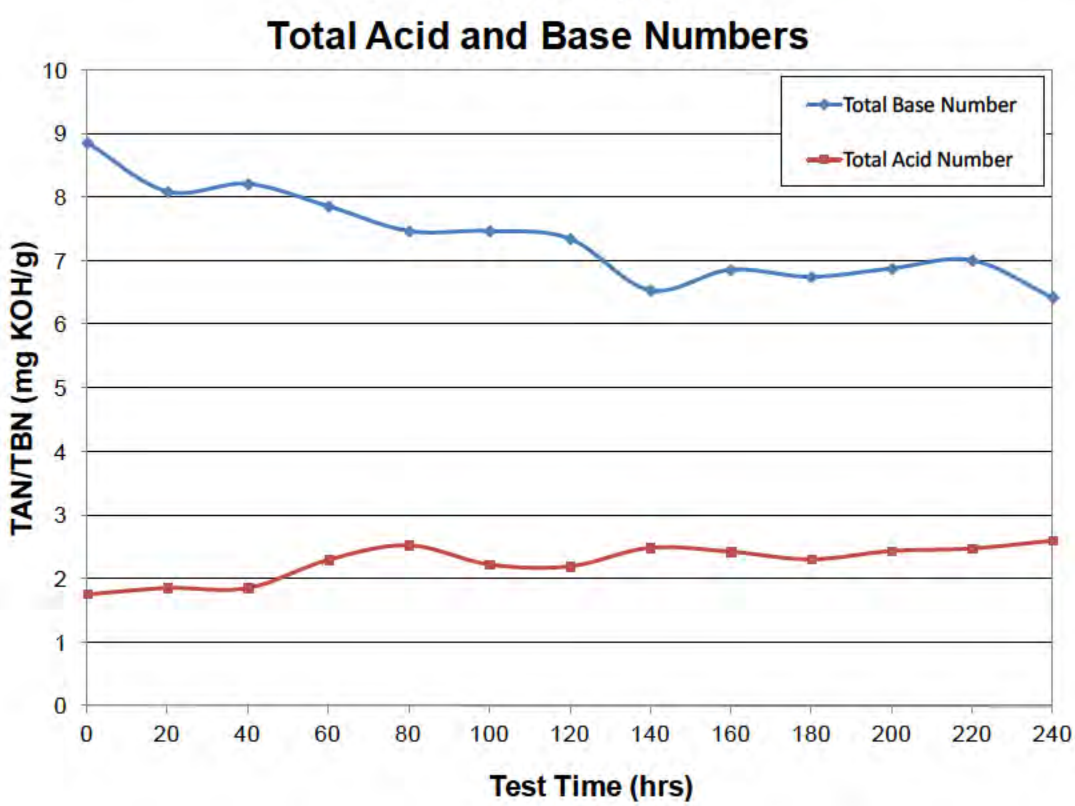



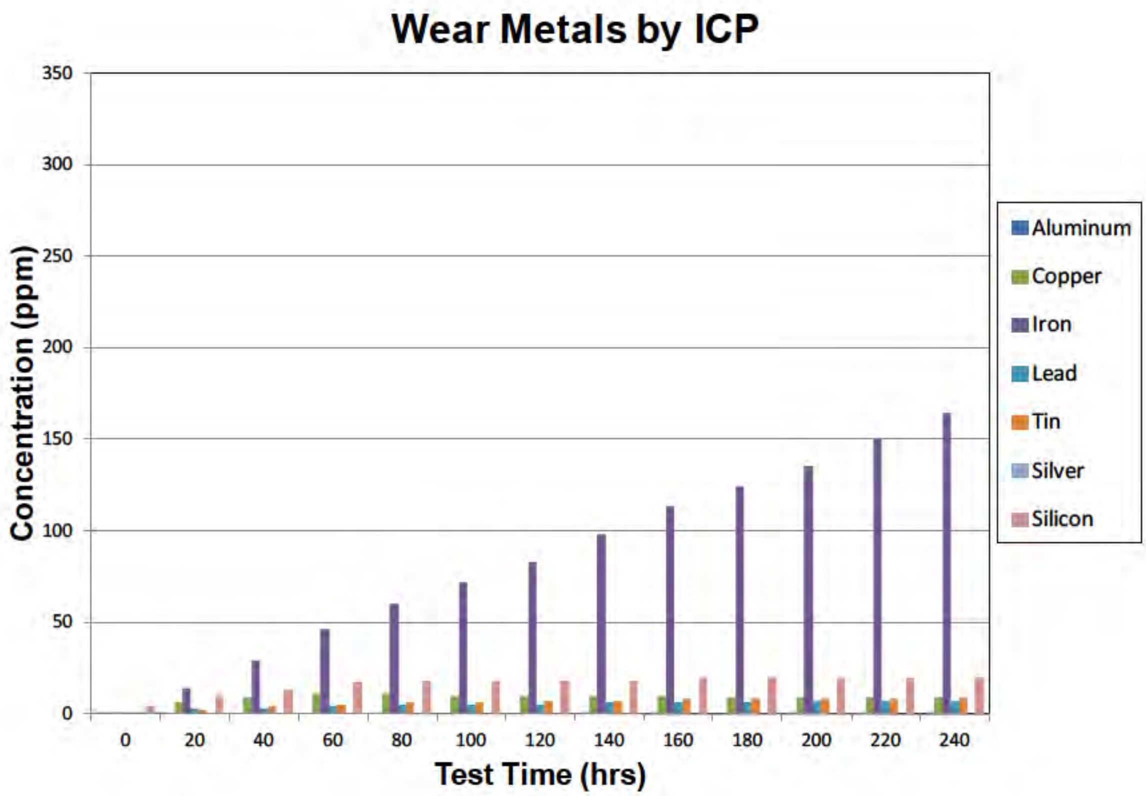
# Engine Oil Analysis

| Property | ASTM Test | Test Hours | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 20 | 40 | 60 | 80 | 100 | 120 | 140 | 160 | 180 | 200 | 220 | 240 |
| Viscosity @ 100°C (cSt) | D445 | 15.6 | 14.5 | 14.5 | 14.6 | 14.7 | 14.9 | 15.0 | 15.1 | 15.2 | 15.4 | 15.4 | 15.6 | 15.7 |
| Total Base Number (mg KOH/g) | D4739 | 8.9 | 8.1 | 8.2 | 7.9 | 7.5 | 7.5 | 7.4 | 6.5 | 6.9 | 6.8 | 6.9 | 7.0 | 6.4 |
| Total Acid Number (mg KOH/g) | D664 | 1.8 | 1.9 | 1.9 | 2.3 | 2.5 | 2.2 | 2.2 | 2.5 | 2.4 | 2.3 | 2.4 | 2.5 | 2.6 |
| Wear Metals (ppm) | D5185 | | | | | | | | | | | | | |
| Al | | <1 | <1 | <1 | <1 | 1 | <1 | <1 | 1 | 1 | <1 | 1 | 1 | 1 |
| Sb | | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Ba | | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| B | | 3 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | <1 | 2 | 2 | 2 | 2 |
| Ca | | 2290 | 2407 | 2446 | 2472 | 2544 | 2586 | 2569 | 2693 | 2570 | 2621 | 2676 | 2761 | 2722 |
| Cr | | <1 | <1 | <1 | 1 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 4 |
| Cu | | <1 | 6 | 9 | 11 | 11 | 10 | 10 | 10 | 10 | 9 | 9 | 9 | 9 |
| Fe | | 1 | 14 | 29 | 46 | 60 | 72 | 83 | 98 | 113 | 124 | 135 | 150 | 164 |
| Pb | | <1 | 3 | 3 | 4 | 5 | 5 | 5 | 6 | 6 | 6 | 7 | 7 | 7 |
| Mg | | 271 | 280 | 286 | 300 | 302 | 309 | 301 | 321 | 306 | 307 | 311 | 320 | 318 |
| Mn | | <1 | <1 | <1 | <1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 |
| Mo | | 1 | 2 | 3 | 4 | 5 | 6 | 6 | 7 | 8 | 8 | 9 | 10 | 10 |
| Ni | | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | 1 | 1 | 1 | 1 | 2 |
| P | | 1177 | 1171 | 1149 | 1122 | 1151 | 1162 | 1136 | 1168 | 1128 | 1109 | 1148 | 1161 | 1131 |
| Si | | 4 | 10 | 13 | 17 | 18 | 18 | 18 | 18 | 20 | 20 | 19 | 19 | 20 |
| Ag | | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Na | | <5 | <5 | <5 | 5 | <5 | 5 | <5 | 7 | <5 | <5 | 5 | 6 | <5 |
| Sn | | <1 | 2 | 4 | 5 | 6 | 6 | 7 | 7 | 8 | 8 | 8 | 8 | 9 |
| Zn | | 1379 | 1398 | 1363 | 1375 | 1435 | 1412 | 1423 | 1448 | 1463 | 1452 | 1461 | 1472 | 1477 |
| K | | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 |
| Sr | | 1 | 1 | <1 | 1 | <1 | <1 | <1 | <1 | 2 | <1 | <1 | <1 | 1 |
| V | | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Ti | | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Cd | | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |

## Engine Oil Analysis Trends





Wear Metals by ICP
Concentration (ppm)
350
300
250
200
150
100
50
0
0
20
40
60
80
100
120
140
160
180
200
220
240
Test Time (hrs)
Aluminum
Copper
Iron
Lead
Tin
Silver
Silicon

## Oil Consumption Data

Average oil consumption per test hour was 0.249 lbs/hr.

| | Additions (lbs) | Samples (lbs) | Consumption (lbs) | Consumption Accumulated |
|---|---|---|---|---|
| **20 hr** | 4.6 | 0.23 | 4.37 | 4.37 |
| **40 hr** | 6.3 | 0.22 | 6.08 | 10.45 |
| **60 hr** | 7 | 0.22 | 6.78 | 17.23 |
| **80 hr** | 7.15 | 0.23 | 6.92 | 24.15 |
| **100 hr** | 5.51 | 0.22 | 5.29 | 29.44 |
| **120 hr** | 5.25 | 0.22 | 5.03 | 34.47 |
| **140 hr** | 3.48 | 0.22 | 3.26 | 37.73 |
| **160 hr** | 4.86 | 0.23 | 4.63 | 42.36 |
| **180 hr** | 5.63 | 0.24 | 5.39 | 47.75 |
| **200 hr** | 3.5 | 0.23 | 3.27 | 51.02 |
| **220 hr** | 2.34 | 0.23 | 2.11 | 53.13 |
| **240 hr** | 6.75 | 0.24 | 6.51 | 59.64 |
| | **Initial Fill** | 37.5 | **Total Additions** | 62.37 |
| | **EOT Drain** | 37.44 | **Total Samples** | 2.73 |

| | |
|---|---|
| (Initial Fill + Additions) | 99.87 |
| (EOT Drain + Samples) | 40.17 |
| **Total Oil Consumption** | 59.7 |

## Engine Measurements

### Pre-Test Cylinder Bore Measurements, inches

| Cylinder | Depth | Thrust/Anti-Thrust | Front/Back | Avg Bore DIA | Out of Round |
|---|---|---|---|---|---|
| 1L | 13mm From Top | 3.8761 | 3.8764 | | 0.0003 |
| | 25mm Above Port | 3.8760 | 3.8764 | 3.8762 | 0.0004 |
| | 25mm Below Port | 3.8759 | 3.8762 | | 0.0003 |
| | 13mm From Bottom | 3.8764 | 3.8762 | | 0.0002 |
| | Taper | 0.0005 | 0.0002 | | |
| 2L | 13mm From Top | 3.8765 | 3.8762 | | 0.0003 |
| | 25mm Above Port | 3.8764 | 3.8763 | 3.8763 | 0.0001 |
| | 25mm Below Port | 3.8762 | 3.8760 | | 0.0002 |
| | 13mm From Bottom | 3.8764 | 3.8763 | | 0.0001 |
| | Taper | 0.0003 | 0.0003 | | |
| 3L | 13mm From Top | 3.8764 | 3.8760 | | 0.0004 |
| | 25mm Above Port | 3.8764 | 3.8762 | 3.8763 | 0.0002 |
| | 25mm Below Port | 3.8761 | 3.8760 | | 0.0001 |
| | 13mm From Bottom | 3.8767 | 3.8762 | | 0.0005 |
| | Taper | 0.0006 | 0.0002 | | |
| 1R | 13mm From Top | 3.8760 | 3.8763 | | 0.0003 |
| | 25mm Above Port | 3.8762 | 3.8761 | 3.8761 | 0.0001 |
| | 25mm Below Port | 3.8759 | 3.8759 | | 0.0000 |
| | 13mm From Bottom | 3.8763 | 3.8761 | | 0.0002 |
| | Taper | 0.0004 | 0.0004 | | |
| 2R | 13mm From Top | 3.8766 | 3.8761 | | 0.0005 |
| | 25mm Above Port | 3.8764 | 3.8761 | 3.8763 | 0.0003 |
| | 25mm Below Port | 3.8762 | 3.8760 | | 0.0002 |
| | 13mm From Bottom | 3.8765 | 3.8765 | | 0.0000 |
| | Taper | 0.0004 | 0.0005 | | |
| 3R | 13mm From Top | 3.8762 | 3.8764 | | 0.0002 |
| | 25mm Above Port | 3.8762 | 3.8763 | 3.8763 | 0.0001 |
| | 25mm Below Port | 3.8760 | 3.8761 | | 0.0001 |
| | 13mm From Bottom | 3.8765 | 3.8766 | | 0.0001 |
| | Taper | 0.0005 | 0.0005 | | |

## Post-Test Cylinder Bore Measurements, inches

| Cylinder | Depth | Thrust/Anti-Thrust | Front/Back | Avg Bore DIA | Out of Round |
|---|---|---|---|---|---|
| 1L | 13mm From Top | 3.8769 | 3.8762 | | 0.0007 |
| | 25mm Above Port | 3.8763 | 3.8763 | 3.8763 | 0.0000 |
| | 25mm Below Port | 3.8761 | 3.8763 | | 0.0002 |
| | 13mm From Bottom | 3.8761 | 3.8763 | | 0.0002 |
| | Taper | 0.0008 | 0.0001 | | |
| 2L | 13mm From Top | 3.8767 | 3.8765 | | 0.0002 |
| | 25mm Above Port | 3.8765 | 3.8763 | 3.8764 | 0.0002 |
| | 25mm Below Port | 3.8764 | 3.8761 | | 0.0003 |
| | 13mm From Bottom | 3.8763 | 3.8765 | | 0.0002 |
| | Taper | 0.0004 | 0.0004 | | |
| 3L | 13mm From Top | 3.8770 | 3.8762 | | 0.0008 |
| | 25mm Above Port | 3.8764 | 3.8762 | 3.8764 | 0.0002 |
| | 25mm Below Port | 3.8762 | 3.8761 | | 0.0001 |
| | 13mm From Bottom | 3.8764 | 3.8764 | | 0.0000 |
| | Taper | 0.0008 | 0.0003 | | |
| 1R | 13mm From Top | 3.8766 | 3.8764 | | 0.0002 |
| | 25mm Above Port | 3.8764 | 3.8764 | 3.8764 | 0.0000 |
| | 25mm Below Port | 3.8761 | 3.8763 | | 0.0002 |
| | 13mm From Bottom | 3.8761 | 3.8766 | | 0.0005 |
| | Taper | 0.0005 | 0.0003 | | |
| 2R | 13mm From Top | 3.8772 | 3.8762 | | 0.0010 |
| | 25mm Above Port | 3.8768 | 3.8765 | 3.8766 | 0.0003 |
| | 25mm Below Port | 3.8766 | 3.8762 | | 0.0004 |
| | 13mm From Bottom | 3.8765 | 3.8769 | | 0.0004 |
| | Taper | 0.0007 | 0.0007 | | |
| 3R | 13mm From Top | 3.8767 | 3.8762 | | 0.0005 |
| | 25mm Above Port | 3.8764 | 3.8761 | 3.8764 | 0.0003 |
| | 25mm Below Port | 3.8764 | 3.8760 | | 0.0004 |
| | 13mm From Bottom | 3.8762 | 3.8769 | | 0.0007 |
| | Taper | 0.0005 | 0.0009 | | |

## Cylinder Bore Diameter Changes, inches

| Cylinder | Depth | Thrust/Anti-Thrust | Front/Back | Avg Bore DIA Change | Out of Round |
|---|---|---|---|---|---|
| 1L | 13mm From Top | 0.0008 | 0.0002 | | 0.0004 |
| | 25mm Above Port | 0.0003 | 0.0001 | 0.0003 | 0.0004 |
| | 25mm Below Port | 0.0002 | 0.0001 | | 0.0001 |
| | 13mm From Bottom | 0.0003 | 0.0001 | | 0.0000 |
| | Taper | 0.0006 | 0.0001 | | |
| 2L | 13mm From Top | 0.0002 | 0.0003 | | 0.0001 |
| | 25mm Above Port | 0.0001 | 0.0000 | 0.0002 | 0.0001 |
| | 25mm Below Port | 0.0002 | 0.0001 | | 0.0001 |
| | 13mm From Bottom | 0.0001 | 0.0002 | | 0.0001 |
| | Taper | 0.0001 | 0.0003 | | |
| 3L | 13mm From Top | 0.0006 | 0.0002 | | 0.0004 |
| | 25mm Above Port | 0.0000 | 0.0000 | 0.0002 | 0.0000 |
| | 25mm Below Port | 0.0001 | 0.0001 | | 0.0000 |
| | 13mm From Bottom | 0.0003 | 0.0002 | | 0.0005 |
| | Taper | 0.0006 | 0.0002 | | |
| 1R | 13mm From Top | 0.0006 | 0.0001 | | 0.0001 |
| | 25mm Above Port | 0.0002 | 0.0003 | 0.0003 | 0.0001 |
| | 25mm Below Port | 0.0002 | 0.0004 | | 0.0002 |
| | 13mm From Bottom | 0.0002 | 0.0005 | | 0.0003 |
| | Taper | 0.0004 | 0.0004 | | |
| 2R | 13mm From Top | 0.0006 | 0.0001 | | 0.0005 |
| | 25mm Above Port | 0.0004 | 0.0004 | 0.0003 | 0.0000 |
| | 25mm Below Port | 0.0004 | 0.0002 | | 0.0002 |
| | 13mm From Bottom | 0.0000 | 0.0004 | | 0.0004 |
| | Taper | 0.0006 | 0.0003 | | |
| 3R | 13mm From Top | 0.0005 | 0.0002 | | 0.0003 |
| | 25mm Above Port | 0.0002 | 0.0002 | 0.0003 | 0.0002 |
| | 25mm Below Port | 0.0004 | 0.0001 | | 0.0003 |
| | 13mm From Bottom | 0.0003 | 0.0003 | | 0.0006 |
| | Taper | 0.0003 | 0.0002 | | |
| Avgerage All Cylinders | 13mm From Top | 0.0006 | 0.0002 | | |
| | 25mm Above Port | 0.0002 | 0.0002 | | |
| | 25mm Below Port | 0.0002 | 0.0002 | | |
| | 13mm From Bottom | 0.0002 | 0.0003 | | |

## Pre-Test Liner Surface Finish, µm

| Pre Test Liner Surface Finish, µm | | | | | |
|---|---|---|---|---|---|
| 1L | 2L | 3L | 1R | 2R | 3R |
| 1.31 | 1.38 | 1.48 | 1.32 | 1.41 | 1.43 |

## Piston Skirt to Bore Clearance, inches

| | Cylinder | Average Bore Diameter | Piston Skirt Diameter | Clearance |
|---|---|---|---|---|
| Pre - Test | 1 | 3.8762 | 3.8705 | 0.0058 |
| | 2 | 3.8763 | 3.8703 | 0.0060 |
| | 3 | 3.8763 | 3.8704 | 0.0059 |
| | 4 | 3.8761 | 3.8704 | 0.0058 |
| | 5 | 3.8763 | 3.8704 | 0.0059 |
| | 6 | 3.8763 | 3.8704 | 0.0059 |
| | | | | |
| Post - Test | 1 | 3.8763 | 3.8704 | 0.0059 |
| | 2 | 3.8764 | 3.8694 | 0.0071 |
| | 3 | 3.8764 | 3.8691 | 0.0073 |
| | 4 | 3.8764 | 3.8696 | 0.0068 |
| | 5 | 3.8766 | 3.8702 | 0.0064 |
| | 6 | 3.8764 | 3.8694 | 0.0070 |
| | | | | |

## Connecting Rod Bearing Mass Change, grams

| Rod Bearing | Shell | Before | After | Change |
|---|---|---|---|---|
| 1L | Top | 73.6495 | 73.6297 | 0.0198 |
| | Bottom | 67.8243 | 67.8210 | 0.0033 |
| 2L | Top | 73.4362 | 73.4133 | 0.0229 |
| | Bottom | 67.7831 | 67.7786 | 0.0045 |
| 3L | Top | 73.4769 | 73.4644 | 0.0125 |
| | Bottom | 67.8587 | 67.8555 | 0.0032 |
| 1R | Top | 73.4915 | 73.4771 | 0.0144 |
| | Bottom | 68.3085 | 68.3036 | 0.0049 |
| 2R | Top | 73.4822 | 73.4681 | 0.0141 |
| | Bottom | 68.1717 | 68.1779 | -0.0062 |
| 3R | Top | 73.2623 | 73.2486 | 0.0137 |
| | Bottom | 69.3699 | 69.3658 | 0.0041 |

| | |
|---|---|
| Maximum | 0.0229 |
| Average | 0.0093 |

## Slipper Bushing Mass Change, grams

| Slipper Bushing | Before | After | Change |
|---|---|---|---|
| 1L | 56.2768 | 56.2085 | 0.0683 |
| 2L | 55.9443 | 55.8420 | 0.1023 |
| 3L | 56.2014 | 56.0414 | 0.1600 |
| 1R | 56.0874 | 56.0086 | 0.0788 |
| 2R | 56.2125 | 56.1151 | 0.0974 |
| 3R | 56.1273 | 55.9975 | 0.1298 |

| | |
|---|---|
| Maximum | 0.1600 |
| Average | 0.1061 |

## Pre-Test Slipper Bushing Tin Plate Thickness, inches

| Slipper Bushing Tin Plate Thickness | | | | | |
|---|---|---|---|---|---|
| 1L | 2L | 3L | 1R | 2R | 3R |
| 0.02370 | 0.02300 | 0.02310 | 0.02330 | 0.02385 | 0.02310 |

## Top, Second, and Third Ring Radial Measurements, inches

| Top Ring | | | | |
|---|---|---|---|---|
| Cylinder | Position | Before | After | Delta |
| 1L | 1 | 0.15950 | 0.15870 | 0.00080 |
| | 2 | 0.15895 | 0.15875 | 0.00020 |
| | 3 | 0.16040 | 0.16005 | 0.00035 |
| | 4 | 0.16025 | 0.16020 | 0.00005 |
| | 5 | 0.15895 | 0.15820 | 0.00075 |
| 2L | 1 | 0.15590 | 0.15510 | 0.00080 |
| | 2 | 0.15550 | 0.15520 | 0.00030 |
| | 3 | 0.15590 | 0.15570 | 0.00020 |
| | 4 | 0.15570 | 0.15550 | 0.00020 |
| | 5 | 0.15690 | 0.15600 | 0.00090 |
| 3L | 1 | 0.15680 | 0.15600 | 0.00080 |
| | 2 | 0.15630 | 0.15590 | 0.00040 |
| | 3 | 0.15905 | 0.15860 | 0.00045 |
| | 4 | 0.15905 | 0.15865 | 0.00040 |
| | 5 | 0.15765 | 0.15655 | 0.00110 |
| 1R | 1 | 0.15630 | 0.15505 | 0.00125 |
| | 2 | 0.15570 | 0.15570 | 0.00000 |
| | 3 | 0.15625 | 0.15590 | 0.00035 |
| | 4 | 0.15655 | 0.15620 | 0.00035 |
| | 5 | 0.15775 | 0.15615 | 0.00160 |
| 2R | 1 | 0.15655 | 0.15560 | 0.00095 |
| | 2 | 0.15660 | 0.15635 | 0.00025 |
| | 3 | 0.15685 | 0.15625 | 0.00060 |
| | 4 | 0.15675 | 0.15640 | 0.00035 |
| | 5 | 0.15690 | 0.15590 | 0.00100 |
| 3R | 1 | 0.15555 | 0.15505 | 0.00050 |
| | 2 | 0.15570 | 0.15555 | 0.00015 |
| | 3 | 0.15655 | 0.15645 | 0.00010 |
| | 4 | 0.15570 | 0.15545 | 0.00025 |
| | 5 | 0.15590 | 0.15535 | 0.00055 |

*Note - Measurements with a negitive delta value, shown in italics, are considered pre-test measurements error

| | |
|---|---|
| Maximum | 0.00160 |
| Average | 0.00053 |

| Second Ring | | | | |
|---|---|---|---|---|
| Cylinder | Position | Before | After | Delta |
| 1L | 1 | 0.14860 | 0.14765 | 0.00095 |
| | 2 | 0.14815 | 0.14740 | 0.00075 |
| | 3 | 0.14840 | 0.14720 | 0.00120 |
| | 4 | 0.14895 | 0.14780 | 0.00115 |
| | 5 | 0.14880 | 0.14780 | 0.00100 |
| 2L | 1 | 0.14590 | 0.14500 | 0.00090 |
| | 2 | 0.14690 | 0.14650 | 0.00040 |
| | 3 | 0.14705 | 0.14650 | 0.00055 |
| | 4 | 0.14620 | 0.14565 | 0.00055 |
| | 5 | 0.14540 | 0.14480 | 0.00060 |
| 3L | 1 | 0.14730 | 0.14655 | 0.00075 |
| | 2 | 0.14750 | 0.14715 | 0.00035 |
| | 3 | 0.17640 | 0.17570 | 0.00070 |
| | 4 | 0.14715 | 0.14675 | 0.00040 |
| | 5 | 0.14735 | 0.14670 | 0.00065 |
| 1R | 1 | 0.14710 | 0.14610 | 0.00100 |
| | 2 | 0.14785 | 0.14720 | 0.00065 |
| | 3 | 0.14670 | 0.14605 | 0.00065 |
| | 4 | 0.14620 | 0.14550 | 0.00070 |
| | 5 | 0.14690 | 0.14610 | 0.00080 |
| 2R | 1 | 0.14680 | 0.14600 | 0.00080 |
| | 2 | 0.14720 | 0.14660 | 0.00060 |
| | 3 | 0.14775 | 0.14700 | 0.00075 |
| | 4 | 0.14895 | 0.14815 | 0.00080 |
| | 5 | 0.14810 | 0.14750 | 0.00060 |
| 3R | 1 | 0.14770 | 0.14720 | 0.00050 |
| | 2 | 0.14815 | 0.14755 | 0.00060 |
| | 3 | 0.14890 | 0.14635 | 0.00255 |
| | 4 | 0.14625 | 0.14590 | 0.00035 |
| | 5 | 0.14685 | 0.14635 | 0.00050 |

*Note - Measurements with a negitive delta value, shown in italics, are considered pre-test measurements error

| | |
|---|---|
| Maximum | 0.00255 |
| Average | 0.00076 |

| Third Ring | | | | |
|---|---|---|---|---|
| Cylinder | Position | Before | After | Delta |
| 1L | 1 | 0.14865 | 0.14805 | 0.00060 |
| | 2 | 0.14950 | 0.14905 | 0.00045 |
| | 3 | 0.14810 | 0.14725 | 0.00085 |
| | 4 | 0.14820 | 0.14745 | 0.00075 |
| | 5 | 0.14830 | 0.14765 | 0.00065 |
| 2L | 1 | 0.14655 | 0.14630 | 0.00025 |
| | 2 | 0.14560 | 0.14540 | 0.00020 |
| | 3 | 0.14625 | 0.14610 | 0.00015 |
| | 4 | 0.14710 | 0.14695 | 0.00015 |
| | 5 | 0.14675 | 0.14635 | 0.00040 |
| 3L | 1 | 0.14730 | 0.14690 | 0.00040 |
| | 2 | 0.14720 | 0.14690 | 0.00030 |
| | 3 | 0.14620 | 0.14575 | 0.00045 |
| | 4 | 0.14675 | 0.14660 | 0.00015 |
| | 5 | 0.14725 | 0.14685 | 0.00040 |
| 1R | 1 | 0.14655 | 0.14620 | 0.00035 |
| | 2 | 0.14790 | 0.14765 | 0.00025 |
| | 3 | 0.14680 | 0.14655 | 0.00025 |
| | 4 | 0.14615 | 0.14580 | 0.00035 |
| | 5 | 0.14655 | 0.14560 | 0.00095 |
| 2R | 1 | 0.14735 | 0.14705 | 0.00030 |
| | 2 | 0.14885 | 0.14855 | 0.00030 |
| | 3 | 0.14855 | 0.14825 | 0.00030 |
| | 4 | 0.14750 | 0.14720 | 0.00030 |
| | 5 | 0.14720 | 0.14685 | 0.00035 |
| 3R | 1 | 0.14800 | 0.14785 | 0.00015 |
| | 2 | 0.14675 | 0.14640 | 0.00035 |
| | 3 | 0.14680 | 0.14650 | 0.00030 |
| | 4 | 0.14820 | 0.14800 | 0.00020 |
| | 5 | 0.14800 | 0.14775 | 0.00025 |

*Note - Measurements with a negitive delta value, shown in italics, are considered pre-test measurements error

| | |
|---|---|
| Maximum | 0.00095 |
| Average | 0.00037 |

## Piston Ring Gap Measurements, inches

| Cylinder | Ring No. | Before | After | Increase |
|---|---|---|---|---|
| 1L | 1 | 0.035 | 0.045 | 0.010 |
| | 2 | 0.025 | 0.038 | 0.013 |
| | 3 | 0.025 | 0.035 | 0.010 |
| | 4 | 0.015 | 0.026 | 0.011 |
| | 5a | 0.013 | 0.021 | 0.008 |
| | 5b | 0.013 | 0.021 | 0.008 |
| 2L | 1 | 0.029 | 0.035 | 0.006 |
| | 2 | 0.027 | 0.035 | 0.008 |
| | 3 | 0.024 | 0.033 | 0.009 |
| | 4 | 0.015 | 0.024 | 0.009 |
| | 5a | 0.013 | 0.020 | 0.007 |
| | 5b | 0.013 | 0.021 | 0.008 |
| 3L | 1 | 0.033 | 0.035 | 0.002 |
| | 2 | 0.025 | 0.033 | 0.008 |
| | 3 | 0.026 | 0.034 | 0.008 |
| | 4 | 0.014 | 0.022 | 0.008 |
| | 5a | 0.013 | 0.020 | 0.007 |
| | 5b | 0.013 | 0.020 | 0.007 |
| 1R | 1 | 0.028 | 0.035 | 0.007 |
| | 2 | 0.026 | 0.035 | 0.009 |
| | 3 | 0.026 | 0.035 | 0.009 |
| | 4 | 0.013 | 0.021 | 0.008 |
| | 5a | 0.015 | 0.021 | 0.006 |
| | 5b | 0.015 | 0.021 | 0.006 |
| 2R | 1 | 0.033 | 0.035 | 0.002 |
| | 2 | 0.027 | 0.035 | 0.008 |
| | 3 | 0.028 | 0.035 | 0.007 |
| | 4 | 0.013 | 0.023 | 0.010 |
| | 5a | 0.014 | 0.022 | 0.008 |
| | 5b | 0.013 | 0.022 | 0.009 |
| 3R | 1 | 0.032 | 0.033 | 0.001 |
| | 2 | 0.026 | 0.033 | 0.007 |
| | 3 | 0.027 | 0.034 | 0.007 |
| | 4 | 0.010 | 0.021 | 0.011 |
| | 5a | 0.013 | 0.022 | 0.009 |
| | 5b | 0.013 | 0.022 | 0.009 |

| | |
|---|---|
| Ring No. 1 max increase | 0.010 |
| Ring No. 2 max increase | 0.013 |
| Ring No. 3 max increase | 0.010 |
| Ring No. 4 max increase | 0.011 |
| Ring No. 5a max increase | 0.009 |
| Ring No. 5b max increase | 0.009 |

| | |
|---|---|
| Ring No. 1 avg increase | 0.005 |
| Ring No. 2 avg increase | 0.009 |
| Ring No. 3 avg increase | 0.008 |
| Ring No. 4 avg increase | 0.010 |
| Ring No. 5a avg increase | 0.008 |
| Ring No. 5b avg increase | 0.008 |

## Piston Ring Mass Measurements, inches

| Cylinder | Ring No. | Before | After | Delta |
|---|---|---|---|---|
| 1L | 1 | 23.5815 | 23.5670 | 0.0145 |
| | 2 | 20.3114 | 20.1974 | 0.1140 |
| | 3 | 20.2918 | 20.2317 | 0.0601 |
| | 4 | 27.4618 | 27.4449 | 0.0169 |
| | 5 | 24.6281 | 24.6040 | 0.0241 |
| 2L | 1 | 22.9939 | 22.9750 | 0.0189 |
| | 2 | 20.0646 | 20.0242 | 0.0404 |
| | 3 | 20.0661 | 20.0536 | 0.0125 |
| | 4 | 27.8223 | 27.8044 | 0.0179 |
| | 5 | 24.0037 | 23.9860 | 0.0177 |
| 3L | 1 | 23.2390 | 23.2242 | 0.0148 |
| | 2 | 20.1780 | 20.1311 | 0.0469 |
| | 3 | 20.1394 | 20.1197 | 0.0197 |
| | 4 | 27.5357 | 27.5178 | 0.0179 |
| | 5 | 24.3062 | 24.2876 | 0.0186 |
| 1R | 1 | 23.0231 | 23.0120 | 0.0111 |
| | 2 | 20.1552 | 20.0835 | 0.0717 |
| | 3 | 20.1442 | 20.1114 | 0.0328 |
| | 4 | 27.5512 | 27.5310 | 0.0202 |
| | 5 | 24.2948 | 24.2740 | 0.0208 |
| 2R | 1 | 23.1091 | 23.0938 | 0.0153 |
| | 2 | 20.2545 | 20.2006 | 0.0539 |
| | 3 | 20.3200 | 20.3009 | 0.0191 |
| | 4 | 27.3550 | 27.3399 | 0.0151 |
| | 5 | 24.3167 | 24.2977 | 0.0190 |
| 3R | 1 | 23.0662 | 23.0567 | 0.0095 |
| | 2 | 20.1822 | 20.1419 | 0.0403 |
| | 3 | 20.2256 | 20.2146 | 0.0110 |
| | 4 | 27.3387 | 27.3213 | 0.0174 |
| | 5 | 24.4991 | 24.4795 | 0.0196 |

| | |
|---|---|
| Ring No. 1 max decrease | 0.0189 |
| Ring No. 2 max decrease | 0.1140 |
| Ring No. 3 max decrease | 0.0601 |
| Ring No. 4 max decrease | 0.0202 |
| Ring No. 5 max decrease | 0.0241 |

| | |
|---|---|
| Ring No. 1 avg decrease | 0.0140 |
| Ring No. 2 avg decrease | 0.0612 |
| Ring No. 3 avg decrease | 0.0259 |
| Ring No. 4 avg decrease | 0.0176 |
| Ring No. 5 avg decrease | 0.0200 |

## Oil Control & Expander Ring Tension, pounds

| | Oil Control & Expander Ring Tension | | | | | |
|---|---|---|---|---|---|---|
| | 1L | 2L | 3L | 1R | 2R | 3R |
| **Top Oil Ring** | 7.7 | 8.3 | 7.5 | 10.7 | 7.7 | 7.7 |
| **Second Oil Ring** | 7.5 | 7.4 | 7.3 | 10.2 | 8 | 8.3 |

***NOTE – To be used as reference only.***
***Measurements taken with non-calibrated legacy equipment.***

## Post Test Engine Ratings

## Piston Ratings, Demerits

| Ratings | Cylinder Number | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1L | 2L | 3L | 1R | 2R | 3R | Avg |
| **Ring Sticking** (F=Free, CS=Cold Stuck, HS=Hot Stuck, CP=Collapsed Ring, No. Denotes % Of Ring Circumference) | | | | | | | |
| Top | F | F | F | F | F | F | -- |
| Second | 25% CS | F | 40% CS | 10% CS | 95% CS | 90% CS | -- |
| Third | F | F | F | F | F | F | -- |
| Oil Control Rings | F | F | F | F | F | F | -- |
| **2nd Ring Carbon** | | | | | | | |
| Heavy Carbon | 26 | 33 | 93 | 70 | 76 | 53 | -- |
| Light Carbon | 74 | 67 | 7 | 30 | 20 | 37 | -- |
| **Piston Carbon, Demerits** | | | | | | | |
| No.1 Groove | 59.50 | 65.25 | 74.50 | 61.75 | 60.50 | 40.50 | 60.33 |
| No.2 Groove | 38.50 | 43.75 | 35.50 | 32.50 | 27.25 | 29.75 | 34.54 |
| No.3 Groove | 25.00 | 25.00 | 25.00 | 25.00 | 23.25 | 23.50 | 24.46 |
| No.1 Land | 35.50 | 45.25 | 41.00 | 48.50 | 30.50 | 40.75 | 40.25 |
| No.2 Land | 55.00 | 64.00 | 51.00 | 60.25 | 61.75 | 50.50 | 57.08 |
| No.3 Land | 20.00 | 0.00 | 13.25 | 10.75 | 9.00 | 10.50 | 10.58 |
| No.4 Land | 6.75 | 11.25 | 10.00 | 6.00 | 2.75 | 4.50 | 6.88 |
| **Piston Lacquer, Demerits** | | | | | | | |
| No.1 Groove | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| No.2 Groove | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.06 | 0.01 |
| No.3 Groove | 0.00 | 0.00 | 0.00 | 0.00 | 0.21 | 0.27 | 0.08 |
| No.1 Land | 0.27 | 0.00 | 0.37 | 0.18 | 0.18 | 0.54 | 0.26 |
| No.2 Land | 0.00 | 0.00 | 0.09 | 0.00 | 0.16 | 0.27 | 0.09 |
| No.3 Land | 0.72 | 0.65 | 1.92 | 2.30 | 2.94 | 3.07 | 1.93 |
| No.4 Land | 2.25 | 1.90 | 1.89 | 2.25 | 3.66 | 3.03 | 2.50 |
| **Total, Demerits** | 243.49 | 257.05 | 254.52 | 249.48 | 222.15 | 207.24 | 238.99 |
| | | | | | | | |
| **Miscellanous** | | | | | | | |
| Top Groove Fill, % | 60 | 65 | 75 | 71 | 46 | 40 | 59.50 |
| Intermediate Groove Fill, % | 73 | 70 | 64 | 57 | 50 | 49 | 60.50 |
| Top Land Heavy Carbon, % | 15 | 27 | 23 | 32 | 8 | 23 | 21.33 |
| Top Lan Flaked Carbon, % | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |

## Ring Face Distress, Demerits

| Cylinder No. | Ring No. | Extreme Distress (1.00) % Area | Heavy Distress (0.75) % Area | Medium Distress (0.50) % Area | Light Distress (0.25) % Area | No Distress (0.00) % Area | Total Demerits |
|---|---|---|---|---|---|---|---|
| **1L** | 1 | | | | 17 | 83 | 0.0425 |
| | 2 | | | | | | 0 |
| | 3 | | | | | | 0 |
| **2L** | 1 | | | 1 | 4 | 95 | 0.015 |
| | 2 | | | | | | 0 |
| | 3 | | | | | | 0 |
| **3L** | 1 | | | | 10 | 90 | 0.025 |
| | 2 | | | | | | 0 |
| | 3 | | | | | | 0 |
| **1R** | 1 | | 3 | 1 | 14 | 82 | 0.0625 |
| | 2 | | | | | | 0 |
| | 3 | | | | | | 0 |
| **2R** | 1 | | | | 8 | 92 | 0.02 |
| | 2 | | | | | | 0 |
| | 3 | | | | | | 0 |
| **3R** | 1 | | | | 3 | 97 | 0.0075 |
| | 2 | | | | | | 0 |
| | 3 | | | | | | 0 |

| Piston Ring Face Distress | Fire Ring | 2nd Ring | 3rd Ring |
|---|---|---|---|
| Average Demerits | 0.0288 | 0.0000 | 0.0000 |

## EOT Cylinder Liner Ratings, % Area

| | Cylinder Liner Ratings | | | | | |
|---|---|---|---|---|---|---|
| | % Scuffing | | Total % Area Scuffed | % Polish | | Total % Area Polished |
| | T | AT | | T | AT | |
| 1L | 0 | 0 | 0 | 8 | 3 | 11 |
| 2L | 0 | 0 | 0 | 0 | 10 | 10 |
| 3L | 0 | 0 | 0 | 7 | 4 | 11 |
| 1R | 0 | 0 | 0 | 2 | 4 | 6 |
| 2R | 0 | 0 | 0 | 3 | 5 | 8 |
| 3R | 0 | 0 | 0 | 6 | 4 | 10 |
| Percent of total ring travel area | | | | | | |

## Periodic Bore Inspection Results, % Area

| Periodic Bore Inspection, % Scuffed Area | | | | |
|---|---|---|---|---|
| **Cyl** | **0hr** | **60hr** | **120hr** | **180hr** |
| **1L** | 0 | 0 | 0 | 0 |
| **2L** | 0 | 0 | 0 | 0 |
| **3L** | 0 | 0 | 0 | 0 |
| **1R** | 0 | 0 | 0 | 0 |
| **2R** | 0 | 0 | 0 | 0 |
| **3R** | 0 | 0 | 0 | 0 |

## Piston Skirt Ratings

| | Piston Skirt Ratings | |
|---|---|---|
| | Thrust | Anti-Thrust |
| 1L | Few Light Scratches, 1% Scuffing | Few Light Scratches, 2% Scuffing |
| 2L | Few Light Scratches | Few Light Scratches |
| 3L | Few Light Scratches | Few Light Scratches |
| 1R | Few Light Scratches | Few Light Scratches |
| 2R | Few Light Scratches | Few Light Scratches |
| 3R | Numerous Light Scratches | Few Light Scratches |

## EOT Intake Port Plugging & Slipper Bushing Exposed Copper, %

| Intake Port Plugging | |
|---|---|
| 1L | 2.5 |
| 2L | 2 |
| 3L | 3 |
| 1R | 0.5 |
| 2R | 1 |
| 3R | 25.5 |
| **Average** | 5.75 |

| Slipper Bushing % Exposed Copper | |
|---|---|
| 1L | 2 |
| 2L | 15 |
| 3L | 10 |
| 1R | 6 |
| 2R | 8 |
| 3R | 12 |
| **Average** | 8.83 |

**PHOTOGRAPHS**

DDC 6V53T - Tracked Vehicle Cycle

| Oil Code: | LO257264 | EOT Date: | 9/13/11 |
|---|---|---|---|
| Test No.: | LO257264-6V53T2-T-240 | Test Length: | 240 |

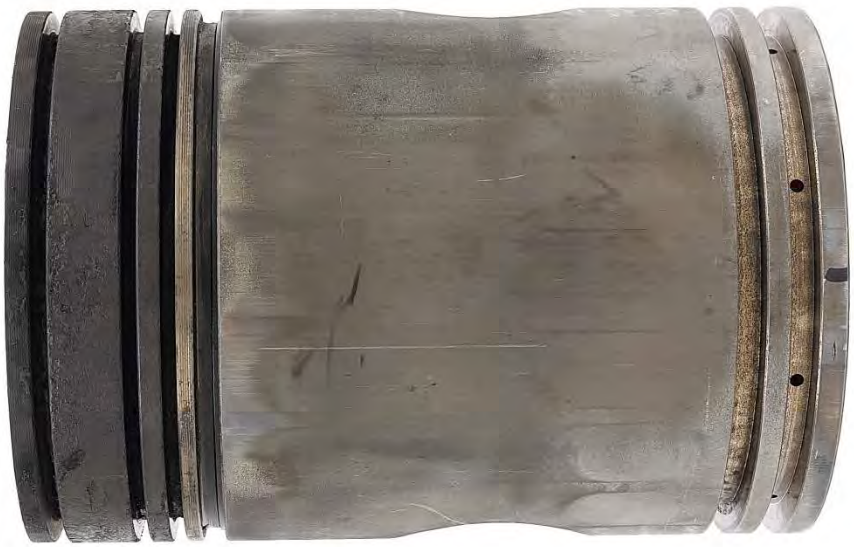
Ring Pack 1 Left

Ring Pack 1 Right

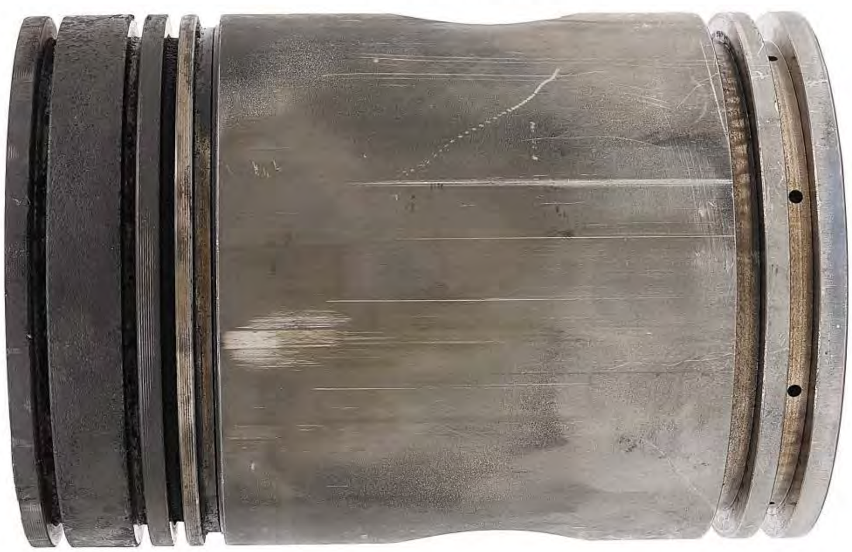
DDC 6V53T - Tracked Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO257264 | **EOT Date:** | 9/13/11 |
| **Test No.:** | LO257264-6V53T2-T-240 | **Test Length:** | 240 |

**Piston 1 Left Thrust**



**Piston 1 Left Anti-thrust**

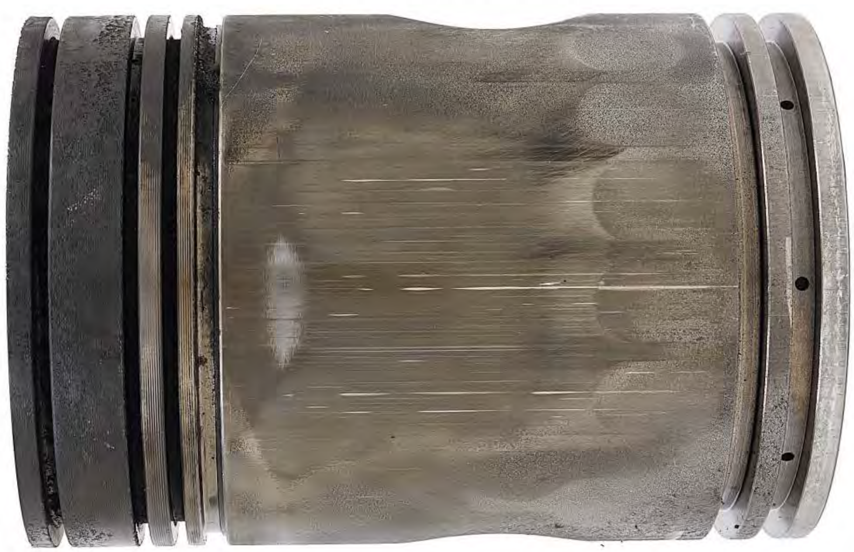


DDC 6V53T - Tracked Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO257264 | **EOT Date:** | 9/13/11 |
| **Test No.:** | LO257264-6V53T2-T-240 | **Test Length:** | 240 |

**Piston 1 Right Thrust**

**Piston 1 Right Anti-thrust**



DDC 6V53T - Tracked Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO257264 | **EOT Date:** | 9/13/11 |
| **Test No.:** | LO257264-6V53T2-T-240 | **Test Length:** | 240 |

**Liner 1 Left Thrust and Anti-thrust**

DDC 6V53T - Tracked Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO257264 | **EOT Date:** | 9/13/11 |
| **Test No.:** | LO257264-6V53T2-T-240 | **Test Length:** | 240 |

**Liner 1 Right Thrust and Anti-thrust**

DDC 6V53T - Tracked Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO257264 | **EOT Date:** | 9/13/11 |
| **Test No.:** | LO257264-6V53T2-T-240 | **Test Length:** | 240 |

Ring Pack 2 Left

Ring Pack 2 Right

DDC 6V53T - Tracked Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO257264 | **EOT Date:** | 9/13/11 |
| **Test No.:** | LO257264-6V53T2-T-240 | **Test Length:** | 240 |

**Piston 2 Left Thrust**

**Piston 2 Left Anti-thrust**

## DDC 6V53T - Tracked Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO257264 | **EOT Date:** | 9/13/11 |
| **Test No.:** | LO257264-6V53T2-T-240 | **Test Length:** | 240 |

**Piston 2 Right Thrust**

**Piston 2 Right Anti-thrust**

DDC 6V53T - Tracked Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO257264 | **EOT Date:** | 9/13/11 |
| **Test No.:** | LO257264-6V53T2-T-240 | **Test Length:** | 240 |

**Liner 2 Left Thrust and Anti-thrust**

| Oil Code: | LO257264 | EOT Date: | 9/13/11 |
|---|---|---|---|
| Test No.: | LO257264-6V53T2-T-240 | Test Length: | 240 |

Liner 2 Right Thrust and Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle

| Oil Code: | LO257264 | EOT Date: | 9/13/11 |
|---|---|---|---|
| Test No.: | LO257264-6V53T2-T-240 | Test Length: | 240 |

Ring Pack 3 Left

Ring Pack 3 Right

DDC 6V53T - Tracked Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO257264 | **EOT Date:** | 9/13/11 |
| **Test No.:** | LO257264-6V53T2-T-240 | **Test Length:** | 240 |

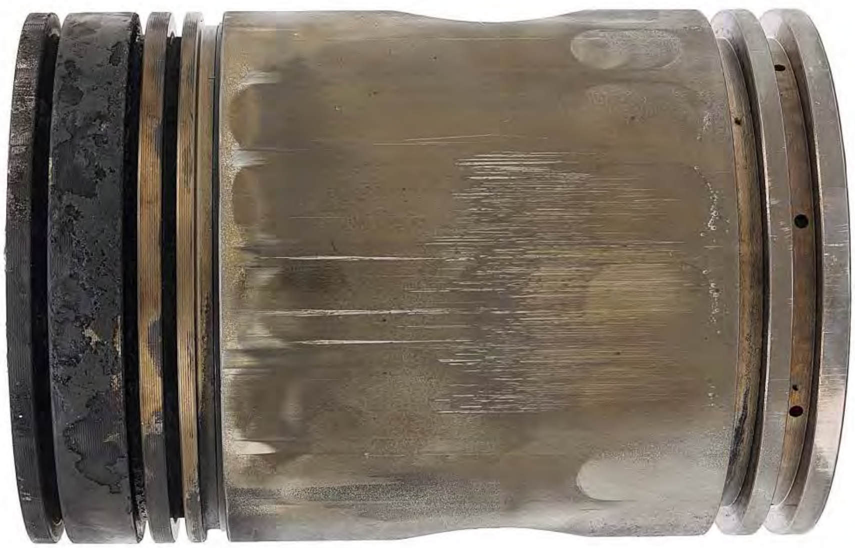
**Piston 3 Left Thrust**

**Piston 3 Left Anti-thrust**

DDC 6V53T - Tracked Vehicle Cycle

| Oil Code: | LO257264 | EOT Date: | 9/13/11 |
|---|---|---|---|
| Test No.: | LO257264-6V53T2-T-240 | Test Length: | 240 |

Piston 3 Right Thrust



Piston 3 Right Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle

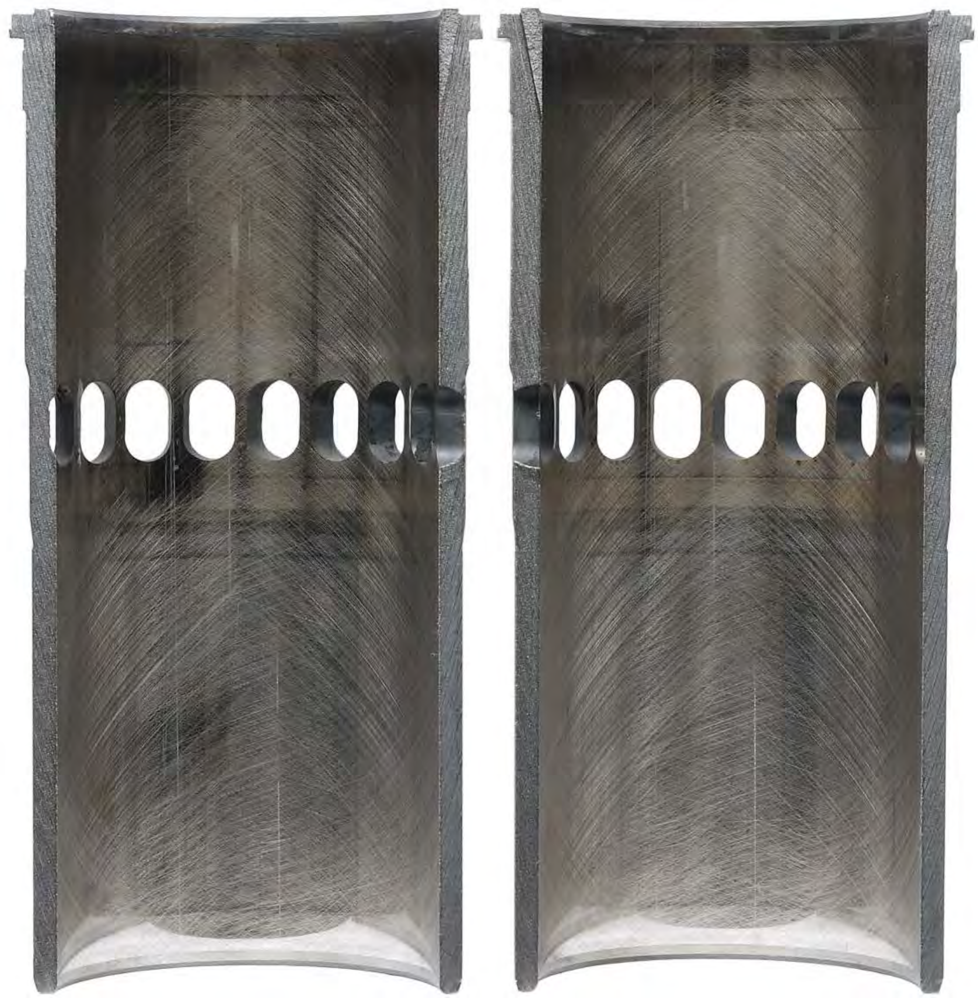
| | | | |
|---|---|---|---|
| **Oil Code:** | LO257264 | **EOT Date:** | 9/13/11 |
| **Test No.:** | LO257264-6V53T2-T-240 | **Test Length:** | 240 |

**Liner 3 Left Thrust and Anti-thrust**

DDC 6V53T - Tracked Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO257264 | **EOT Date:** | 9/13/11 |
| **Test No.:** | LO257264-6V53T2-T-240 | **Test Length:** | 240 |

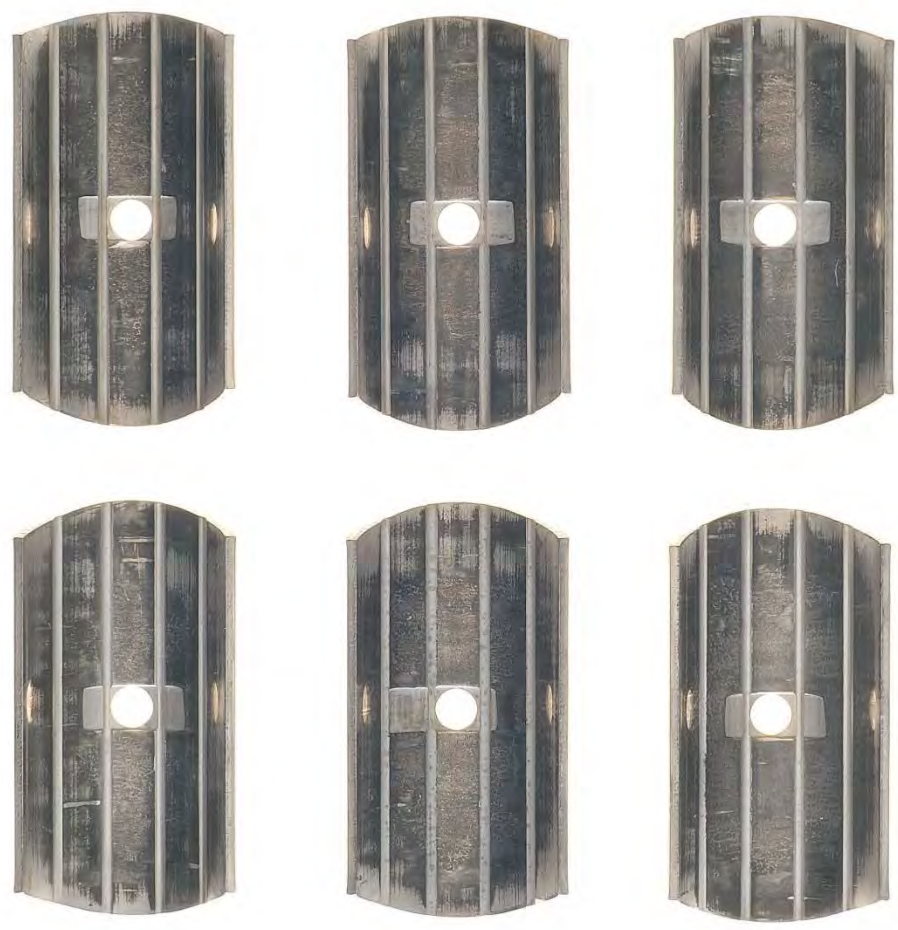
**Liner 3 Right Thrust and Anti-thrust**



DDC 6V53T - Tracked Vehicle Cycle

| Oil Code: | LO257264 | EOT Date: | 9/13/11 |
|---|---|---|---|
| Test No.: | LO257264-6V53T2-T-240 | Test Length: | 240 |

Slipper Bushings 1R, 2R, 3R



Slipper Bushings 1L, 2L, 3L

DDC 6V53T - Tracked Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO257264 | **EOT Date:** | 9/13/11 |
| **Test No.:** | LO257264-6V53T2-T-240 | **Test Length:** | 240 |

**Connecting Rod Bearings**

**Upper 1L, 2L, 3L, 1R, 2R, 3R** **Lower 1L, 2L, 3L, 1R, 2R, 3R**

# APPENDIX – B2
# EVALUATION OF SCPL CANDIDATE
# LO-268869

# EVALUATION OF SCPL CANDIDATE LO-268869

## Project 14734.17

**Detroit Diesel Corporation 6V53T**

**Test Lubricant: LO-268869**
**Test Fuel: Jet-A w/DCI-4A**
**Test Number: LO268869-6V53T1-T-240**
**Start of Test Date: October 11, 2011**
**End of Test Date: October 27, 2011**
**Test Duration: 240 Hours**
**Test Procedure: Tracked Vehicle Engine Cycle**

***Conducted for***

**U.S. Army TARDEC**
**Force Projection Technologies**
**Warren, Michigan**

# Table of Contents

## Introduction

This test was used to determine the performance of SCPL candidate LO268869 when used in the Detroit Diesel Corporation (DDC) 6V53T engine, by the procedures outlined in the Tracked Vehicle Engine Cycle (CRC Report No.406, Development of Military Fuel/Lubricant/Engine Compatibility Test). This work was completed in support of Project 14734.17, Single Common Powertrain Lubricants for Combat/Tactical Equipment.

## Test Engine

The oil was evaluated in the DDC 6V53T turbo-supercharged diesel engine representative of engines currently fielded in the M113 Armored Personnel Carrier (APC). Prior to testing, the engine was rebuilt using premeasured cylinder kits and rod bearings to provide a known starting condition for post test wear measurements. Engine clearances and specifications were verified, and the engine was assembled following standard assembly procedures.

## Test Stand Configuration

The engine was mounted in a test stand specifically configured for DDC engine testing. Engine monitoring, control, and data acquisition was supplied by Southwest Research Institute (SwRI) developed PRISM software. An appropriately sized absorption dynamometer was used to supply engine loading. Engine oil and coolant temperatures were controlled with the use of liquid-to-liquid heat exchangers. Engine intake air was supplied at ambient conditions, and inlet fuel temperature was controlled through an auxiliary fuel heater loop.

## Test Procedure

The procedure outline below is followed in sequential order for each lubricant test in the DDC 6V53T engine.

- Initial Oil Flush:
  -Engine is charged with fresh test oil and a new filter (not weighed).
  -Engine operated at 1200 rpm and 88 lb-ft load until engine and oil temperatures stabilize.
  -Engine shut down and oil charge drained to remove and solvent left from engine rebuild

- Engine Run In:
  -Engine is charged with fresh test oil and a new filter (weighed and recorded)
  -Engine is started and run-in following procedures outline below.
  -Immediately after run-in is complete, a no-load governor check is completed (2950-3030rpm). If engine governed speed is out of spec, adjust and retest.

**Table 1 - Test Engine Run-In Procedure**

| Engine Speed [RPM] | Load [lb-ft] | Power (Observed) [bhp] | Duration [min] |
|---|---|---|---|
| 1000 | None commanded | -- | 10 |
| 2800 | None commanded | -- | 30 |
| 1800 | 88 | 30 | 15 |
| 2200 | 310 | 130 | 30 |
| 2500 | 420 | 200 | 30 |
| 2800 | 422 | 225 | 30 |

- Engine Shake Down:
  -Engine operated for 5hrs at 2800 rpm and 390 lb-ft load
  -After shakedown is complete, engine output is checked at max power and torque load points
  -Completed using run-in oil charge

- Pre Test Engine Powercurve:
  -Full load engine power is mapped over entire speed range in 200 rpm increments
  -Completed using run-in oil charge. Once complete, engine oil charge is drained and recorded.

- Testing:
  -Engine is charged with fresh test oil and a new filter (weighed and recorded)
  -Engine is operated on test for 240hrs. Test termination can be determined early due to severe piston/liner scuffing, or upon major oil degradation.
  -Oil samples collected daily for used oil analysis
  -Airbox inspections take place at 0, 60, 120, and 180 hours.

- Post Test Engine Powercurve:
  -Full load engine power is mapped over entire speed range in 200 rpm increments
  -Completed using test oil charge. Once complete, engine oil charge is drained and recorded.

## Test Cycle

The test cycle followed during oil evaluation was the standard 240 hr Tracked Vehicle Engine Cycle as outlined in CRC Report No. 406, Development of Military Fuel/Lubricant/Engine Compatibility Test. Test termination would occur at the completion of 240 hrs. Early test termination could be called due to severe oil degradation, or upon experiencing major piston and liner scuffing during the test. The test cycle consists of cyclic modes alternating between idle, max power, and max torque load points. Total daily runtime consisted of 20hrs of operation followed by a 4hr engine off soak period. The cyclic mode consisted of the following modes repeated 4 times daily: 30 minutes at idle speed, 2 hours at max power, 30 minutes of idle speed, 2 hours at max torque. Multiple engine parameters were controlled throughout testing to ensure test consistency, and are specified below in Table 2.

**Table 2 - Test Cycle Operating Parameters**

| Parameter | Max Power | Max Torque | Idle |
|---|---|---|---|
| Speed [rpm] | 2800 +/- 25 | 1600 +/- 25 | 950 +/- 25 |
| Water Jacket Out [°F] | 170 +/- 5 | 170 +/- 5 | 170 +/- 5 |
| Inlet Fuel [°F] | 100 +/- 5 | 100 +/- 5 | 100 +/- 5 |
| Oil Sump [°F] | 245 +/- 5 | 230 +/- 5 | NS (190) |

Engine coolant was a 60/40 blend of ethylene glycol antifreeze and deionized water. Test fuel was Jet-A with the max treat rate of corrosion inhibitor/lubricity enhancer DCI-4A.

## Oil Sampling

Four ounces of engine oil was sampled every 20 hrs for used oil analysis. Engine oil analysis consisted of the following tests outlined in Table 3. All oil samples were weighed and logged to take into account during calculations of total engine oil consumption for the test duration.

**Table 3 - Used Oil Analysis Procedures**

| Daily Used Oil Analysis | |
|---|---|
| ASTM D445 | Kinematic Viscosity @ 100°C |
| ASTM D5185 | Wear Metals by ICP |
| ASTM D4739 | Total Base Number |
| ASTM D664 | Total Acid Number |

Used oil analysis results can be seen in the engine oil analysis section of the report.

## Oil Level Checks

Engine oil level was checked daily and replenished as needed to restore oil level to full mark. This process occurred daily after the completion of the 4hr soak prior to restarting testing. All oil additions were weighed and logged to take into account during calculation of total engine oil consumption for the test duration.

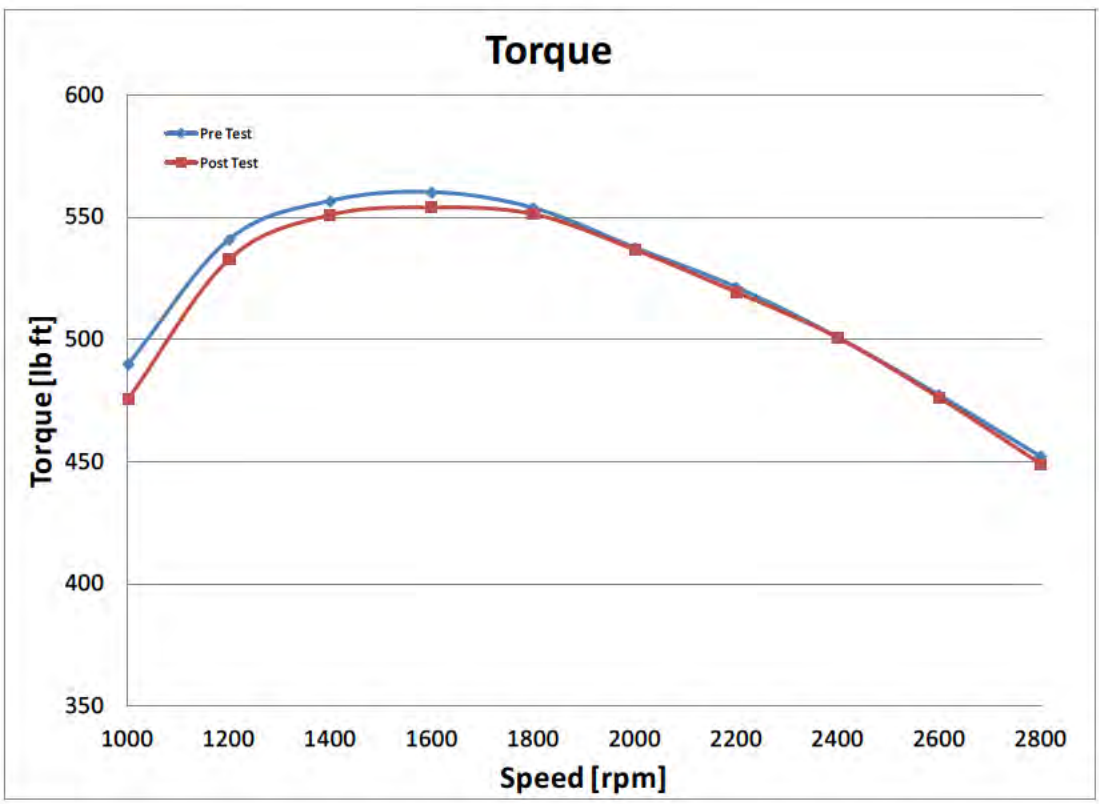
## Engine Operating Conditions Summary

Below is a summary of the engine operating conditions over the test duration. The complete 240hr test schedule was completed by the lubricant.

| | | Peak Power (2800 RPM) | | Peak Torque (1600 RPM) | | Idle Conditions (950 RPM) | |
|---|---|---|---|---|---|---|---|
| **Perameter:** | **Units:** | **Average** | **Std. Dev.** | **Average** | **Std. Dev.** | **Average** | **Std. Dev.** |
| Engine Speed | RPM | 2799.86 | 5.69 | 1600.06 | 4.94 | 870.25 | 4.75 |
| Torque* | ft*lb | 462.47 | 42.57 | 565.71 | 36.31 | -- | -- |
| Fuel Flow | lb/hr | 92.03 | 1.26 | 63.85 | 0.92 | 2.61 | 0.44 |
| Power* | bhp | 246.50 | 22.22 | 172.32 | 10.55 | -- | -- |
| BSFC* | lb/bhp*hr | 0.376 | 0.034 | 0.372 | 0.023 | -- | -- |
| Engine Blowby | acfm | 8.93 | 1.77 | 6.62 | 0.78 | 3.78 | 0.70 |
| Relative Humidity | % | 42.78 | 17.10 | 44.25 | 17.58 | 44.75 | 17.57 |
| **Temperatures:** | | | | | | | |
| Coolant In | °F | 160.61 | 1.46 | 158.70 | 1.59 | 163.64 | 9.19 |
| Coolant Out | °F | 170.00 | 1.30 | 169.99 | 1.39 | 166.22 | 9.40 |
| Oil Galley | °F | 218.88 | 2.35 | 210.04 | 1.04 | 189.01 | 15.46 |
| Oil Sump | °F | 245.00 | 0.46 | 230.00 | 0.41 | 192.28 | 15.96 |
| Fuel In | °F | 100.00 | 0.81 | 100.05 | 0.82 | 99.88 | 2.50 |
| Dry Bulb | °F | 81.24 | 6.86 | 80.18 | 7.74 | 78.82 | 7.32 |
| Intake Air | °F | 76.89 | 3.87 | 75.73 | 3.12 | 75.51 | 2.40 |
| Air After Turbo | °F | 281.87 | 4.15 | 202.44 | 3.01 | 83.06 | 3.08 |
| Air After Supercharger | °F | 270.02 | 3.98 | 198.63 | 2.90 | 142.50 | 12.39 |
| Cylinder 1 Exhaust | °F | 785.51 | 8.26 | 617.25 | 6.39 | 202.98 | 9.61 |
| Cylinder 2 Exhaust | °F | 846.25 | 9.05 | 722.13 | 6.27 | 214.73 | 10.06 |
| Cylinder 3 Exhaust | °F | 803.45 | 9.09 | 692.67 | 6.50 | 189.46 | 9.15 |
| Cylinder 4 Exhaust | °F | 804.89 | 9.06 | 660.59 | 11.71 | 190.13 | 12.14 |
| Cylinder 5 Exhaust | °F | 889.94 | 10.22 | 847.96 | 12.15 | 200.92 | 11.06 |
| Cylinder 6 Exhaust | °F | 834.71 | 7.65 | 798.13 | 9.95 | 181.75 | 10.54 |
| Exhaust Exit Left | °F | 876.29 | 8.52 | 854.90 | 8.43 | 194.56 | 10.30 |
| Exhaust Exit Right | °F | 867.27 | 9.68 | 802.86 | 9.25 | 209.61 | 9.45 |
| Exhaust After Turbo | °F | 760.36 | 262.35 | 803.02 | 318.79 | 389.43 | 476.98 |
| **Pressures:** | | | | | | | |
| Oil Galley | psiG | 41.09 | 1.09 | 26.24 | 0.80 | 14.95 | 2.43 |
| Ambient Pressure | psiA | 14.36 | 0.06 | 14.35 | 0.06 | 14.36 | 0.06 |
| Pressure After Turbo | psiG | 20.08 | 0.44 | 11.27 | 0.26 | 0.21 | 0.32 |
| Pressure After Supercharger | psiG | 22.26 | 0.47 | 10.86 | 0.27 | 0.55 | 0.14 |
| Pressure Exhaust Left | psiG | 19.25 | 0.38 | 9.97 | 0.21 | 0.40 | 0.11 |
| Pressure Exhaust Right | psiG | 18.31 | 0.34 | 9.43 | 0.17 | 0.44 | 0.09 |
| Pressure Exhaust After Turbo | psiG | 0.66 | 0.16 | 0.06 | 0.04 | -0.01 | 0.07 |
| Fuel Pressure | psiG | 30.55 | 2.33 | 12.01 | 1.75 | 4.67 | 0.40 |

* Non-corrected Values

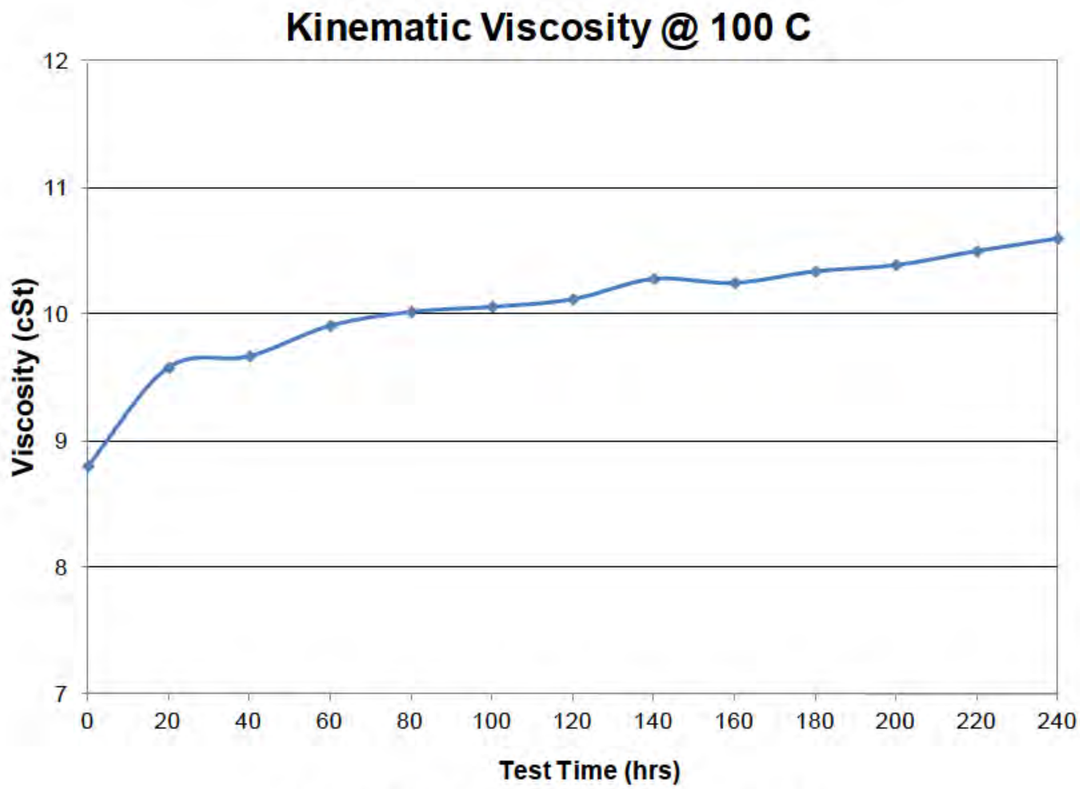
**Engine Performance Curves**

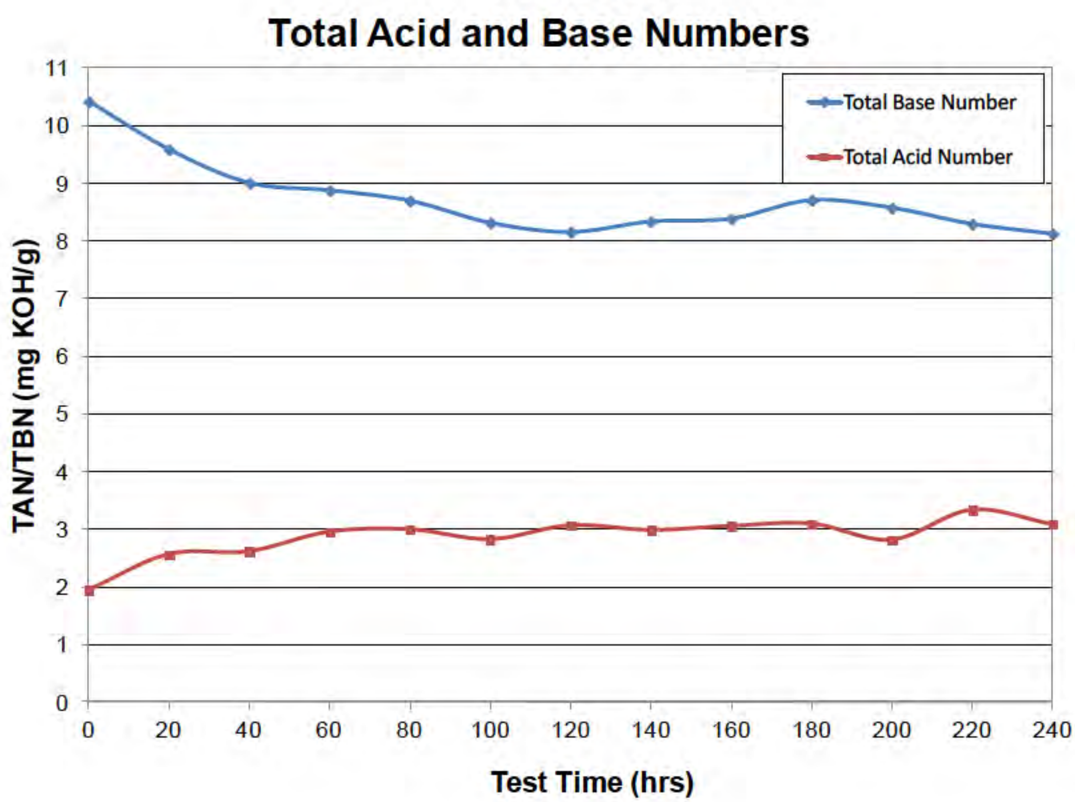



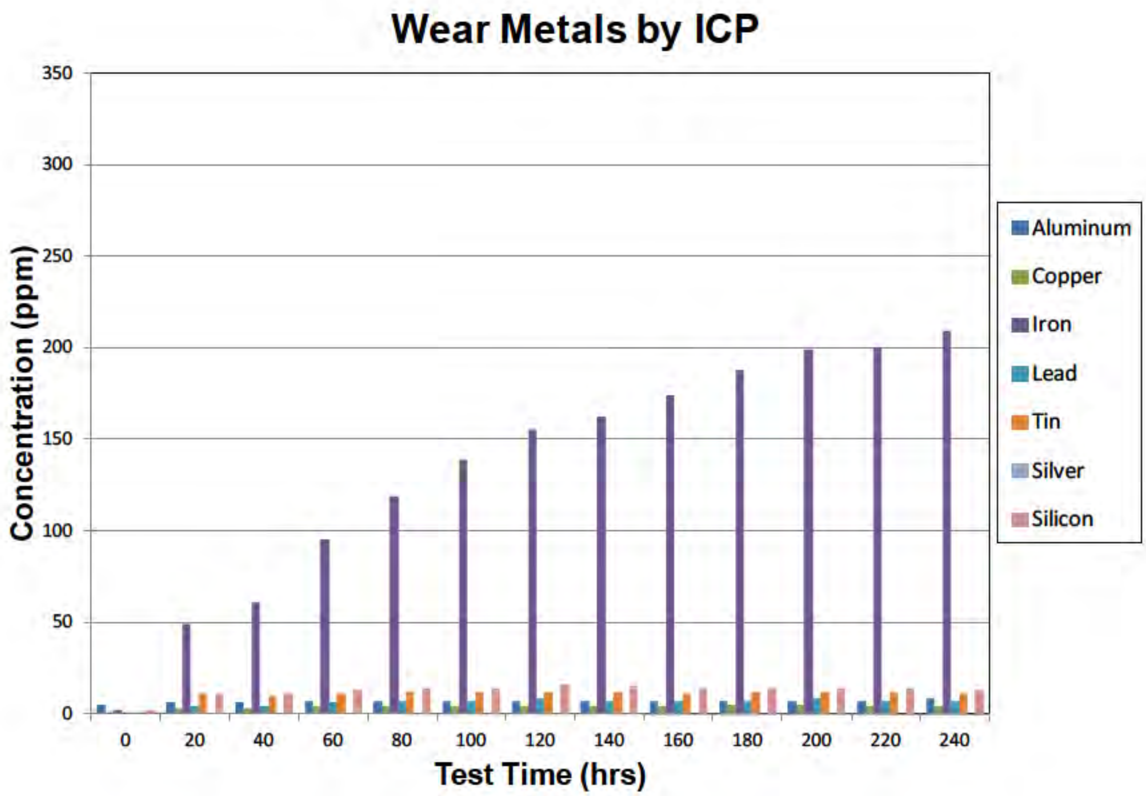
# Engine Oil Analysis

| Property | ASTM Test | Test Hours | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 20 | 40 | 60 | 80 | 100 | 120 | 140 | 160 | 180 | 200 | 220 | 240 |
| Viscosity @ 100°C (cSt) | D445 | 8.8 | 9.6 | 9.7 | 9.9 | 10.0 | 10.1 | 10.1 | 10.3 | 10.3 | 10.3 | 10.4 | 10.5 | 10.6 |
| Total Base Number (mg KOH/g) | D4739 | 10.4 | 9.6 | 9.0 | 8.9 | 8.7 | 8.3 | 8.2 | 8.3 | 8.4 | 8.7 | 8.6 | 8.3 | 8.1 |
| Total Acid Number (mg KOH/g) | D664 | 1.9 | 2.6 | 2.6 | 3.0 | 3.0 | 2.8 | 3.1 | 3.0 | 3.1 | 3.1 | 2.8 | 3.3 | 3.1 |
| Wear Metals (ppm) | D5185 | | | | | | | | | | | | | |
| Al | | 5 | 6 | 6 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 8 |
| Sb | | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Ba | | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| B | | <1 | <1 | 2 | <1 | <1 | <1 | 1 | 2 | 2 | <1 | 2 | <1 | <1 |
| Ca | | 3563 | 3744 | 3710 | 3700 | 3762 | 3911 | 3912 | 3843 | 4152 | 3993 | 3987 | 3968 | 4134 |
| Cr | | <1 | 2 | 2 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 4 | 5 |
| Cu | | <1 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 5 | 4 | 4 |
| Fe | | 2 | 49 | 61 | 95 | 119 | 139 | 155 | 162 | 174 | 188 | 199 | 200 | 209 |
| Pb | | <1 | 4 | 4 | 6 | 7 | 7 | 8 | 7 | 7 | 7 | 8 | 7 | 7 |
| Mg | | 11 | 19 | 15 | 15 | 13 | 16 | 14 | 15 | 13 | 15 | 14 | 13 | 14 |
| Mn | | <1 | <1 | <1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Mo | | <1 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 11 | 12 | 12 | 12 | 13 |
| Ni | | <1 | <1 | <1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 |
| P | | 1314 | 1271 | 1251 | 1249 | 1172 | 1244 | 1209 | 1199 | 1187 | 1226 | 1216 | 1182 | 1261 |
| Si | | 2 | 11 | 11 | 13 | 14 | 14 | 16 | 15 | 14 | 14 | 14 | 14 | 13 |
| Ag | | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Na | | 6 | 9 | 8 | 9 | 8 | 10 | 10 | 8 | 9 | 8 | 9 | 8 | 9 |
| Sn | | <1 | 11 | 10 | 11 | 12 | 12 | 12 | 12 | 11 | 12 | 12 | 12 | 11 |
| Zn | | 1863 | 1873 | 1870 | 1913 | 1902 | 1930 | 1887 | 1907 | 1929 | 1935 | 1927 | 1952 | 1906 |
| K | | 8 | 8 | 11 | 9 | 11 | 9 | 9 | 8 | 10 | 9 | 9 | 9 | 10 |
| Sr | | 1 | 1 | 2 | 1 | 2 | 2 | <1 | 2 | 2 | 1 | 2 | 2 | <1 |
| V | | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Ti | | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Cd | | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |

<u>**Engine Oil Analysis Trends**</u>





Wear Metals by ICP
Concentration (ppm)
350
300
250
200
150
100
50
0
0
20
40
60
80
100
120
140
160
180
200
220
240
Test Time (hrs)
Aluminum
Copper
Iron
Lead
Tin
Silver
Silicon

## Oil Consumption Data

Average oil consumption per test hour was 0.359 lbs/hr.

| | Additions (lbs) | Samples (lbs) | Consumption (lbs) | Consumption Accumulated |
|---|---|---|---|---|
| **20 hr** | 8.8 | 0.2 | 8.6 | 8.6 |
| **40 hr** | 7.44 | 0.22 | 7.22 | 15.82 |
| **60 hr** | 8.76 | 0.22 | 8.54 | 24.36 |
| **80 hr** | 8.32 | 0.23 | 8.09 | 32.45 |
| **100 hr** | 6.96 | 0.23 | 6.73 | 39.18 |
| **120 hr** | 7.98 | 0.22 | 7.76 | 46.94 |
| **140 hr** | 6.81 | 0.22 | 6.59 | 53.53 |
| **160 hr** | 6.02 | 0.23 | 5.79 | 59.32 |
| **180 hr** | 7.34 | 0.23 | 7.11 | 66.43 |
| **200 hr** | 7.32 | 0.23 | 7.09 | 73.52 |
| **220 hr** | 7.29 | 0.22 | 7.07 | 80.59 |
| **240 hr** | 8.4 | 0.23 | 8.17 | 88.76 |

| | | | |
|---|---|---|---|
| **Initial Fill** | 33.6 | **Total Additions** | 91.44 |
| **EOT Drain** | 36.17 | **Total Samples** | 2.68 |

| | |
|---|---|
| (Initial Fill + Additions) | 125.04 |
| (EOT Drain + Samples) | 38.85 |
| **Total Oil Consumption** | 86.19 |

# Engine Measurements

## Pre-Test Cylinder Bore Measurements, inches

| Cylinder | Depth | Thrust/Anti-Thrust | Front/Back | Avg Bore DIA | Out of Round |
|---|---|---|---|---|---|
| 1L | 13mm From Top | 3.8761 | 3.8762 | | 0.0001 |
| | 25mm Above Port | 3.8764 | 3.8762 | 3.8762 | 0.0002 |
| | 25mm Below Port | 3.8763 | 3.8757 | | 0.0006 |
| | 13mm From Bottom | 3.8766 | 3.8763 | | 0.0003 |
| | Taper | 0.0005 | 0.0006 | | |
| 2L | 13mm From Top | 3.8763 | 3.8763 | | 0.0000 |
| | 25mm Above Port | 3.8762 | 3.8762 | 3.8762 | 0.0000 |
| | 25mm Below Port | 3.8760 | 3.8760 | | 0.0000 |
| | 13mm From Bottom | 3.8766 | 3.8763 | | 0.0003 |
| | Taper | 0.0006 | 0.0003 | | |
| 3L | 13mm From Top | 3.8762 | 3.8761 | | 0.0001 |
| | 25mm Above Port | 3.8760 | 3.8760 | 3.8760 | 0.0000 |
| | 25mm Below Port | 3.8759 | 3.8757 | | 0.0002 |
| | 13mm From Bottom | 3.8760 | 3.8762 | | 0.0002 |
| | Taper | 0.0003 | 0.0005 | | |
| 1R | 13mm From Top | 3.8763 | 3.8763 | | 0.0000 |
| | 25mm Above Port | 3.8761 | 3.8761 | 3.8763 | 0.0000 |
| | 25mm Below Port | 3.8760 | 3.8760 | | 0.0000 |
| | 13mm From Bottom | 3.8765 | 3.8767 | | 0.0002 |
| | Taper | 0.0005 | 0.0007 | | |
| 2R | 13mm From Top | 3.8766 | 3.8761 | | 0.0005 |
| | 25mm Above Port | 3.8765 | 3.8761 | 3.8763 | 0.0004 |
| | 25mm Below Port | 3.8762 | 3.8759 | | 0.0003 |
| | 13mm From Bottom | 3.8766 | 3.8765 | | 0.0001 |
| | Taper | 0.0004 | 0.0006 | | |
| 3R | 13mm From Top | 3.8766 | 3.8762 | | 0.0004 |
| | 25mm Above Port | 3.8764 | 3.8762 | 3.8763 | 0.0002 |
| | 25mm Below Port | 3.8762 | 3.8760 | | 0.0002 |
| | 13mm From Bottom | 3.8764 | 3.8765 | | 0.0001 |
| | Taper | 0.0004 | 0.0005 | | |

## Post-Test Cylinder Bore Measurements, inches

| Cylinder | Depth | Thrust/Anti-Thrust | Front/Back | Avg Bore DIA | Out of Round |
|---|---|---|---|---|---|
| 1L | 13mm From Top | 3.8776 | 3.8763 | | 0.0013 |
| | 25mm Above Port | 3.8768 | 3.8763 | 3.8766 | 0.0005 |
| | 25mm Below Port | 3.8765 | 3.8760 | | 0.0005 |
| | 13mm From Bottom | 3.8766 | 3.8766 | | 0.0000 |
| | Taper | 0.0011 | 0.0006 | | |
| 2L | 13mm From Top | 3.8770 | 3.8765 | | 0.0005 |
| | 25mm Above Port | 3.8765 | 3.8763 | 3.8765 | 0.0002 |
| | 25mm Below Port | 3.8763 | 3.8763 | | 0.0000 |
| | 13mm From Bottom | 3.8766 | 3.8766 | | 0.0000 |
| | Taper | 0.0007 | 0.0003 | | |
| 3L | 13mm From Top | N/A | N/A | | N/A |
| | 25mm Above Port | N/A | N/A | N/A | N/A |
| | 25mm Below Port | N/A | N/A | | N/A |
| | 13mm From Bottom | N/A | N/A | | N/A |
| | Taper | 0.0000 | 0.0000 | | |
| 1R | 13mm From Top | 3.8770 | 3.8764 | | 0.0006 |
| | 25mm Above Port | 3.8765 | 3.8764 | 3.8766 | 0.0001 |
| | 25mm Below Port | 3.8763 | 3.8763 | | 0.0000 |
| | 13mm From Bottom | 3.8765 | 3.8770 | | 0.0005 |
| | Taper | 0.0007 | 0.0007 | | |
| 2R | 13mm From Top | 3.8770 | 3.8763 | | 0.0007 |
| | 25mm Above Port | 3.8767 | 3.8761 | 3.8765 | 0.0006 |
| | 25mm Below Port | 3.8767 | 3.8761 | | 0.0006 |
| | 13mm From Bottom | 3.8765 | 3.8768 | | 0.0003 |
| | Taper | 0.0005 | 0.0007 | | |
| 3R | 13mm From Top | 3.8771 | 3.8763 | | 0.0008 |
| | 25mm Above Port | 3.8766 | 3.8763 | 3.8765 | 0.0003 |
| | 25mm Below Port | 3.8765 | 3.8761 | | 0.0004 |
| | 13mm From Bottom | 3.8763 | 3.8765 | | 0.0002 |
| | Taper | 0.0008 | 0.0004 | | |

## Cylinder Bore Diameter Changes, inches

| Cylinder | Depth | Thrust/Anti-Thrust | Front/Back | Avg Bore DIA Change | Out of Round |
|---|---|---|---|---|---|
| 1L | 13mm From Top | 0.0015 | 0.0001 | | 0.0012 |
| | 25mm Above Port | 0.0004 | 0.0001 | 0.0004 | 0.0003 |
| | 25mm Below Port | 0.0002 | 0.0003 | | 0.0001 |
| | 13mm From Bottom | 0.0000 | 0.0003 | | 0.0003 |
| | Taper | 0.0015 | 0.0002 | | |
| 2L | 13mm From Top | 0.0007 | 0.0002 | | 0.0005 |
| | 25mm Above Port | 0.0003 | 0.0001 | 0.0003 | 0.0002 |
| | 25mm Below Port | 0.0003 | 0.0003 | | 0.0000 |
| | 13mm From Bottom | 0.0000 | 0.0003 | | 0.0003 |
| | Taper | 0.0007 | 0.0002 | | |
| 3L | 13mm From Top | N/A | N/A | | N/A |
| | 25mm Above Port | N/A | N/A | N/A | N/A |
| | 25mm Below Port | N/A | N/A | | N/A |
| | 13mm From Bottom | N/A | N/A | | N/A |
| | Taper | N/A | N/A | | |
| 1R | 13mm From Top | 0.0007 | 0.0001 | | 0.0006 |
| | 25mm Above Port | 0.0004 | 0.0003 | 0.0003 | 0.0001 |
| | 25mm Below Port | 0.0003 | 0.0003 | | 0.0000 |
| | 13mm From Bottom | 0.0000 | 0.0003 | | 0.0003 |
| | Taper | 0.0007 | 0.0002 | | |
| 2R | 13mm From Top | 0.0004 | 0.0002 | | 0.0002 |
| | 25mm Above Port | 0.0002 | 0.0000 | 0.0002 | 0.0002 |
| | 25mm Below Port | 0.0005 | 0.0002 | | 0.0003 |
| | 13mm From Bottom | 0.0001 | 0.0003 | | 0.0002 |
| | Taper | 0.0004 | 0.0003 | | |
| 3R | 13mm From Top | 0.0005 | 0.0001 | | 0.0004 |
| | 25mm Above Port | 0.0002 | 0.0001 | 0.0002 | 0.0001 |
| | 25mm Below Port | 0.0003 | 0.0001 | | 0.0002 |
| | 13mm From Bottom | 0.0001 | 0.0000 | | 0.0001 |
| | Taper | 0.0004 | 0.0001 | | |
| Avgerage All Cylinders | 13mm From Top | 0.0008 | 0.0001 | | |
| | 25mm Above Port | 0.0003 | 0.0001 | | |
| | 25mm Below Port | 0.0003 | 0.0002 | | |
| | 13mm From Bottom | 0.0000 | 0.0002 | | |

## Pre-Test Liner Surface Finish, µm

| Pre Test Liner Surface Finish, µm | | | | | |
|---|---|---|---|---|---|
| 1L | 2L | 3L | 1R | 2R | 3R |
| 1.46 | 1.33 | 1.46 | 1.49 | 1.31 | 1.32 |

## Piston Skirt to Bore Clearance, inches

| | Cylinder | Average Bore Diameter | Piston Skirt Diameter | Clearance |
|---|---|---|---|---|
| Pre - Test | 1 | 3.8762 | 3.8707 | 0.0056 |
| | 2 | 3.8762 | 3.8717 | 0.0046 |
| | 3 | 3.8760 | 3.8712 | 0.0048 |
| | 4 | 3.8763 | 3.8696 | 0.0067 |
| | 5 | 3.8763 | 3.8705 | 0.0058 |
| | 6 | 3.8763 | 3.8700 | 0.0063 |
| | | | | |
| Post - Test | 1 | 3.8766 | 3.8698 | 0.0068 |
| | 2 | 3.8765 | 3.8700 | 0.0065 |
| | 3 | N/A | 3.8699 | N/A |
| | 4 | 3.8766 | 3.8688 | 0.0078 |
| | 5 | 3.8765 | 3.8693 | 0.0072 |
| | 6 | 3.8765 | 3.8696 | 0.0069 |
| | | | | |

## Connecting Rod Bearing Mass Change, grams

| Rod Bearing | Shell | Before | After | Change |
|---|---|---|---|---|
| 1L | Top | 73.5096 | 73.4845 | 0.0251 |
| | Bottom | 68.4050 | 68.3979 | 0.0071 |
| 2L | Top | 73.5891 | 73.5602 | 0.0289 |
| | Bottom | 67.9048 | 67.9006 | 0.0042 |
| 3L | Top | 73.5592 | 73.5377 | 0.0215 |
| | Bottom | 68.0659 | 68.0599 | 0.0060 |
| 1R | Top | 73.7570 | 73.7359 | 0.0211 |
| | Bottom | 67.8936 | 67.8878 | 0.0058 |
| 2R | Top | 73.5076 | 73.4869 | 0.0207 |
| | Bottom | 67.9593 | 67.9563 | 0.0030 |
| 3R | Top | 73.4451 | 73.4258 | 0.0193 |
| | Bottom | 67.8821 | 67.8766 | 0.0055 |

| | |
|---|---|
| Maximum | 0.0289 |
| Average | 0.0140 |

## Slipper Bushing Mass Change, grams

| Slipper Bushing | Before | After | Change |
|---|---|---|---|
| 1L | 56.1310 | 55.9758 | 0.1552 |
| 2L | 56.0567 | 55.9313 | 0.1254 |
| 3L | 56.0873 | 55.9811 | 0.1062 |
| 1R | 56.0515 | 55.8908 | 0.1607 |
| 2R | 56.0870 | 55.9288 | 0.1582 |
| 3R | 55.7503 | 55.5740 | 0.1763 |

| | |
|---|---|
| Maximum | 0.1763 |
| Average | 0.1470 |

## Pre-Test Slipper Bushing Tin Plate Thickness, inches

| Slipper Bushing Tin Plate Thickness | | | | | |
|---|---|---|---|---|---|
| 1L | 2L | 3L | 1R | 2R | 3R |
| 0.02355 | 0.02350 | 0.02350 | 0.02245 | 0.02300 | 0.02340 |

# Top, Second, and Third Ring Radial Measurements, inches

| Top Ring | | | | |
|---|---|---|---|---|
| **Cylinder** | **Position** | **Before** | **After** | **Delta** |
| **1L** | 1 | 0.15650 | 0.15520 | 0.00130 |
| | 2 | 0.15585 | 0.15510 | 0.00075 |
| | 3 | 0.15635 | 0.15555 | 0.00080 |
| | 4 | 0.15575 | 0.15485 | 0.00090 |
| | 5 | 0.15685 | 0.15535 | 0.00150 |
| **2L** | 1 | 0.15650 | 0.15565 | 0.00085 |
| | 2 | 0.15800 | 0.15760 | 0.00040 |
| | 3 | 0.15695 | 0.15665 | 0.00030 |
| | 4 | 0.15635 | 0.15600 | 0.00035 |
| | 5 | 0.15720 | 0.15635 | 0.00085 |
| **3L** | 1 | 0.15755 | 0.15620 | 0.00135 |
| | 2 | 0.15620 | 0.15560 | 0.00060 |
| | 3 | 0.15630 | 0.15595 | 0.00035 |
| | 4 | 0.15645 | 0.15600 | 0.00045 |
| | 5 | 0.15750 | 0.15610 | 0.00140 |
| **1R** | 1 | 0.15650 | 0.15525 | 0.00125 |
| | 2 | 0.15625 | 0.15575 | 0.00050 |
| | 3 | 0.15760 | 0.15710 | 0.00050 |
| | 4 | 0.15750 | 0.15705 | 0.00045 |
| | 5 | 0.15685 | 0.15550 | 0.00135 |
| **2R** | 1 | 0.15465 | 0.15365 | 0.00100 |
| | 2 | 0.15500 | 0.15455 | 0.00045 |
| | 3 | 0.15645 | 0.15610 | 0.00035 |
| | 4 | 0.15690 | 0.15650 | 0.00040 |
| | 5 | 0.15620 | 0.15555 | 0.00065 |
| **3R** | 1 | 0.15545 | 0.15395 | 0.00150 |
| | 2 | 0.15460 | 0.15375 | 0.00085 |
| | 3 | 0.15595 | 0.15530 | 0.00065 |
| | 4 | 0.15675 | 0.15590 | 0.00085 |
| | 5 | 0.15610 | 0.15570 | 0.00040 |
| *Note - Measurements with a negitive delta value, shown in italics, are considered pre-test measurements error | | | | |

| | |
|---|---|
| Maximum | 0.00150 |
| Average | 0.00078 |

| Second Ring | | | | |
|---|---|---|---|---|
| **Cylinder** | **Position** | **Before** | **After** | **Delta** |
| **1L** | 1 | 0.14690 | 0.14570 | 0.00120 |
| | 2 | 0.14775 | 0.14660 | 0.00115 |
| | 3 | 0.14735 | 0.14615 | 0.00120 |
| | 4 | 0.14680 | 0.14580 | 0.00100 |
| | 5 | 0.14730 | 0.14625 | 0.00105 |
| **2L** | 1 | 0.14660 | 0.14590 | 0.00070 |
| | 2 | 0.14840 | 0.14765 | 0.00075 |
| | 3 | 0.14725 | 0.14640 | 0.00085 |
| | 4 | 0.14695 | 0.14625 | 0.00070 |
| | 5 | 0.14685 | 0.14605 | 0.00080 |
| **3L** | 1 | 0.14725 | 0.14615 | 0.00110 |
| | 2 | 0.14785 | 0.14665 | 0.00120 |
| | 3 | 0.17860 | 0.14760 | 0.03100 |
| | 4 | 0.14850 | 0.14760 | 0.00090 |
| | 5 | 0.14735 | 0.14625 | 0.00110 |
| **1R** | 1 | 0.14670 | 0.14530 | 0.00140 |
| | 2 | 0.14745 | 0.14655 | 0.00090 |
| | 3 | 0.14750 | 0.14640 | 0.00110 |
| | 4 | 0.14645 | 0.14540 | 0.00105 |
| | 5 | 0.14625 | 0.14470 | 0.00155 |
| **2R** | 1 | 0.14670 | 0.14610 | 0.00060 |
| | 2 | 0.14810 | 0.14745 | 0.00065 |
| | 3 | 0.14755 | 0.14675 | 0.00080 |
| | 4 | 0.14745 | 0.14690 | 0.00055 |
| | 5 | 0.14710 | 0.14640 | 0.00070 |
| **3R** | 1 | 0.14795 | 0.14695 | 0.00100 |
| | 2 | 0.14720 | 0.14645 | 0.00075 |
| | 3 | 0.14635 | 0.14525 | 0.00110 |
| | 4 | 0.14700 | 0.14600 | 0.00100 |
| | 5 | 0.14775 | 0.14655 | 0.00120 |
| *Note - Measurements with a negitive delta value, shown in italics, are considered pre-test measurements error | | | | |

| | |
|---|---|
| Maximum | 0.03100 |
| Average | 0.00197 |

| Third Ring | | | | |
|---|---|---|---|---|
| **Cylinder** | **Position** | **Before** | **After** | **Delta** |
| **1L** | 1 | 0.14665 | 0.14590 | 0.00075 |
| | 2 | 0.14705 | 0.14635 | 0.00070 |
| | 3 | 0.14755 | 0.14675 | 0.00080 |
| | 4 | 0.14680 | 0.14630 | 0.00050 |
| | 5 | 0.14660 | 0.14590 | 0.00070 |
| **2L** | 1 | 0.14665 | 0.14620 | 0.00045 |
| | 2 | 0.14760 | 0.14710 | 0.00050 |
| | 3 | 0.14765 | 0.14730 | 0.00035 |
| | 4 | 0.14705 | 0.14680 | 0.00025 |
| | 5 | 0.14690 | 0.14650 | 0.00040 |
| **3L** | 1 | 0.14800 | 0.14745 | 0.00055 |
| | 2 | 0.14735 | 0.14700 | 0.00035 |
| | 3 | 0.14785 | 0.14745 | 0.00040 |
| | 4 | 0.14845 | 0.14805 | 0.00040 |
| | 5 | 0.14830 | 0.14775 | 0.00055 |
| **1R** | 1 | 0.14795 | 0.14710 | 0.00085 |
| | 2 | 0.14730 | 0.14700 | 0.00030 |
| | 3 | 0.14610 | 0.14560 | 0.00050 |
| | 4 | 0.14670 | 0.14610 | 0.00060 |
| | 5 | 0.14725 | 0.14585 | 0.00140 |
| **2R** | 1 | 0.14720 | 0.14680 | 0.00040 |
| | 2 | 0.14730 | 0.14705 | 0.00025 |
| | 3 | 0.14740 | 0.14715 | 0.00025 |
| | 4 | 0.14815 | 0.14790 | 0.00025 |
| | 5 | 0.14745 | 0.14710 | 0.00035 |
| **3R** | 1 | 0.14650 | 0.14585 | 0.00065 |
| | 2 | 0.14770 | 0.14720 | 0.00050 |
| | 3 | 0.14775 | 0.14710 | 0.00065 |
| | 4 | 0.14635 | 0.14545 | 0.00090 |
| | 5 | 0.14645 | 0.14550 | 0.00095 |
| *Note - Measurements with a negitive delta value, shown in italics, are considered pre-test measurements error | | | | |

| | |
|---|---|
| Maximum | 0.00140 |
| Average | 0.00055 |

## Piston Ring Gap Measurements, inches

| Cylinder | Ring No. | Before | After | Increase |
|---|---|---|---|---|
| 1L | 1 | 0.041 | 0.045 | 0.004 |
| | 2 | 0.028 | 0.039 | 0.011 |
| | 3 | 0.030 | 0.037 | 0.007 |
| | 4 | 0.019 | 0.025 | 0.006 |
| | 5a | 0.016 | 0.022 | 0.006 |
| | 5b | 0.017 | 0.024 | 0.007 |
| 2L | 1 | 0.030 | 0.035 | 0.005 |
| | 2 | 0.031 | 0.038 | 0.007 |
| | 3 | 0.031 | 0.036 | 0.005 |
| | 4 | 0.019 | 0.025 | 0.006 |
| | 5a | 0.017 | 0.022 | 0.005 |
| | 5b | 0.017 | 0.022 | 0.005 |
| 3L | 1 | 0.032 | 0.035 | 0.003 |
| | 2 | 0.029 | 0.039 | 0.010 |
| | 3 | 0.030 | 0.035 | 0.005 |
| | 4 | 0.018 | 0.023 | 0.005 |
| | 5a | 0.017 | 0.023 | 0.006 |
| | 5b | 0.017 | 0.023 | 0.006 |
| 1R | 1 | 0.031 | 0.036 | 0.005 |
| | 2 | 0.030 | 0.040 | 0.010 |
| | 3 | 0.030 | 0.037 | 0.007 |
| | 4 | 0.017 | 0.022 | 0.005 |
| | 5a | 0.017 | 0.024 | 0.007 |
| | 5b | 0.018 | 0.025 | 0.007 |
| 2R | 1 | 0.031 | 0.037 | 0.006 |
| | 2 | 0.029 | 0.036 | 0.007 |
| | 3 | 0.029 | 0.034 | 0.005 |
| | 4 | 0.016 | 0.021 | 0.005 |
| | 5a | 0.018 | 0.024 | 0.006 |
| | 5b | 0.017 | 0.023 | 0.006 |
| 3R | 1 | 0.031 | 0.036 | 0.005 |
| | 2 | 0.031 | 0.040 | 0.009 |
| | 3 | 0.031 | 0.038 | 0.007 |
| | 4 | 0.018 | 0.024 | 0.006 |
| | 5a | 0.019 | 0.025 | 0.006 |
| | 5b | 0.018 | 0.024 | 0.006 |

| | |
|---|---|
| Ring No. 1 max increase | 0.006 |
| Ring No. 2 max increase | 0.011 |
| Ring No. 3 max increase | 0.007 |
| Ring No. 4 max increase | 0.006 |
| Ring No. 5a max increase | 0.007 |
| Ring No. 5b max increase | 0.007 |

| | |
|---|---|
| Ring No. 1 avg increase | 0.005 |
| Ring No. 2 avg increase | 0.009 |
| Ring No. 3 avg increase | 0.006 |
| Ring No. 4 avg increase | 0.006 |
| Ring No. 5a avg increase | 0.006 |
| Ring No. 5b avg increase | 0.006 |

## Piston Ring Mass Measurements, inches

| Cylinder | Ring No. | Before | After | Delta |
|---|---|---|---|---|
| 1L | 1 | 22.8443 | 22.8093 | 0.0350 |
| | 2 | 20.1878 | 20.0504 | 0.1374 |
| | 3 | 20.1517 | 20.0781 | 0.0736 |
| | 4 | 27.4218 | 27.4054 | 0.0164 |
| | 5 | 24.3984 | 24.3678 | 0.0306 |
| 2L | 1 | 23.1662 | 23.1421 | 0.0241 |
| | 2 | 20.2026 | 20.1275 | 0.0751 |
| | 3 | 20.1997 | 20.1747 | 0.0250 |
| | 4 | 27.4120 | 27.3898 | 0.0222 |
| | 5 | 24.3628 | 24.3300 | 0.0328 |
| 3L | 1 | 23.0348 | 23.0003 | 0.0345 |
| | 2 | 20.3096 | 20.1994 | 0.1102 |
| | 3 | 20.2840 | 20.2455 | 0.0385 |
| | 4 | 27.4054 | 27.3867 | 0.0187 |
| | 5 | 24.3822 | 24.3542 | 0.0280 |
| 1R | 1 | 23.2131 | 23.1834 | 0.0297 |
| | 2 | 20.1729 | 20.0421 | 0.1308 |
| | 3 | 20.1572 | 20.0988 | 0.0584 |
| | 4 | 27.4500 | 27.4267 | 0.0233 |
| | 5 | 24.3835 | 24.3523 | 0.0312 |
| 2R | 1 | 22.9615 | 22.9389 | 0.0226 |
| | 2 | 20.1967 | 20.1415 | 0.0552 |
| | 3 | 20.2070 | 20.1898 | 0.0172 |
| | 4 | 27.5839 | 27.5625 | 0.0214 |
| | 5 | 24.4885 | 24.4558 | 0.0327 |
| 3R | 1 | 22.9341 | 22.9020 | 0.0321 |
| | 2 | 20.1809 | 20.0737 | 0.1072 |
| | 3 | 20.1792 | 20.1151 | 0.0641 |
| | 4 | 27.3799 | 27.3598 | 0.0201 |
| | 5 | 27.2522 | 27.2059 | 0.0463 |

| | |
|---|---|
| Ring No. 1 max decrease | 0.0350 |
| Ring No. 2 max decrease | 0.1374 |
| Ring No. 3 max decrease | 0.0736 |
| Ring No. 4 max decrease | 0.0233 |
| Ring No. 5 max decrease | 0.0463 |

| | |
|---|---|
| Ring No. 1 avg decrease | 0.0297 |
| Ring No. 2 avg decrease | 0.1026 |
| Ring No. 3 avg decrease | 0.0461 |
| Ring No. 4 avg decrease | 0.0203 |
| Ring No. 5 avg decrease | 0.0336 |

## Oil Control & Expander Ring Tension, pounds

| | Oil Control & Expander Ring Tension | | | | | |
|---|---|---|---|---|---|---|
| | 1L | 2L | 3L | 1R | 2R | 3R |
| **Top Oil Ring** | 7.1 | 7.4 | 7.2 | 7.8 | 8.5 | 7.5 |
| **Second Oil Ring** | 7.6 | 8.0 | 8.1 | 8.4 | 8.1 | 8.0 |

***NOTE – To be used as reference only.***
***Measurements taken with non-calibrated legacy equipment.***

## Post Test Engine Ratings

### Piston Ratings, Demerits

| Ratings | Cylinder Number | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1L | 2L | 3L | 1R | 2R | 3R | Avg |
| **Ring Sticking** (F=Free, CS=Cold Stuck, HS=Hot Stuck, CP=Collapsed Ring, No. Denotes % Of Ring Circumference) | | | | | | | |
| Top | F | F | F | F | F | F | -- |
| Second | F | CS 5% | CS 10% | F | F | F | -- |
| Third | F | F | F | F | F | F | -- |
| Oil Control Rings | F | F | F | F | F | F | -- |
| **2nd Ring Carbon** | | | | | | | |
| Heavy Carbon | 62 | 10 | 78 | 5 | 4 | 40 | -- |
| Light Carbon | 38 | 90 | 22 | 46 | 86 | 60 | -- |
| **Piston Carbon, Demerits** | | | | | | | |
| No.1 Groove | 48.00 | 57.50 | 73.50 | 72.50 | 66.75 | 57.25 | 62.58 |
| No.2 Groove | 42.25 | 26.50 | 37.75 | 37.75 | 36.25 | 30.25 | 35.13 |
| No.3 Groove | 25.00 | 23.00 | 25.00 | 25.00 | 16.50 | 25.00 | 23.25 |
| No.1 Land | 40.75 | 42.25 | 54.25 | 28.75 | 43.00 | 34.00 | 40.50 |
| No.2 Land | 59.50 | 61.00 | 65.50 | 63.25 | 59.50 | 50.50 | 59.88 |
| No.3 Land | 15.75 | 17.00 | 17.00 | 20.50 | 20.50 | 10.00 | 16.79 |
| No.4 Land | 10.00 | 3.00 | 7.50 | 6.75 | 2.50 | 8.75 | 6.42 |
| **Piston Lacquer, Demerits** | | | | | | | |
| No.1 Groove | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| No.2 Groove | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| No.3 Groove | 0.00 | 0.22 | 0.00 | 0.00 | 1.64 | 0.00 | 0.31 |
| No.1 Land | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| No.2 Land | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| No.3 Land | 1.64 | 1.25 | 1.12 | 1.38 | 1.21 | 2.52 | 1.52 |
| No.4 Land | 1.97 | 3.12 | 2.00 | 2.33 | 3.32 | 2.69 | 2.57 |
| **Total, Demerits** | 244.86 | 234.84 | 283.62 | 258.21 | 251.17 | 220.96 | 248.94 |
| | | | | | | | |
| **Miscellanous** | | | | | | | |
| Top Groove Fill, % | 47 | 55 | 76 | 77 | 60 | 57 | 62.00 |
| Intermediate Groove Fill, % | 55 | 60 | 70 | 59 | 57 | 52 | 58.83 |
| Top Land Heavy Carbon, % | 21 | 23 | 39 | 5 | 24 | 12 | 20.67 |
| Top Lan Flaked Carbon, % | 1 | 0 | 0 | 0 | 0 | 0 | 0.17 |

## Ring Face Distress, Demerits

| Cylinder No. | Ring No. | Extreme Distress (1.00) % Area | Heavy Distress (0.75) % Area | Medium Distress (0.50) % Area | Light Distress (0.25) % Area | No Distress (0.00) % Area | Total Demerits |
|---|---|---|---|---|---|---|---|
| 1L | 1 | | | | 7 | 93 | 0.0175 |
| | 2 | | | | | | 0 |
| | 3 | | | | | | 0 |
| 2L | 1 | | | | 8 | 92 | 0.02 |
| | 2 | | | | | | 0 |
| | 3 | | | | | | 0 |
| 3L | 1 | | | | 5 | 95 | 0.0125 |
| | 2 | | | | | | 0 |
| | 3 | | | | | | 0 |
| 1R | 1 | | | | 10 | 90 | 0.025 |
| | 2 | | | | | | 0 |
| | 3 | | | | | | 0 |
| 2R | 1 | | | | 9 | 91 | 0.0225 |
| | 2 | | | | | | 0 |
| | 3 | | | | | | 0 |
| 3R | 1 | | | | 22 | 78 | 0.055 |
| | 2 | | | | | | 0 |
| | 3 | | | | | | 0 |

| Piston Ring Face Distress | Fire Ring | 2nd Ring | 3rd Ring |
|---|---|---|---|
| Average Demerits | 0.0254 | 0.0000 | 0.0000 |

## EOT Cylinder Liner Ratings, % Area

| | Cylinder Liner Ratings | | | | | |
|---|---|---|---|---|---|---|
| | % Scuffing | | Total % Area Scuffed | % Polish | | Total % Area Polished |
| | T | AT | | T | AT | |
| 1L | 0 | 0 | 0 | 15 | 4 | 19 |
| 2L | 0 | 0 | 0 | 10 | 12 | 22 |
| 3L | 0 | 0 | 0 | 5 | 2 | 7 |
| 1R | 0 | 0 | 0 | 5 | 2 | 7 |
| 2R | 0 | 0 | 0 | 2 | 7 | 9 |
| 3R | 0 | 0 | 0 | 4 | 2 | 6 |
| Percent of total ring travel area | | | | | | |

## Periodic Bore Inspection Results, % Area

| Periodic Bore Inspection, % Scuffed Area | | | | |
|---|---|---|---|---|
| **Cyl** | **0hr** | **60hr** | **120hr** | **180hr** |
| **1L** | 0 | 0 | 0 | 0 |
| **2L** | 0 | 0 | 0 | 0 |
| **3L** | 0 | 0 | 3 | 3 |
| **1R** | 0 | 0 | 0 | 0 |
| **2R** | 0 | 0 | 0 | 0 |
| **3R** | 0 | 0 | 0 | 0 |

## Piston Skirt Ratings

| | Piston Skirt Ratings | |
|---|---|---|
| | Thrust | Anti-Thrust |
| 1L | Few Light Scratches & 1% Scuffing | Few Light Scratches |
| 2L | Few Light Scratches | Few Light Scratches |
| 3L | Few Light Scratches | Few Very Light Scratches |
| 1R | Few Light Scratches | Few Light Scratches & 1% Scuffing |
| 2R | Few Light Scratches | Few Light Scratches & 1% Scuffing |
| 3R | Few Very Light Scratches | Few Light Scraches & 1% Scuffing |

## EOT Intake Port Plugging & Slipper Bushing Exposed Copper, %

| Intake Port Plugging | |
|---|---|
| 1L | 2 |
| 2L | 2 |
| 3L | 3 |
| 1R | 3 |
| 2R | 2 |
| 3R | 3 |
| **Average** | 2.5 |

| Slipper Bushing % Exposed Copper | |
|---|---|
| 1L | 1 |
| 2L | 1 |
| 3L | 2 |
| 1R | 2 |
| 2R | 1 |
| 3R | 2 |
| **Average** | 1.50 |

**PHOTOGRAPHS**

DDC 6V53T - Tracked Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO268869 | **EOT Date:** | 10/27/11 |
| **Test No.:** | LO268869-6V53T1-T-240 | **Test Length:** | 240 |

Ring Pack 1 Left

Ring Pack 1 Right

DDC 6V53T - Tracked Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO268869 | **EOT Date:** | 10/27/11 |
| **Test No.:** | LO268869-6V53T1-T-240 | **Test Length:** | 240 |

**Piston 1 Left Thrust**

**Piston 1 Left Anti-thrust**

DDC 6V53T - Tracked Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO268869 | **EOT Date:** | 10/27/11 |
| **Test No.:** | LO268869-6V53T1-T-240 | **Test Length:** | 240 |

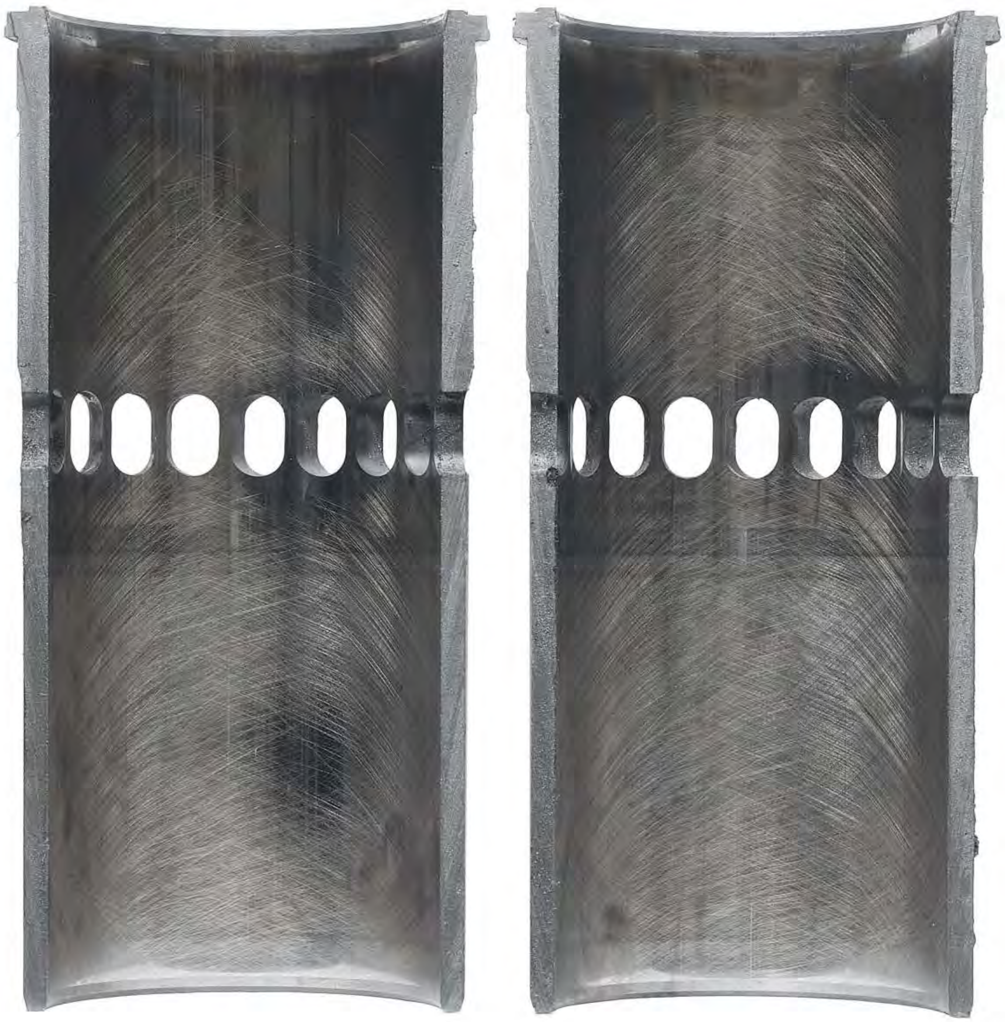
**Piston 1 Right Thrust**

**Piston 1 Right Anti-thrust**

DDC 6V53T - Tracked Vehicle Cycle

| Oil Code: | LO268869 | EOT Date: | 10/27/11 |
|---|---|---|---|
| Test No.: | LO268869-6V53T1-T-240 | Test Length: | 240 |

Liner 1 Left Thrust and Anti-thrust



DDC 6V53T - Tracked Vehicle Cycle

| Oil Code: | LO268869 | EOT Date: | 10/27/11 |
|---|---|---|---|
| Test No.: | LO268869-6V53T1-T-240 | Test Length: | 240 |

Liner 1 Right Thrust and Anti-thrust

**DDC 6V53T - Tracked Vehicle Cycle**

| | | | |
|---|---|---|---|
| **Oil Code:** | LO268869 | **EOT Date:** | 10/27/11 |
| **Test No.:** | LO268869-6V53T1-T-240 | **Test Length:** | 240 |

**Ring Pack 2 Left**

**Ring Pack 2 Right**

DDC 6V53T - Tracked Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO268869 | **EOT Date:** | 10/27/11 |
| **Test No.:** | LO268869-6V53T1-T-240 | **Test Length:** | 240 |

**Piston 2 Left Thrust**

**Piston 2 Left Anti-thrust**

DDC 6V53T - Tracked Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO268869 | **EOT Date:** | 10/27/11 |
| **Test No.:** | LO268869-6V53T1-T-240 | **Test Length:** | 240 |

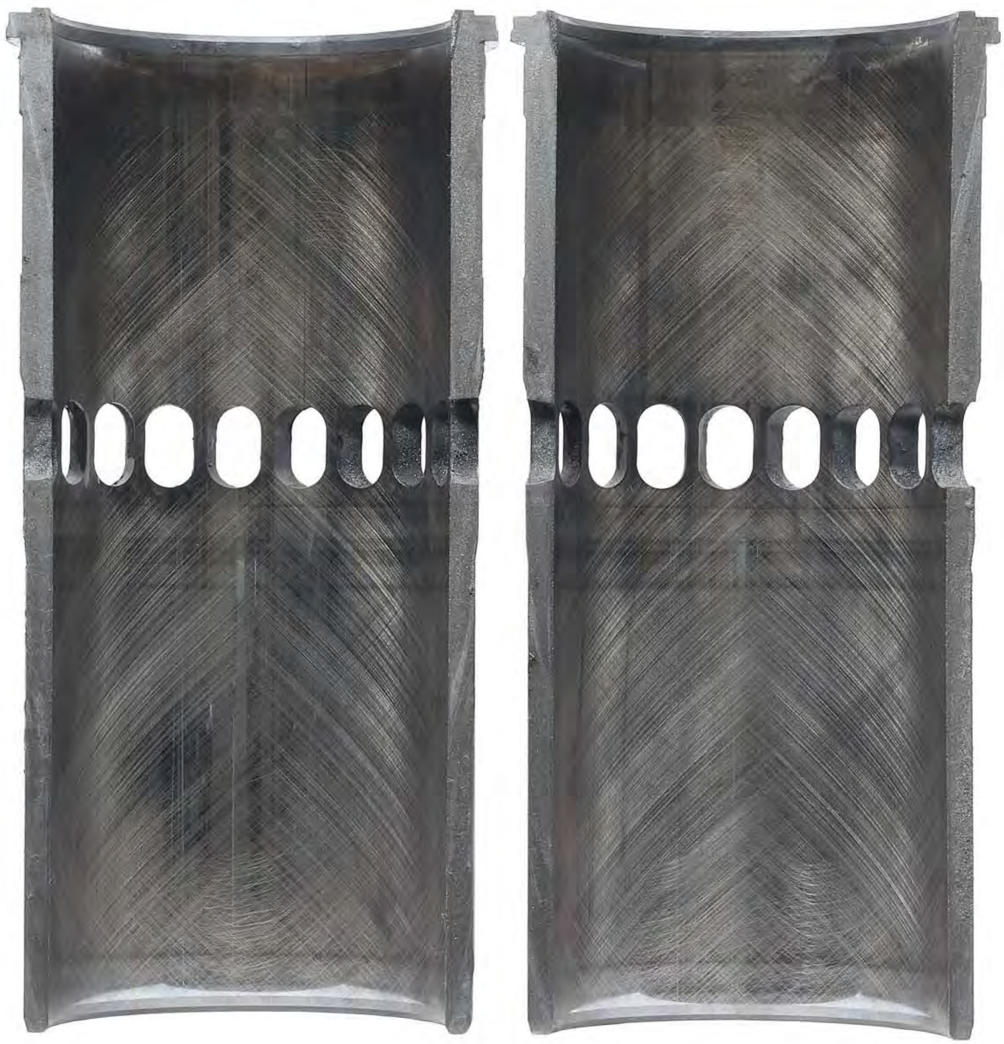
**Piston 2 Right Thrust**

**Piston 2 Right Anti-thrust**

DDC 6V53T - Tracked Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO268869 | **EOT Date:** | 10/27/11 |
| **Test No.:** | LO268869-6V53T1-T-240 | **Test Length:** | 240 |

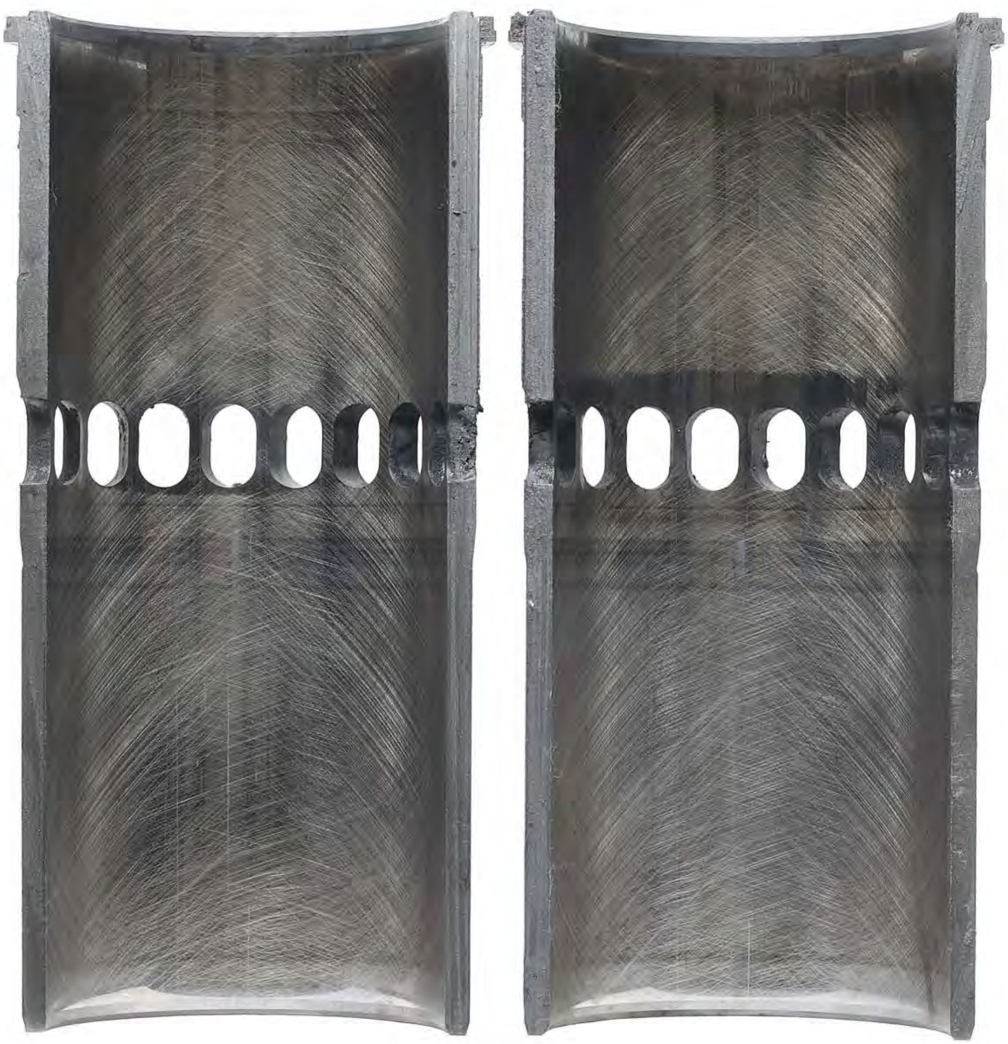
**Liner 2 Left Thrust and Anti-thrust**



DDC 6V53T - Tracked Vehicle Cycle

| Oil Code: | LO268869 | EOT Date: | 10/27/11 |
|---|---|---|---|
| Test No.: | LO268869-6V53T1-T-240 | Test Length: | 240 |

Liner 2 Right Thrust and Anti-thrust



DDC 6V53T - Tracked Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO268869 | **EOT Date:** | 10/27/11 |
| **Test No.:** | LO268869-6V53T1-T-240 | **Test Length:** | 240 |

**Ring Pack 3 Left**

**Ring Pack 3 Right**

| Oil Code: | LO268869 | EOT Date: | 10/27/11 |
|---|---|---|---|
| Test No.: | LO268869-6V53T1-T-240 | Test Length: | 240 |

Piston 3 Left Thrust

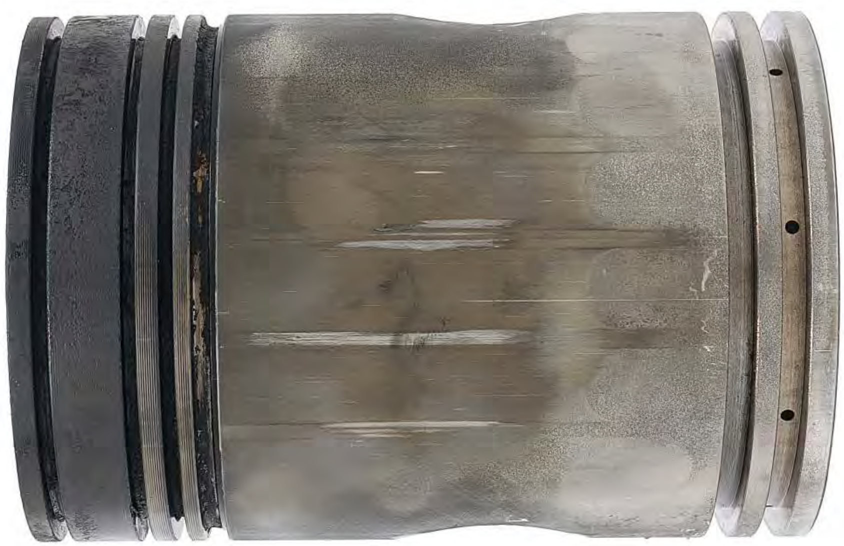
Piston 3 Left Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO268869 | **EOT Date:** | 10/27/11 |
| **Test No.:** | LO268869-6V53T1-T-240 | **Test Length:** | 240 |

**Piston 3 Right Thrust**

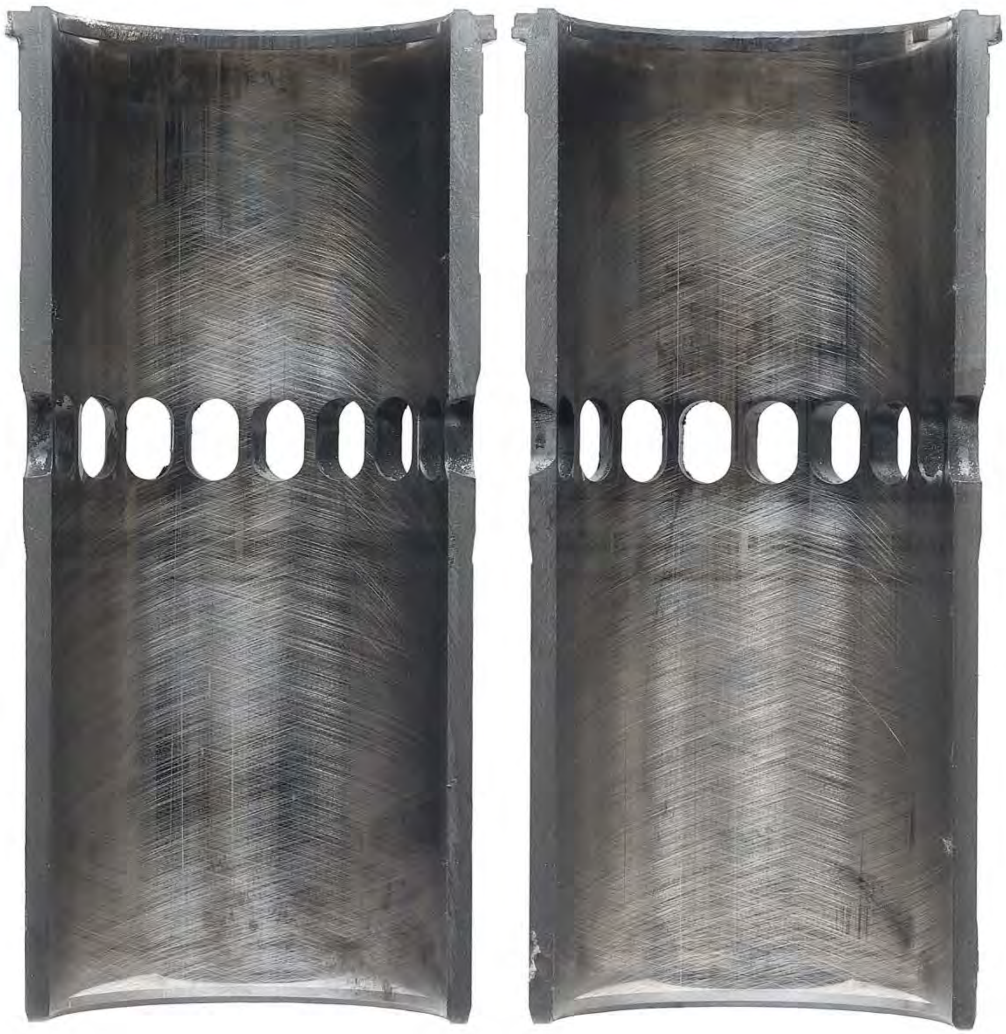
**Piston 3 Right Anti-thrust**



DDC 6V53T - Tracked Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO268869 | **EOT Date:** | 10/27/11 |
| **Test No.:** | LO268869-6V53T1-T-240 | **Test Length:** | 240 |

**Liner 3 Left Thrust and Anti-thrust**



DDC 6V53T - Tracked Vehicle Cycle

| Oil Code: | LO268869 | EOT Date: | 10/27/11 |
|---|---|---|---|
| Test No.: | LO268869-6V53T1-T-240 | Test Length: | 240 |

Liner 3 Right Thrust and Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle

| Oil Code: | LO268869 | EOT Date: | 10/27/11 |
|---|---|---|---|
| Test No.: | LO268869-6V53T1-T-240 | Test Length: | 240 |

Slipper Bushings 1R, 2R, 3R

Slipper Bushings 1L, 2L, 3L

DDC 6V53T - Tracked Vehicle Cycle

| | | | |
|---|---|---|---|
| **Oil Code:** | LO268869 | **EOT Date:** | 10/27/11 |
| **Test No.:** | LO268869-6V53T1-T-240 | **Test Length:** | 240 |

**Connecting Rod Bearings**

**Upper 1L, 2L, 3L, 1R, 2R, 3R** **Lower 1L, 2L, 3L, 1R, 2R, 3R**

# APPENDIX – C1
# ROLLER FOLLOWER WEAR TEST
# LO-268869

# D 5966
# Roller Follower Wear Test

Version 20040401

**Title / Validity Declaration Page**

Conducted for

## U.S. ARMY TARDEC

| | | |
|---|---|---|
| V | V | = Valid; The Reference Oil / Non-Reference Oil was Evaluated in Accordance with the Test Prodecure. |
| | I | = Invalid; The Reference Oil / Non-Reference Oil was Evaluated in Accordance with the Test Procedure. |

| | | | |
|---|---|---|---|
| **Stand:** 65 | **Stand Run No.:** 404 | **Engine No.:** 222 | **Engine Run No.:** 9 |
| **End of Test Date:** 20120203 | | **End of Test Time:** 16:59 CST | |
| **Oil Code:*** LO-268869 | | | |
| **Formulation / Stand Code:**[A] | | | |
| **Alternate Codes:**[B] | | | |

In my opinion this test has been conducted in a valid manner in accordance with the Test Method D 5966 and the appropriate amendments through the information letter system. The remarks included in the report describe the anomalies associated with this test.

The results of this report relate only to the items tested.

This report shall not be reproduced, except in full, without the written approval of Southwest Research Institute®.

* *CMIR or Non-Reference Oil Code*

[A] *ACC -Registered Tests Only*

[B] *When Provided or Required by Client*

Submitted by:

**Southwest Research Institute (R)**
Testing Laboratory

Signature

**Perry Grosch**
Typed Name

**Principal Research Technologist**
Title

# D 5966
## Roller Follower Wear Test
### Test Identification Cover Sheet
### Test Lab Affidavit
Form 1

| Reference Oil Test | | | | |
|---|---|---|---|---|
| Lab | Stand | Stand Run No. | Engine | Engine Run No. |
| SR | 65 | | 222 | |
| Start Date | Date Completed | EOT of Test Time | Test Length | |
| | | | 0 | |
| CMIR | TMC Oil Code | | Viscosity Grade | |
| | | | | |
| Laboratory Oil Code | | | | |
| Engine Displacement | 6.5L | | | |
| Average Wear (mils) | | | | |
| | | | | |

| Non-Reference Oil Test | | | | |
|---|---|---|---|---|
| Lab | Stand | Stand Run No. | Engine | Engine Run No. |
| SR | 65 | 404 | 222 | 9 |
| Start Date | Date Completed | EOT of Test Time | Test Length | |
| 20120201 | 20120203 | 16:59 | 50 | |
| Oil Code | | | Viscosity Grade | |
| LO-268869 | | | N/A | |
| Laboratory Oil Code | 268869 | | | |
| Formulation / Stand Code | | | | |
| | | | | |
| Average Wear (mils) | Severity Adjustment | Adjustment Average Wear | | |
| 0.28 | 0.00 | 0.28 | | |

# D 5966
## Roller Follower Wear Test
### Summary of Roller Follower Wear
Form 2

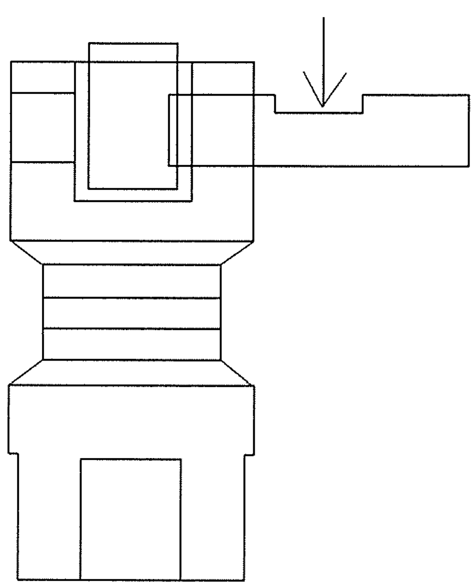
| | |
|---|---|
| **Laboratory:** SR | **EOT Date:** 20120203 |
| **Test Number:** * 65-404-222-9 | |
| **Oil Code:** LO-268869 | |
| **Formulation / Stand Code:** | |

**Test Number is: Stand - Stand Run No. - Engine No. - Engine Run No.*

| Lifter Part Number |
|---|
| 171098650 |

| Profilometer Wear Measurements (mils) | | | |
|---|---|---|---|
| **Lifter Number** | **Wear (mils)** | **Lifter Number** | **Wear (mils)** |
| 1L | 0.21 | 1R | 0.18 |
| 2L | 0.28 | 2R | 0.20 |
| 3L | 0.23 | 3R | 0.12 |
| 4L | 0.25 | 4R | 0.19 |
| 5L | 0.28 | 5R | 0.25 |
| 6L | 0.47 | 6R | 0.19 |
| 7L | 0.45 | 7R | 0.46 |
| 8L | 0.46 | 8R | 0.23 |
| **Wear Statistics** | | | |
| **Minimum** | **Maximum** | **Average** | **Std. Deviation** |
| 0.12 | 0.47 | 0.28 | 0.12 |

Wear is Measured at Location Shown by Arrow.



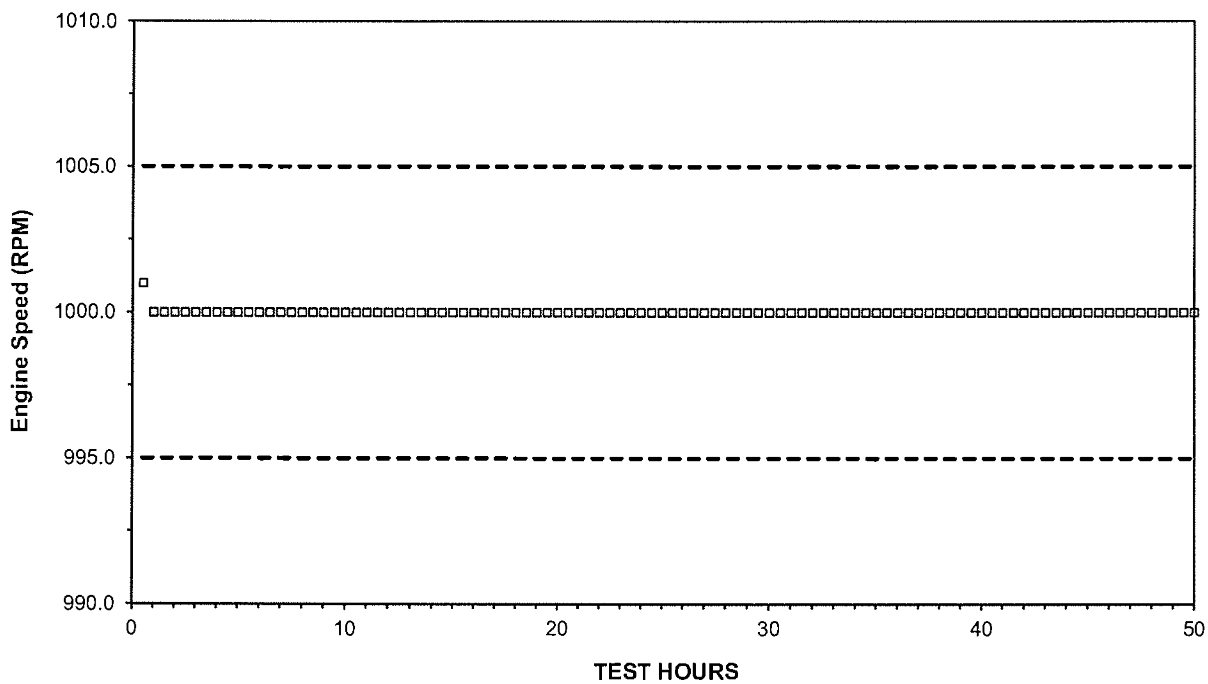
# ROLLER FOLLOWER WEAR TEST
## Operational Data Summary
## Form 3

| | |
|---|---|
| Laboratory: SR | EOT Date: 20120203 |
| Test Number: 65-404-222-9 | |
| Oil Code: LO-268869 | |
| Formulation/Stand Code: | |

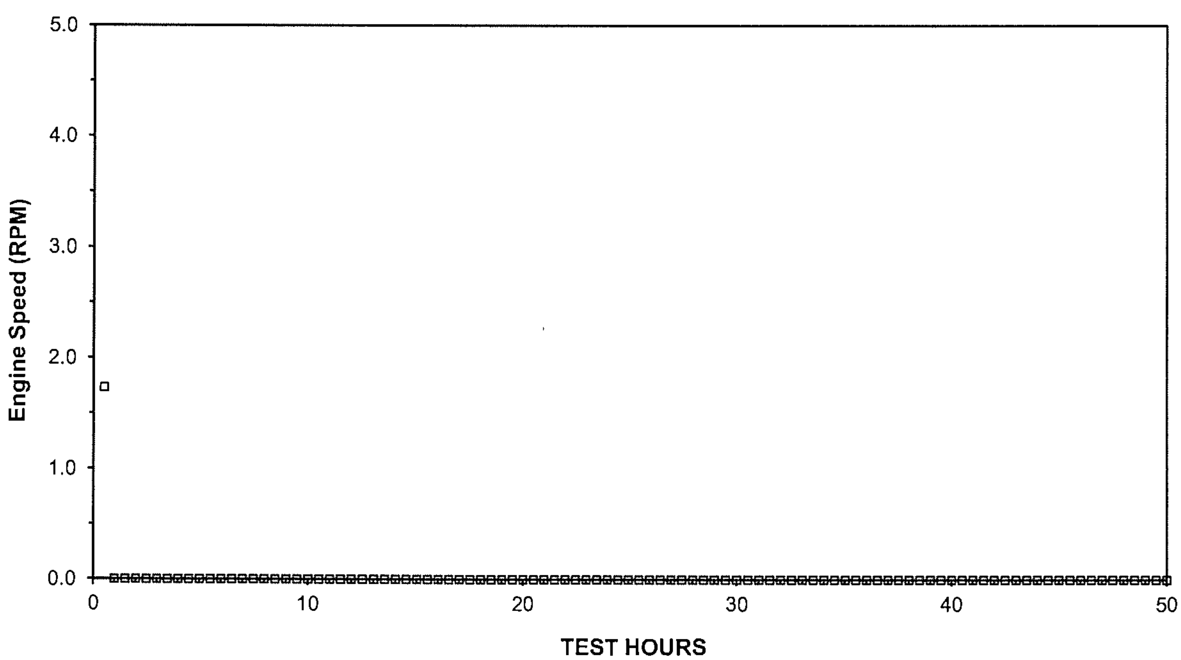
***Test Number Is: Stand - Stand Run No. - Engine No.**

ENGINE SPEED vs TEST HOURS

Process Mean
Xav = 1000.0




Process Variability (s)
Sav = 0.0



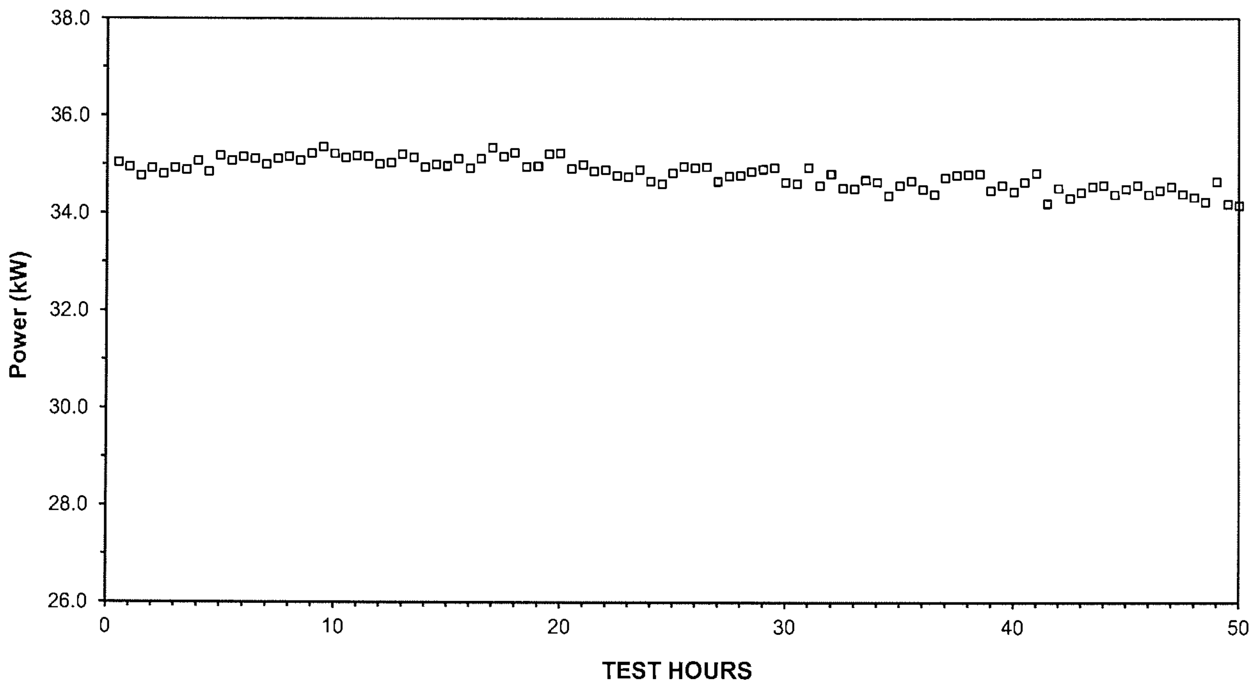
# ROLLER FOLLOWER WEAR TEST
## Operational Data Summary
## Form 4

| | |
|---|---|
| Laboratory: SR | EOT Date: 20120203 |
| Test Number: 65-404-222-9 | |
| Oil Code: LO-268869 | |
| Formulation/Stand Code: | |

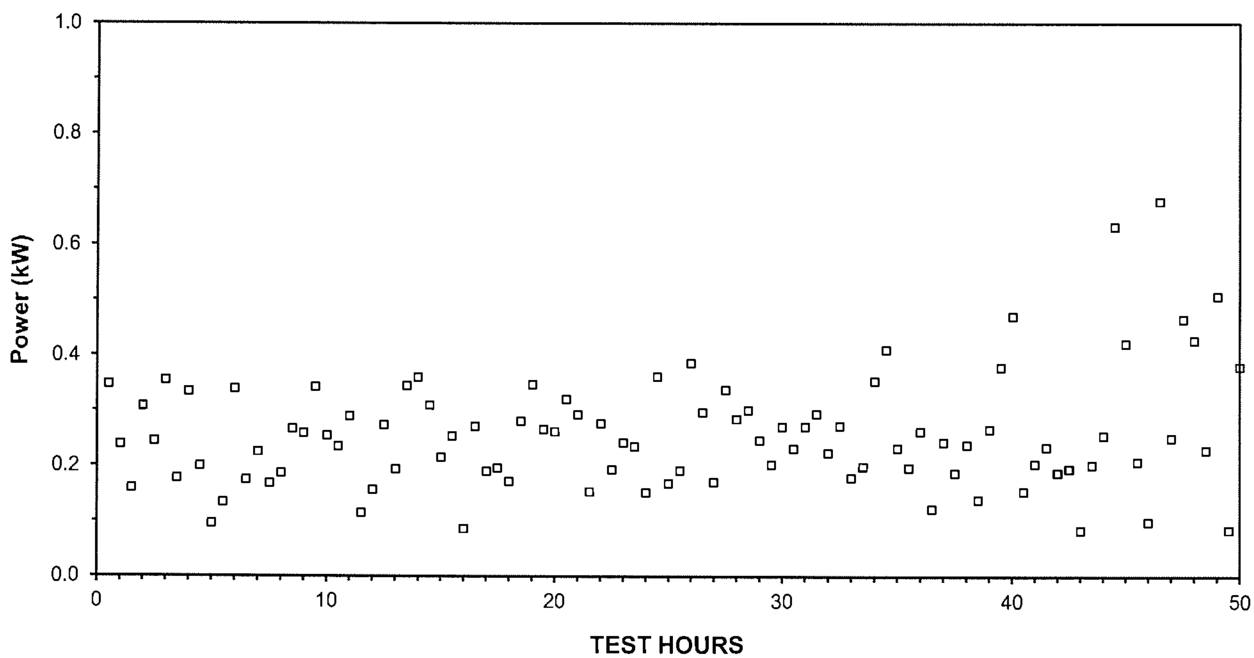
***Test Number Is: Stand - Stand Run No. - Engine No.**

POWER vs TEST HOURS

Process Mean
Xav = 34.8




Process Variability (s)
Sav = 0.3



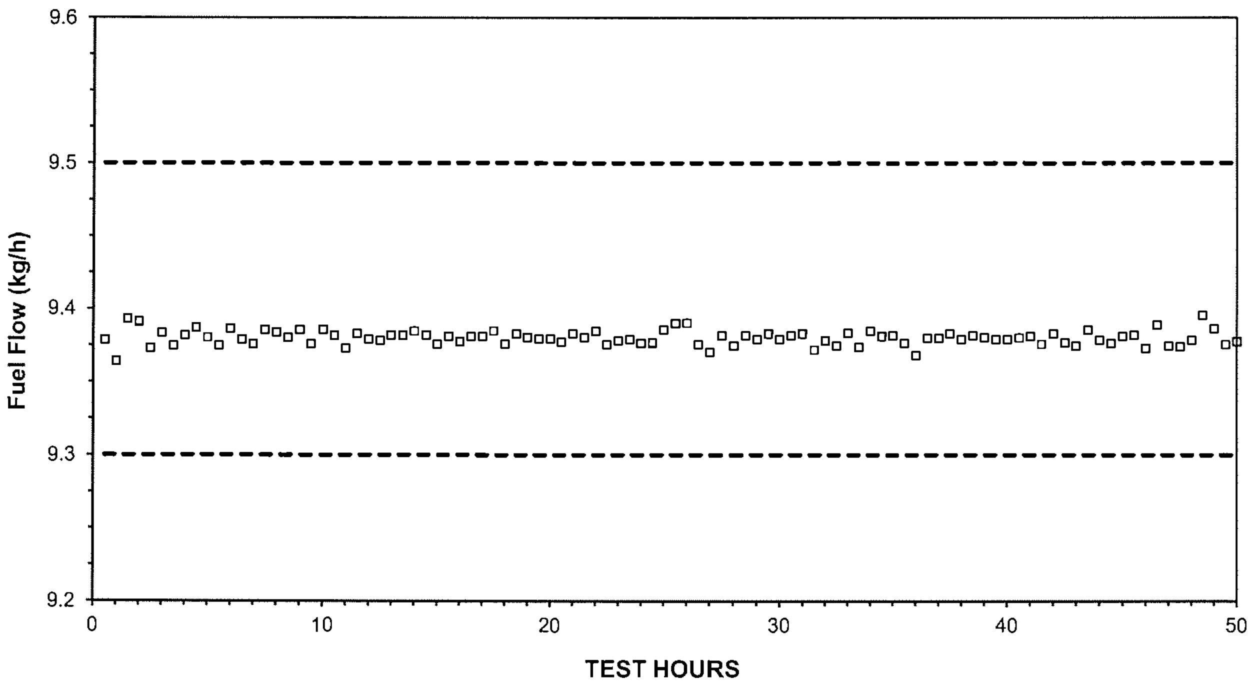
# ROLLER FOLLOWER WEAR TEST
## Operational Data Summary
## Form 5

| | |
|---|---|
| Laboratory: SR | EOT Date: 20120203 |
| Test Number: 65-404-222-9 | |
| Oil Code: LO-268869 | |
| Formulation/Stand Code: | |

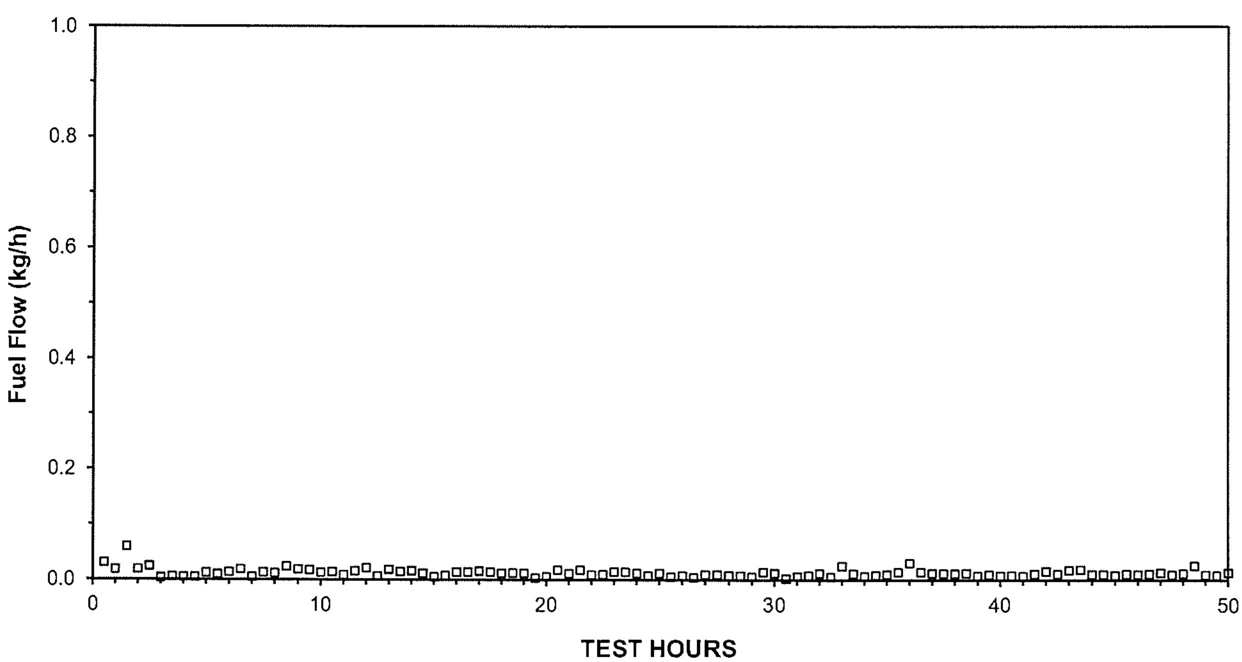
***Test Number Is: Stand - Stand Run No. - Engine No.**

FUEL FLOW vs TEST HOURS

Process Mean
Xav = 9.4




Process Variability (s)
Sav = 0.0



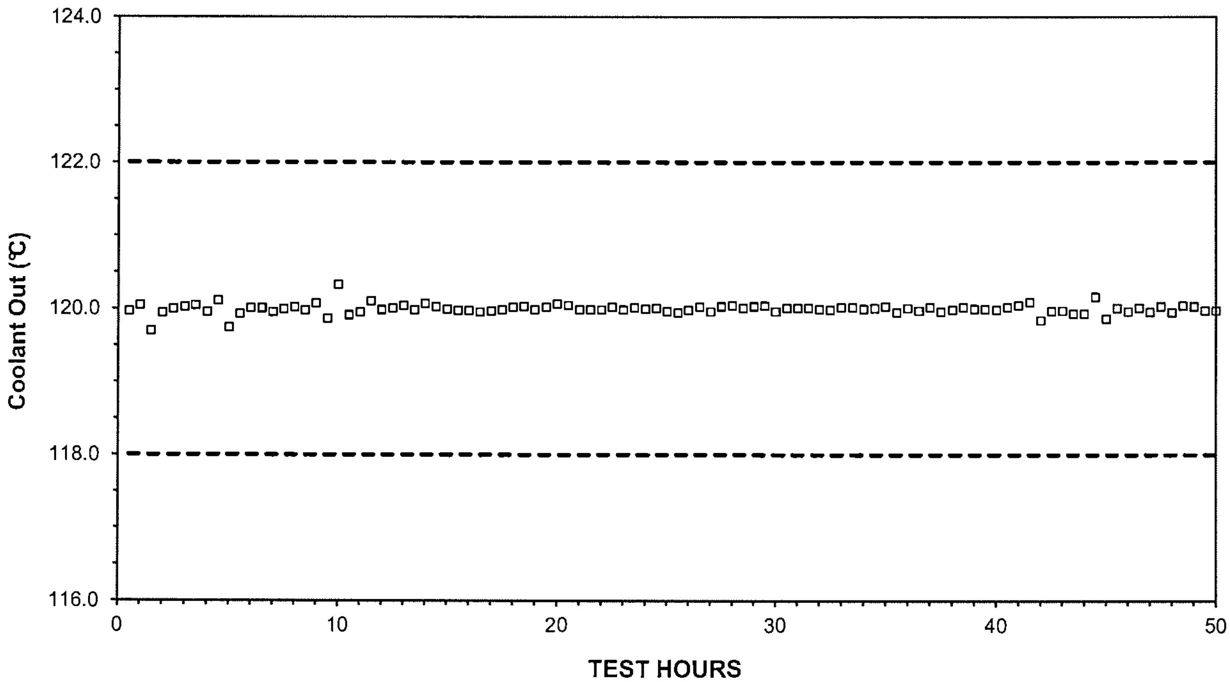
# ROLLER FOLLOWER WEAR TEST
## Operational Data Summary
## Form 6

| | |
|---|---|
| Laboratory: SR | EOT Date: 20120203 |
| Test Number: 65-404-222-9 | |
| Oil Code: LO-268869 | |
| Formulation/Stand Code: | |

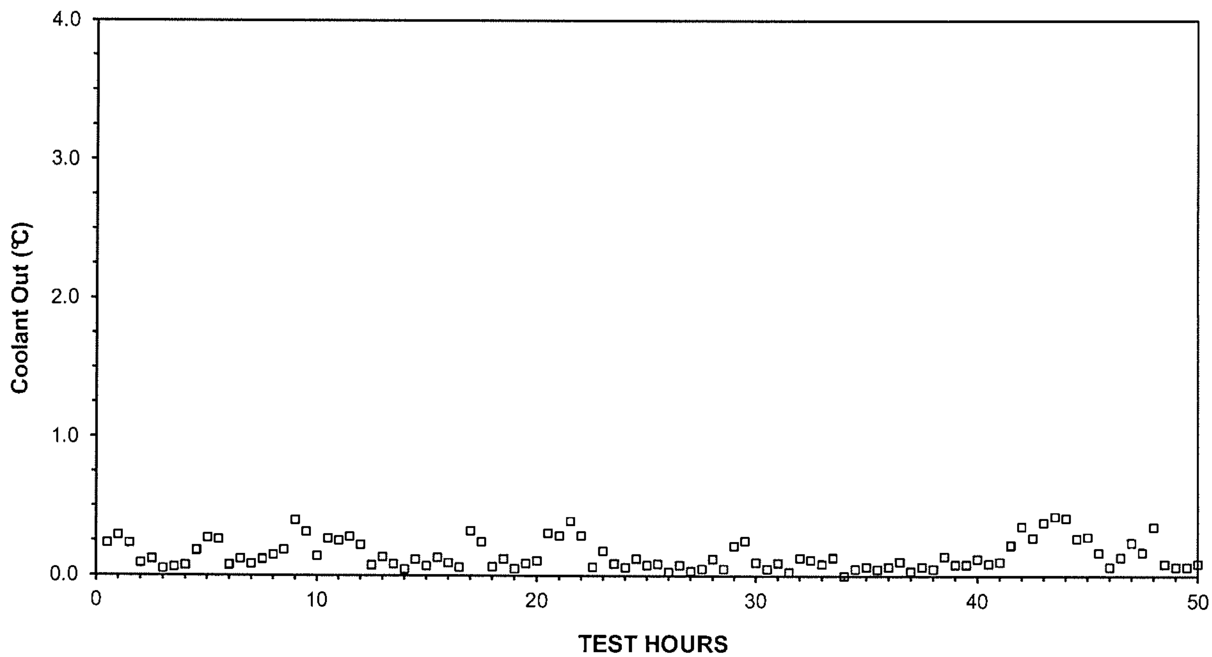
***Test Number Is: Stand - Stand Run No. - Engine No.***

COOLANT OUT TEMPERATURE vs TEST HOURS

Process Mean
Xav = 120.0




Process Variability (s)
Sav = 0.1



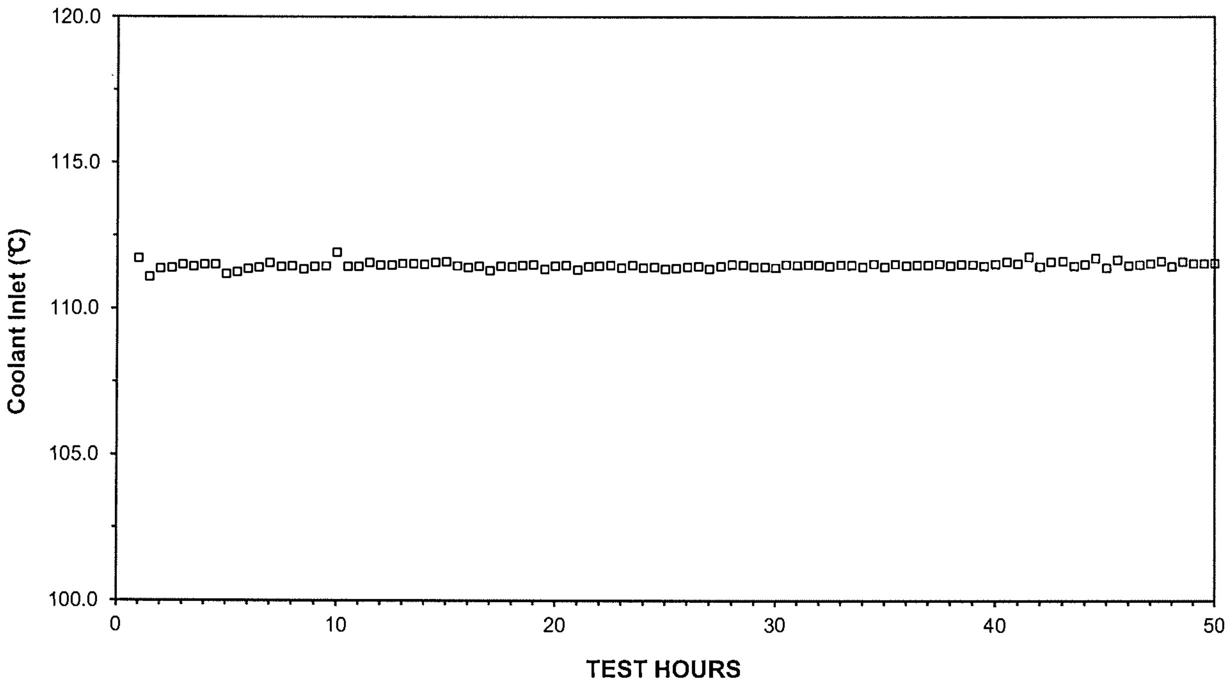
# ROLLER FOLLOWER WEAR TEST
## Operational Data Summary
## Form 7

| | |
|---|---|
| Laboratory: SR | EOT Date: 20120203 |
| Test Number: 65-404-222-9 | |
| Oil Code: LO-268869 | |
| Formulation/Stand Code: | |

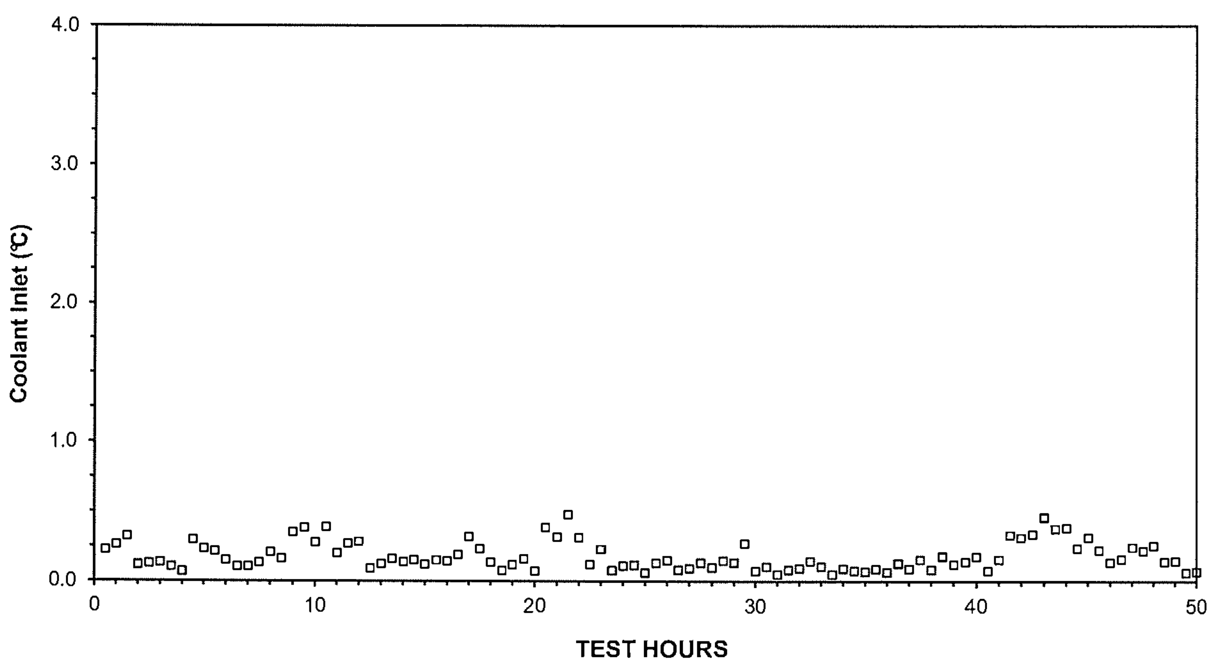
***Test Number Is: Stand - Stand Run No. - Engine No.***

COOLANT INLET TEMPERATURE vs TEST HOURS

Process Mean
Xav = 111.5




Process Variability (s)
Sav = 0.2



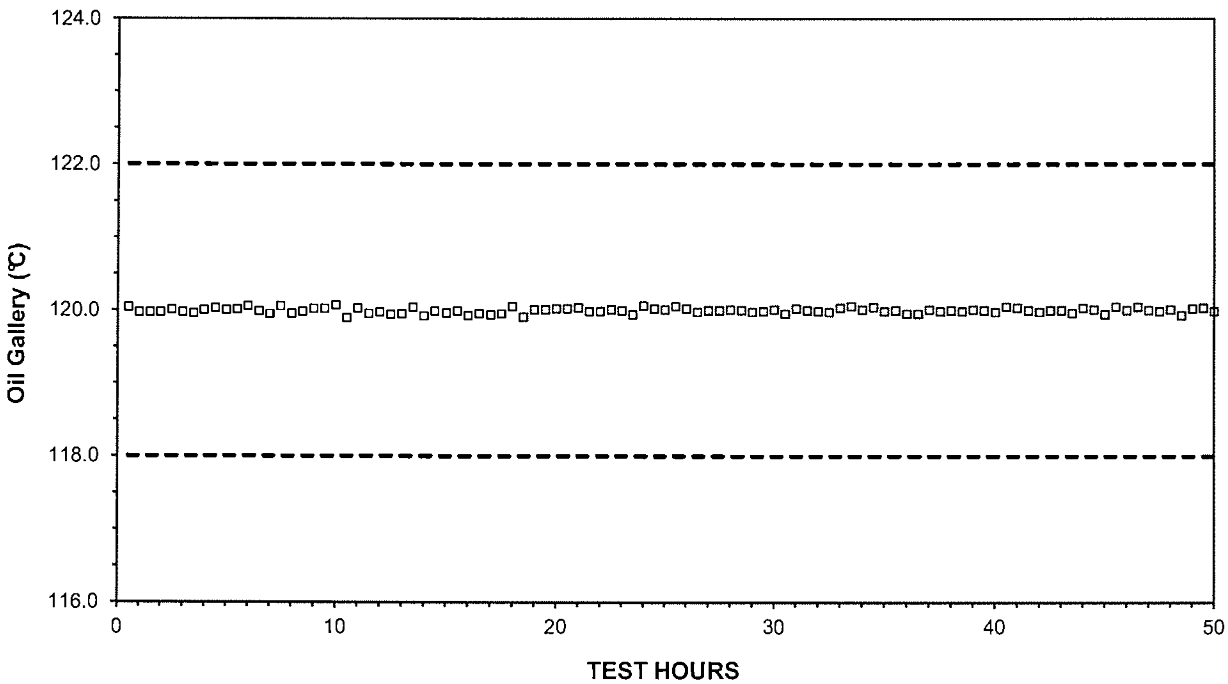
# ROLLER FOLLOWER WEAR TEST
## Operational Data Summary
## Form 8

| | |
|---|---|
| Laboratory: SR | EOT Date: 20120203 |
| Test Number: 65-404-222-9 | |
| Oil Code: LO-268869 | |
| Formulation/Stand Code: | |

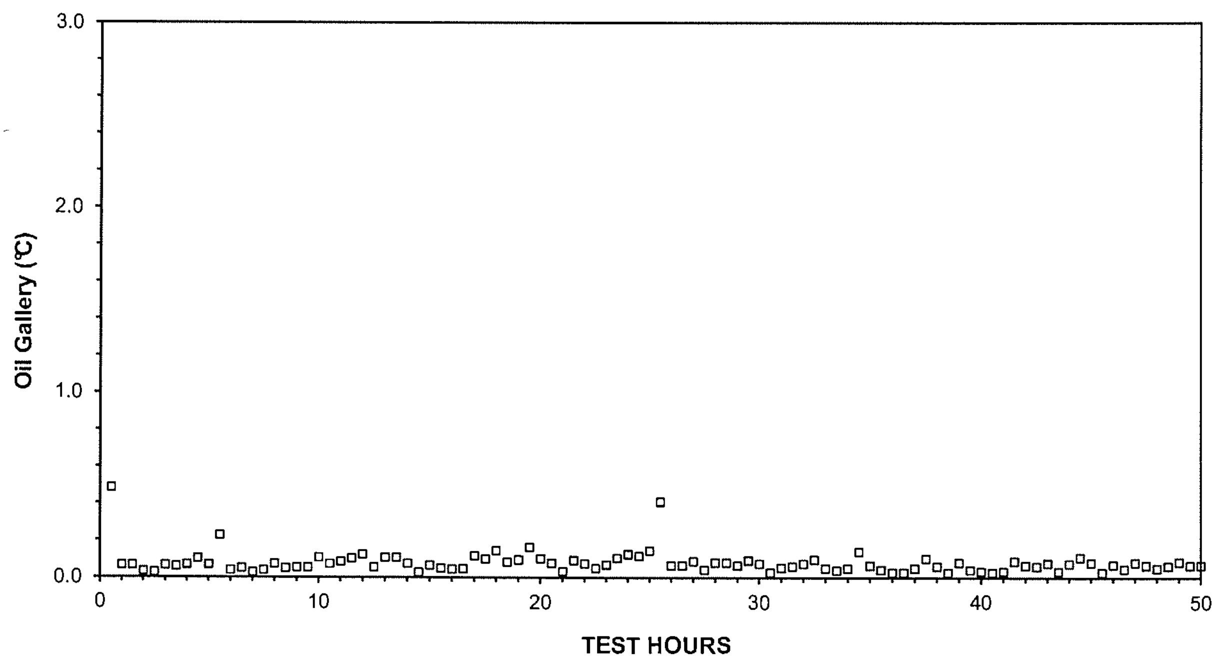
***Test Number Is: Stand - Stand Run No. - Engine No.***

OIL GALLERY TEMPERATURE vs TEST HOURS

Process Mean
Xav = 120.0




Process Variability (s)
Sav = 0.1



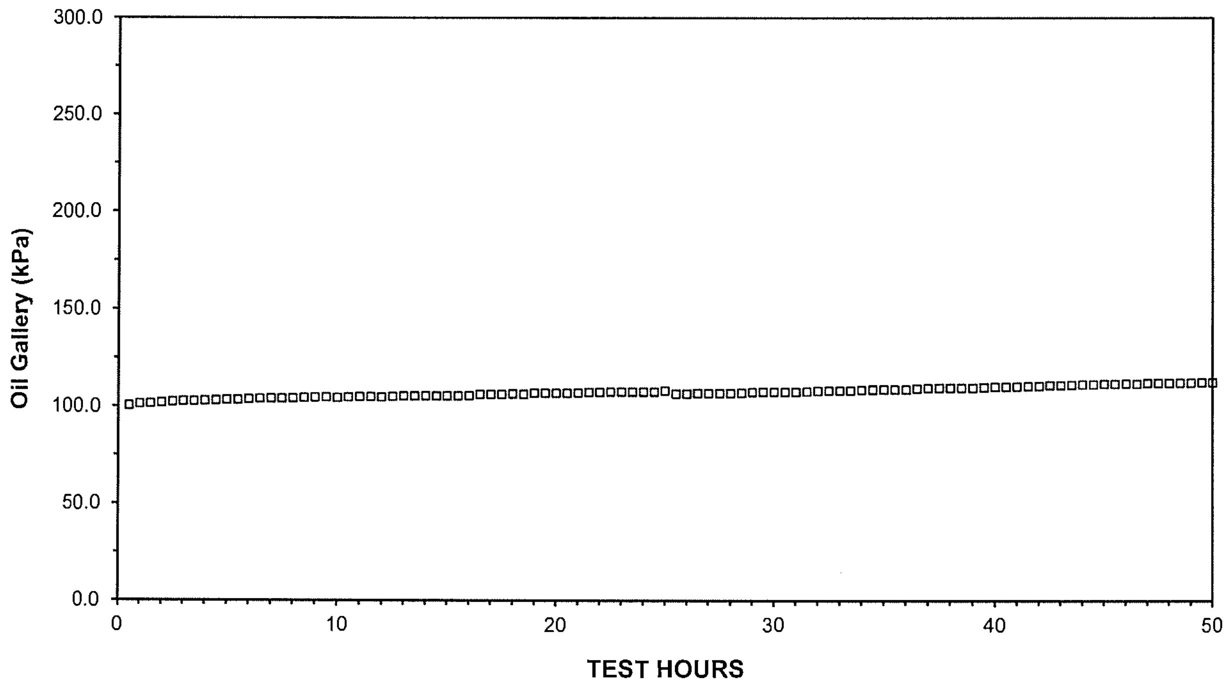
# ROLLER FOLLOWER WEAR TEST
## Operational Data Summary
## Form 9

| | |
|---|---|
| Laboratory: SR | EOT Date: 20120203 |
| Test Number: 65-404-222-9 | |
| Oil Code: LO-268869 | |
| Formulation/Stand Code: | |

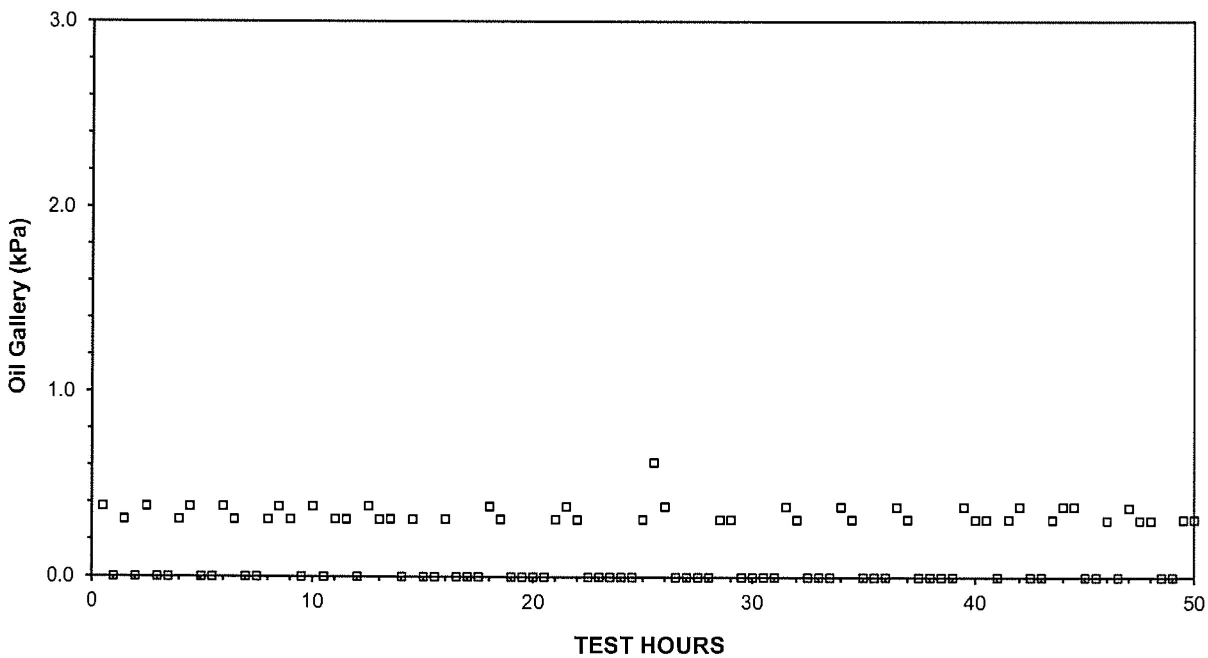
***Test Number Is: Stand - Stand Run No. - Engine No.**

OIL GALLERY PRESSURE vs TEST HOURS

Process Mean
Xav = 107.3




Process Variability (s)
Sav = 0.2

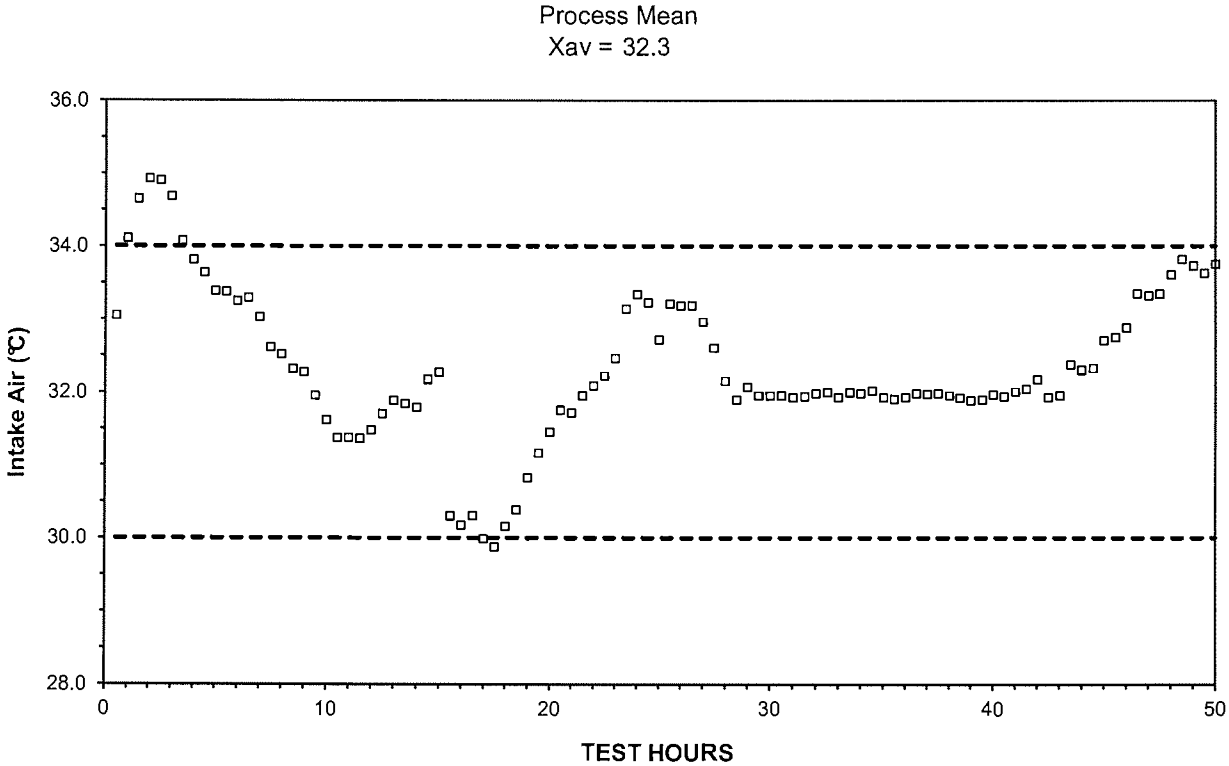


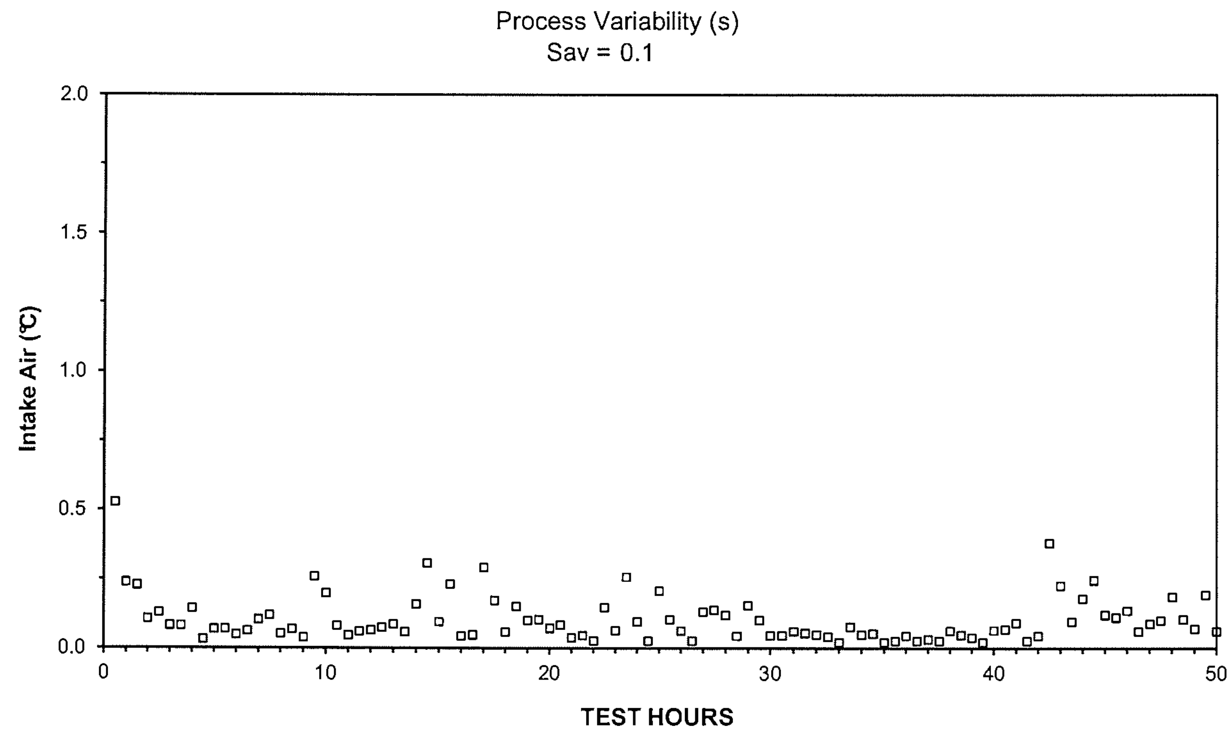
# ROLLER FOLLOWER WEAR TEST
## Operational Data Summary
## Form 10

| | |
|---|---|
| Laboratory: SR | EOT Date: 20120203 |
| Test Number: 65-404-222-9 | |
| Oil Code: LO-268869 | |
| Formulation/Stand Code: | |

***Test Number Is: Stand - Stand Run No. - Engine No.***

INTAKE AIR TEMPERATURE vs TEST HOURS



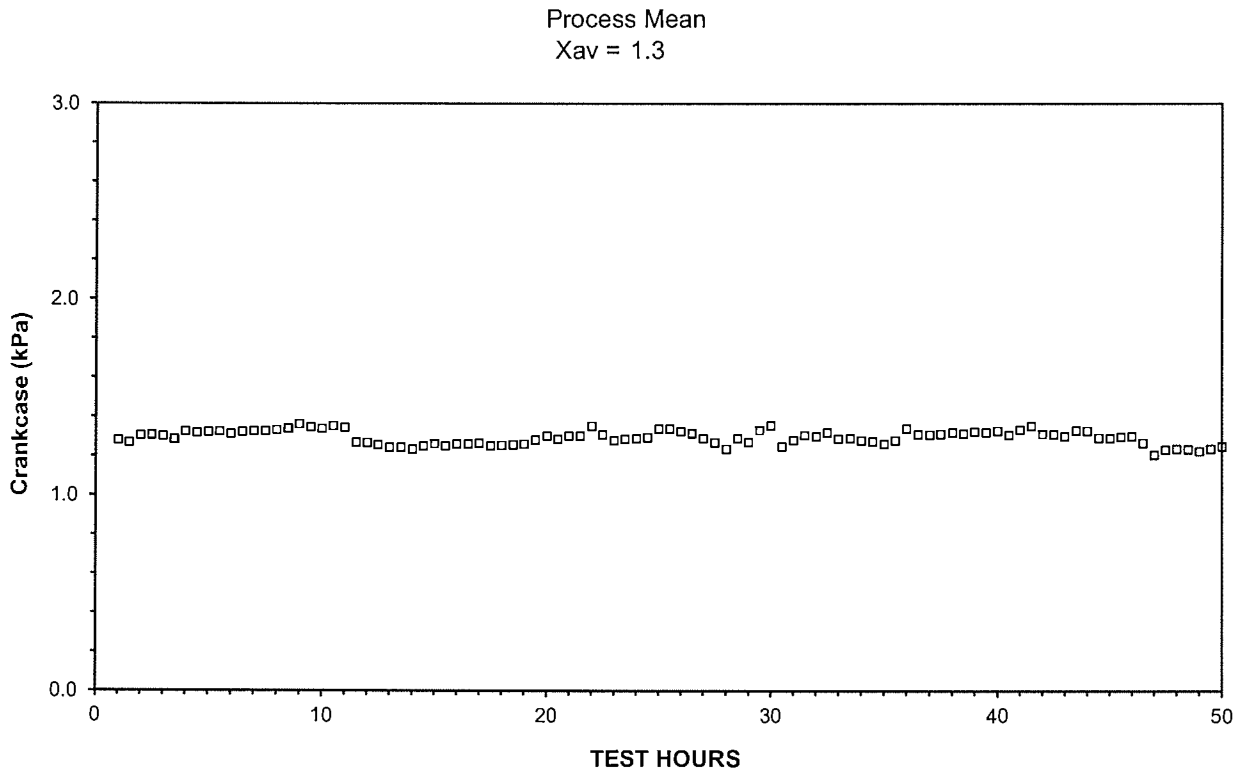



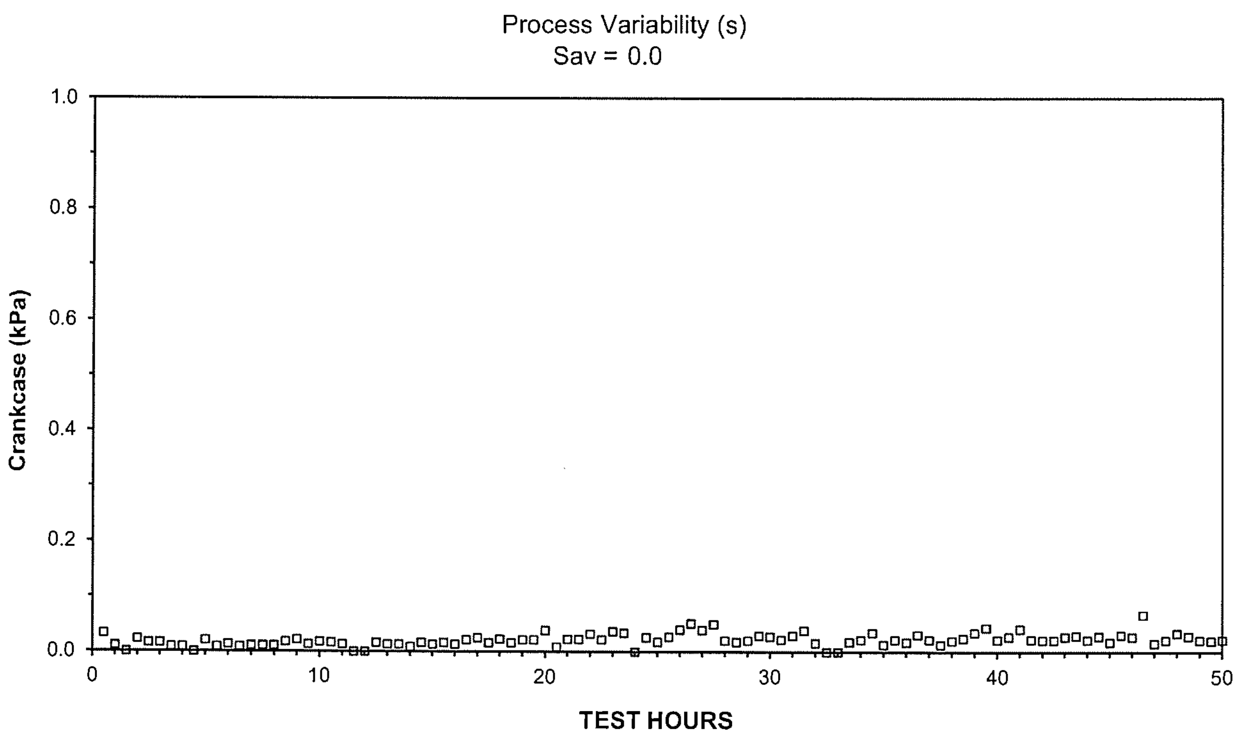
# ROLLER FOLLOWER WEAR TEST
## Operational Data Summary
## Form 11

| | |
|---|---|
| Laboratory: SR | EOT Date: 20120203 |
| Test Number: 65-404-222-9 | |
| Oil Code: LO-268869 | |
| Formulation/Stand Code: | |

***Test Number Is: Stand - Stand Run No. - Engine No.***

CRANKCASE PRESSURE vs TEST HOURS



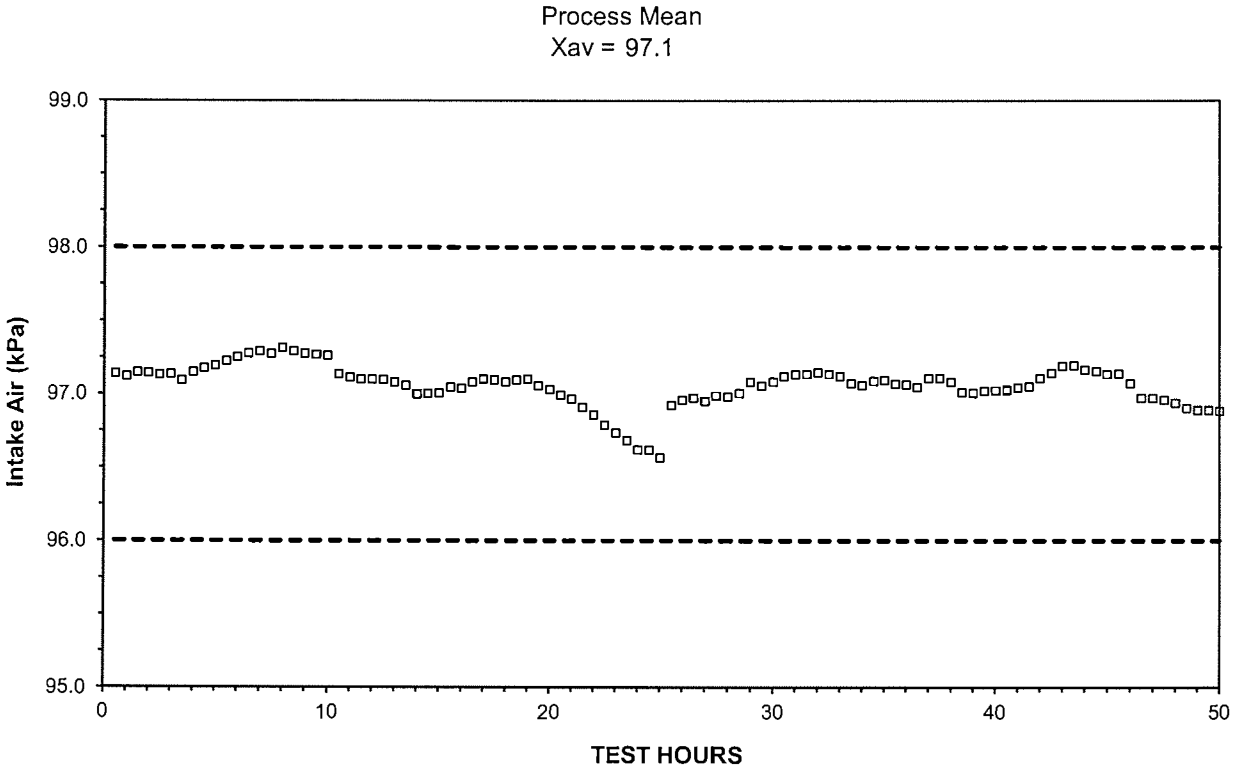



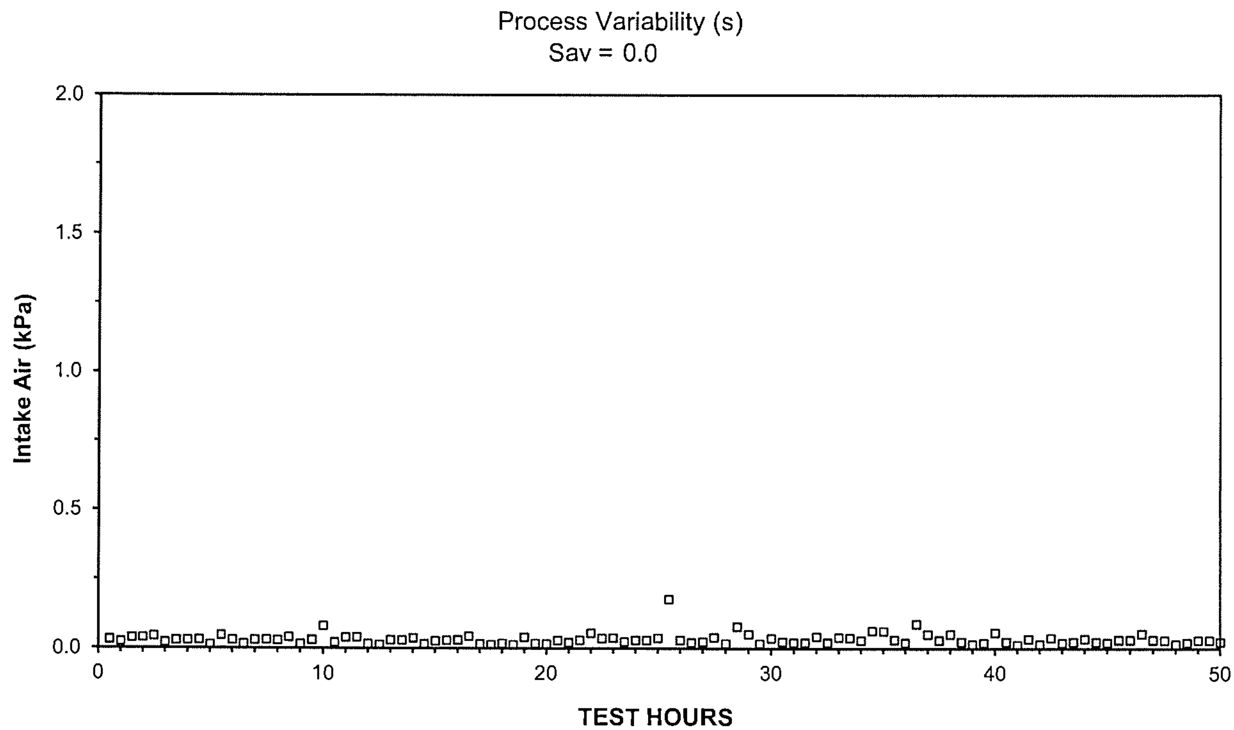
# ROLLER FOLLOWER WEAR TEST
## Operational Data Summary
## Form 12

| | |
|---|---|
| Laboratory: SR | EOT Date: 20120203 |
| Test Number: 65-404-222-9 | |
| Oil Code: LO-268869 | |
| Formulation/Stand Code: | |

***Test Number Is: Stand - Stand Run No. - Engine No.**

INTAKE AIR PRESSURE vs TEST HOURS



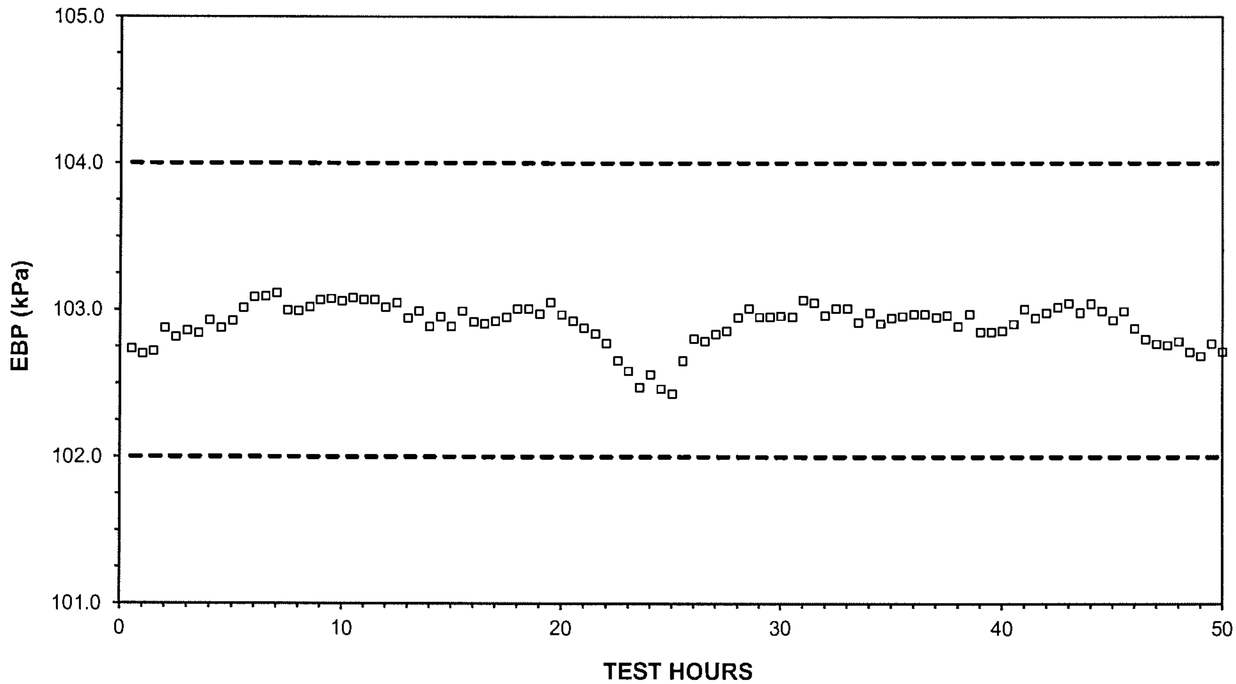
# ROLLER FOLLOWER WEAR TEST
## Operational Data Summary
## Form 13

| | |
|---|---|
| Laboratory: SR | EOT Date: 20120203 |
| Test Number: 65-404-222-9 | |
| Oil Code: LO-268869 | |
| Formulation/Stand Code: | |

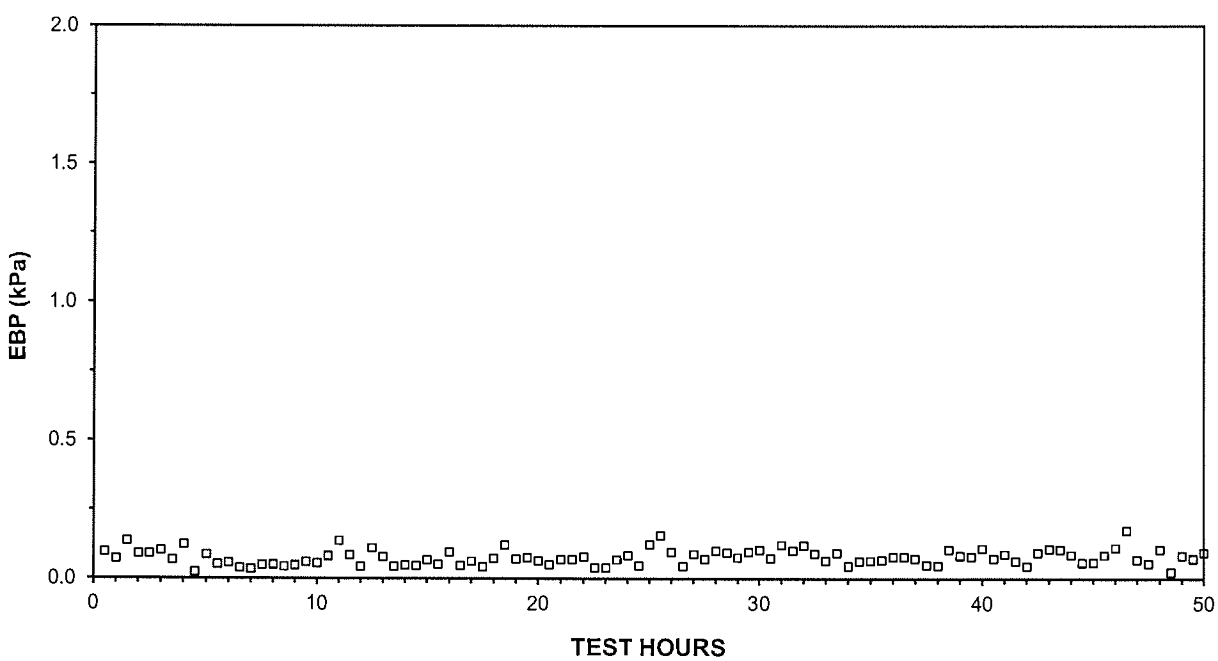
***Test Number Is: Stand - Stand Run No. - Engine No.**

EXHAUST BACK PRESSURE vs TEST HOURS

Process Mean
Xav = 102.9




Process Variability (s)
Sav = 0.1



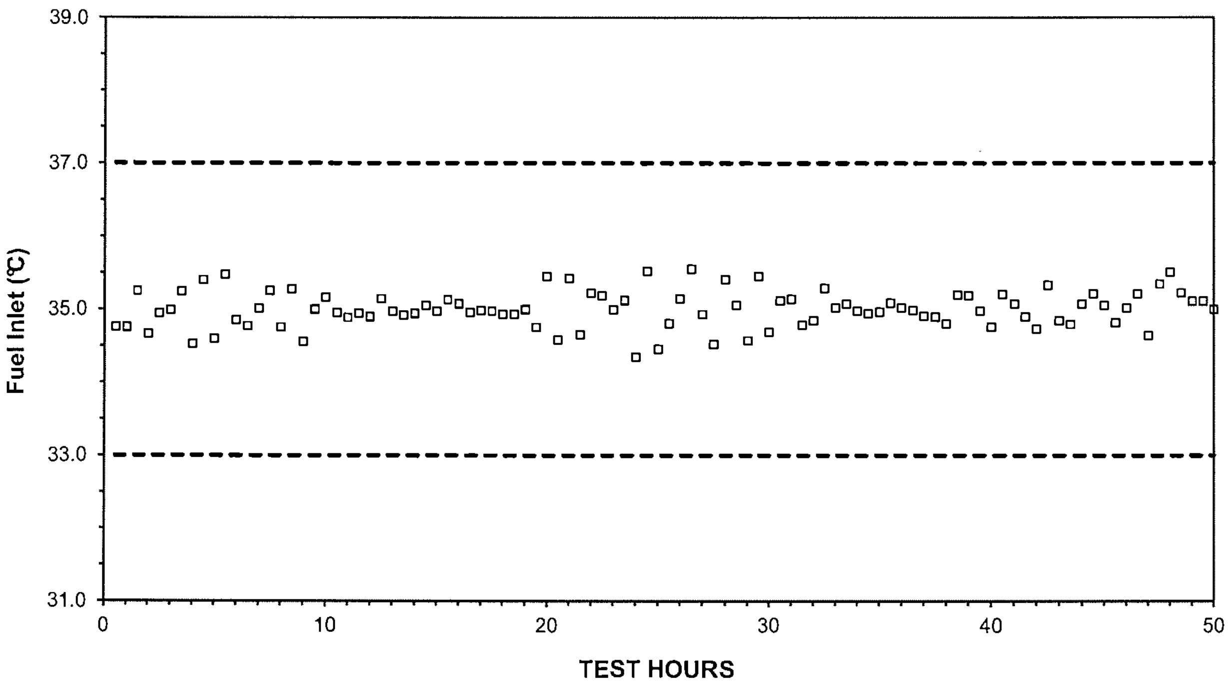
# ROLLER FOLLOWER WEAR TEST
## Operational Data Summary
## Form 14

| Laboratory: SR | EOT Date: 20120203 |
|---|---|
| Test Number: 65-404-222-9 | |
| Oil Code: LO-268869 | |
| Formulation/Stand Code: | |

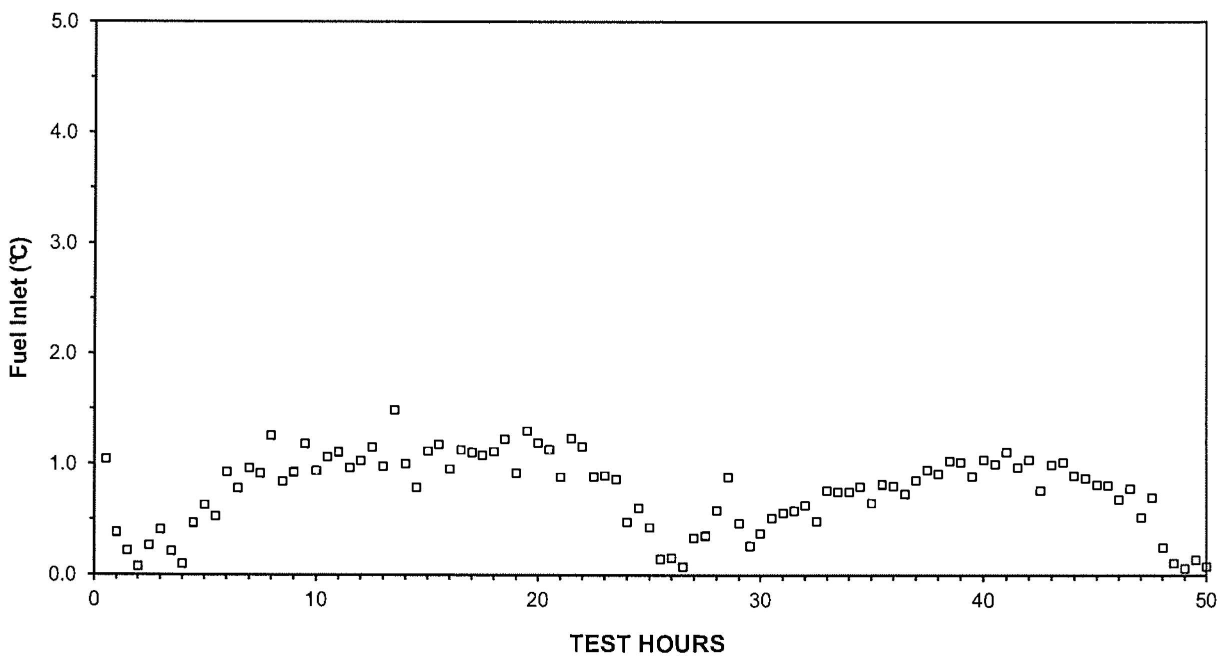
***Test Number Is: Stand - Stand Run No. - Engine No.***

FUEL INLET TEMPERATURE vs TEST HOURS

Process Mean
Xav = 35.0




Process Variability (s)
Sav = 0.8



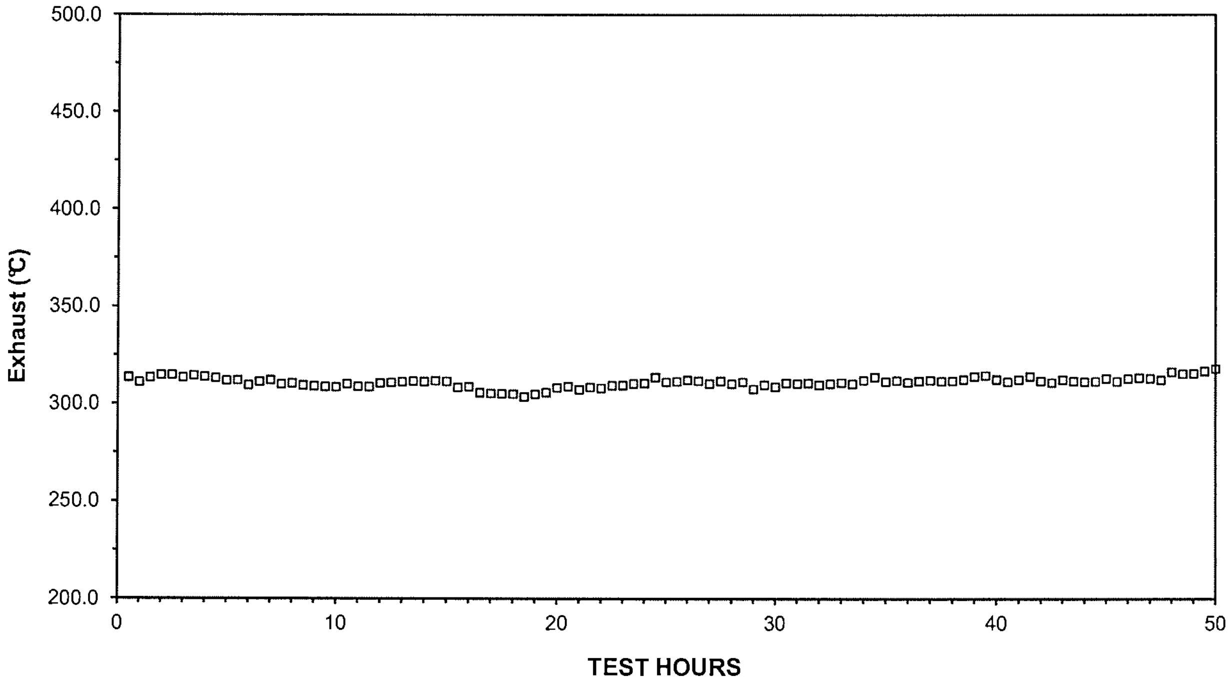
# ROLLER FOLLOWER WEAR TEST
## Operational Data Summary
## Form 15

| | |
|---|---|
| Laboratory: SR | EOT Date: 20120203 |
| Test Number: 65-404-222-9 | |
| Oil Code: LO-268869 | |
| Formulation/Stand Code: | |

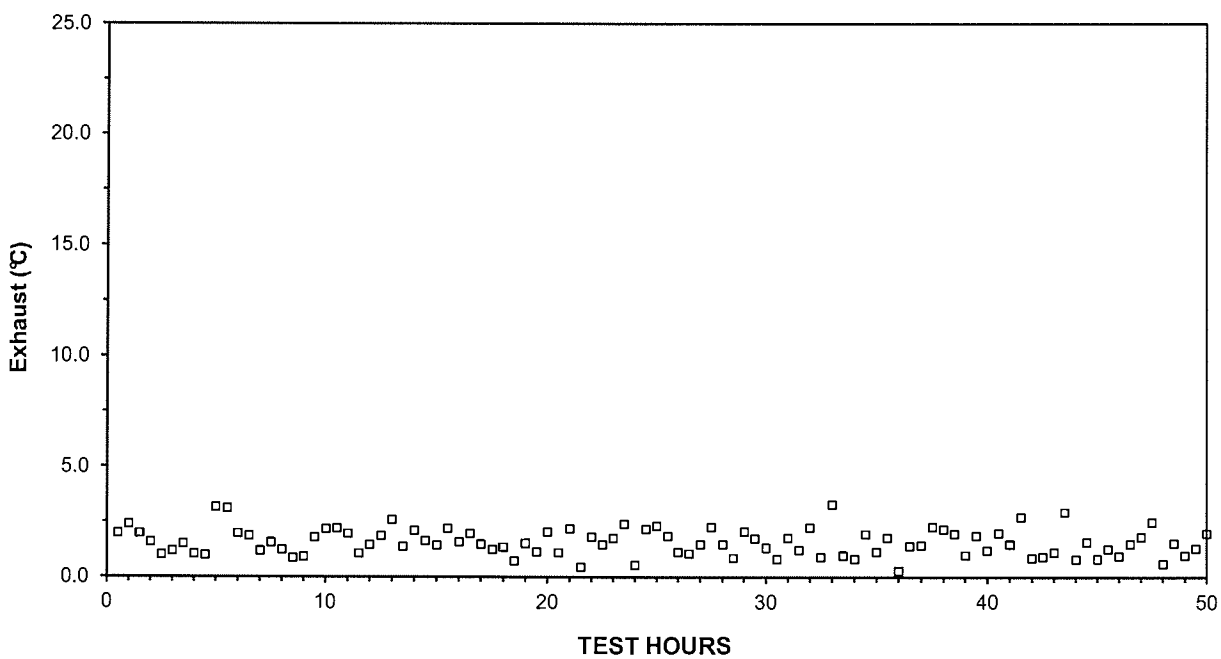
***Test Number Is: Stand - Stand Run No. - Engine No.**

EXHAUST TEMPERATURE vs TEST HOURS

Process Mean
Xav = 311.0




Process Variability (s)
Sav = 1.6



**D 5966**
**Roller Follower Wear Test**
**Operational Summary**
Form 16

| | |
|---|---|
| **Laboratory:** SR | **EOT Date:** 20120203 |
| **Test Number: *** 65-404-222-9 | |
| **Oil Code:** LO-268869 | |
| **Formulation / Stand Code:** | |

**Test Number is: Stand - Stand Run No. - Engine No. - Engine Run No.*

| Test Parameter | Specification | | Average | Std. Dev. | Minimum | Maximum |
|---|---|---|---|---|---|---|
| Engine Speed, r/min | 6.2L Engine 1000 ± 5 | 6.5L Engine 1000 ± 5 | 1000.0 | 0.1 | 1000.0 | 1001.0 |
| Torque, N-m | Record | Record | 333.1 | 2.8 | 327.0 | 338.3 |
| Fuel Flow, kg/h | 9.0 ± 0.1 | 9.4 ± 0.1 | 9.4 | 0.0 | 9.4 | 9.4 |
| Total Oil Consumption, kg | Record | Record | 3.9 | | | |

| Test Parameter | Specification | Average | Std. Dev. | Minimum | Maximum |
|---|---|---|---|---|---|
| Coolant Out, °C | 120 ± 2 | 120.0 | 0.1 | 119.7 | 120.3 |
| Coolant In, °C | Report Only | 111.5 | 0.1 | 111.1 | 111.9 |
| Main Oil Gallery, °C | 120 ± 2 | 120.0 | 0.0 | 119.9 | 120.1 |
| Fuel In, °C | 35 ± 2 | 35.0 | 0.3 | 34.4 | 35.6 |
| Intake Air, °C | 32 ± 2 | 32.3 | 1.0 | 29.9 | 34.9 |
| Oil Sump, °C | Report | 128.2 | 0.2 | 127.8 | 128.7 |
| Exhaust, °C | Report | 311.0 | 2.6 | 303.6 | 317.9 |

| Pressures | Specification | Average | Std. Dev. | Minimum | Maximum |
|---|---|---|---|---|---|
| Crankcase, kPa | Report | 1.3 | 0.0 | 1.4 | 1.2 |
| Back Pressure, kPa | 103 ± 1 | 102.9 | 0.1 | 102.4 | 103.1 |
| Intake Air, kPa | 97 ± 1 | 97.1 | 0.1 | 96.6 | 97.3 |

| Laboratory: SR | EOT Date: 20120203 |
|---|---|
| Test Number: * 65-404-222-9 | |
| Oil Code: LO-268869 | |
| Formulation / Stand Code: | |

**Test Number is: Stand - Stand Run No. - Engine No. - Engine Run No.*

| Hours | Viscosity, cSt @ 100°C | % SOOT |
|---|---|---|
| NEW | 8.80 | 0.2 |
| 025 | 10.90 | 2.5 |
| 050 | 12.07 | 4.4 |

| Hours | Elements | | | | | | |
|---|---|---|---|---|---|---|---|
| | Al | Cr | Cu | Fe | Pb | Si | Sn |
| NEW | 6 | 0 | 0 | 2 | 0 | 2 | 0 |
| 025 | 6 | 2 | 3 | 100 | 5 | 5 | 2 |
| 050 | 7 | 4 | 4 | 202 | 9 | 6 | 3 |

| | |
|---|---|
| Average Bosch Smokes | 6.5 |
| Average BSFC | 0.270 kg/kW-h |

# D 5966
## Roller Follower Wear Test
### Unscheduled Downtime & Maintenance Summary
Form 18

| | |
|---|---|
| **Laboratory:** SR | **EOT Date:** 20120203 |
| **Test Number:** * 65-404-222-9 | |
| **Oil Code:** LO-268869 | |
| **Formulation / Stand Code:** | |

*Test Number is: Stand - Stand Run No. - Engine No. - Engine Run No.*

**Number of Downtime Occurrences:** 0

| Test | Date | Downtime | Reasons |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| **Total Downtime** | | 0:00 | |

**Other Comments**

**Number of Comment Lines:** 0

# D 5966
## Roller Follower Wear Test
### Test Fuel Analysis (Last Batch)
Form 21

| | |
|---|---|
| **Laboratory:** SR | **EOT Date:** 20120203 |
| **Test Number: *** 65-404-222-9 | |
| **Oil Code:** LO-268869 | |
| **Formulation / Stand Code:** | |
| **Supplier:** | **Batch Identifiers:** 11JPPC901 |

**Test Number is: Stand - Stand Run No. - Engine No. - Engine Run No.*

| Measurement | Specifications | Analysis | Test Method |
|---|---|---|---|
| Total Sulfur, % Weight | 0.03 - 0.05 | 0.04 | D 2622 |
| Gravity, °API | 32 - 36 | 35.1 | D 287 |
| **Hydrocarbon Composition** | | | |
| Aromatics, % Vol. | 28 - 35 | 30.7 | D 5186 |
| Olefin | Report | 4.3 | D 1319 |
| Saturates | Report | 65.0 | D 1319 |
| Cetane Index | 42 - 48 | 44.0 | D 4737 |
| Cetane No. | 42 - 48 | 46.0 | D 613 |
| Copper Strip Corrosion | 3 Maximum | 1A | D 130 |
| Flash Point, °C | 54 Minimum | 63 | D 92 |
| Cloud Point, °C | -12 Maximum | -21 | D 2500 |
| Pour Point, °C | -18 Maximum | -27 | D 97 |
| Carbon Residue on 10% Residuum, % | 0.35 Maximum | 0.10 | D 524 (10% Bottoms) |
| Water & Sediment, % Vol. | 0.05 Maximum | 0.00 | D 2709 |
| Ash, % Wgt. | 0.01 Maximum | 0.000 | D 482 |
| Viscosity, cSt @ 40°C | 2.0 - 3.2 | 2.4 | D 445 |
| **Distillation, °C** | | | |
| IBP | 177 - 199 | 173 | D 86 |
| 10% | 210 - 232 | 206 | D 86 |
| 50% | 249 - 277 | 252 | D 86 |
| 90% | 299 - 327 | 326 | D 86 |
| EP | 327 - 360 | 361 | D 86 |

# D 5966
## Roller Follower Wear Test
### Characteristics of the Data Acquisition System
Form 22

| Laboratory: SR | EOT Date: 20120203 |
|---|---|
| Test Number: * 65-404-222-9 | |
| Oil Code: LO-268869 | |
| Formulation / Stand Code: | |

**Test Number is: Stand - Stand Run No. - Engine No. - Engine Run No.*

| Parameter (1) | Sensing Device (2) | Calibration Frequency (3) | Record Device (4) | Observation Frequency (5) | Record Frequency (6) | Log Frequency (7) | System Response (8) |
|---|---|---|---|---|---|---|---|
| **Temperatures** | | | | | | | |
| Main Oil G. | Thermocouple | Every ref test | C/D | 0 | 0 | 1 per min | 2.0s |
| Fuel In. | Thermocouple | Every ref test | C/D | 0 | 0 | 1 per min | 2.0s |
| Intake Air | Thermocouple | Every ref test | C/D | 0 | 0 | 1 per min | 2.0s |
| Oil Sump | Thermocouple | Every ref test | C/D | 0 | 0 | 1 per min | 2.0s |
| Exhaust | Thermocouple | Every ref test | C/D | 0 | 0 | 1 per min | 2.0s |
| Coolant Out | Thermocouple | Every ref test | C/D | 0 | 0 | 1 per min | 2.0s |
| **Other** | | | | | | | |
| Fuel Flow | Mass Flow | Every ref test | C/D | 0 | 0 | 1 per min | 2.5s |
| Engine RPM | Magnetic | Every ref test | C/D | 0 | 0 | 1 per min | 0.5s |
| Load | Strain Gage | Every ref test | C/D | 0 | 0 | 1 per min | 0.5s |
| Intake Press. | Mechanical | Every ref test | C/D | 0 | 0 | 1 per min | N/A |
| Exhaust Press. | Mechanical | Every ref test | C/D | 0 | 0 | 1 per min | N/A |
| Oil Gallery Press. | Mechanical | Every ref test | C/D | 0 | 0 | 1 per min | N/A |

**Legend:**

(1) Operating Parameter
(2) The Type of Device Used to Measure Temperature, Pressure or Flow
  T/C - Thermocouple
(3) Frequency at Which the Measurement System is Calibrated
(4) The Type of Device Where Data is Recorded
  LG - Handlog Sheet
  DL - Automatic Data Logger
  SC - Strip Chart Recorded
  C/M - Computer, Using Manual Data Entry
  C/D - Computer, Using Direct I/O Entry
(5) Data are Observed but Only if Recorded Off Spec.
(6) Data are Recorded but are not Retained at EOT
(7) Data are Logged as Permanent Record, Note Specify if:
  SS - Snapshot Taken at Specified Frequency
  AG/X Average of X Data Points at Specified Frequency
(8) Time for the Output to Reach 63.2% of Final Value for Step Change at Input

| | |
|---|---|
| **Laboratory:** SR | **EOT Date:** 20120203 |
| **Test Number: *** 65-404-222-9 | |
| **Oil Code:** LO-268869 | |
| **Formulation / Stand Code:** | |

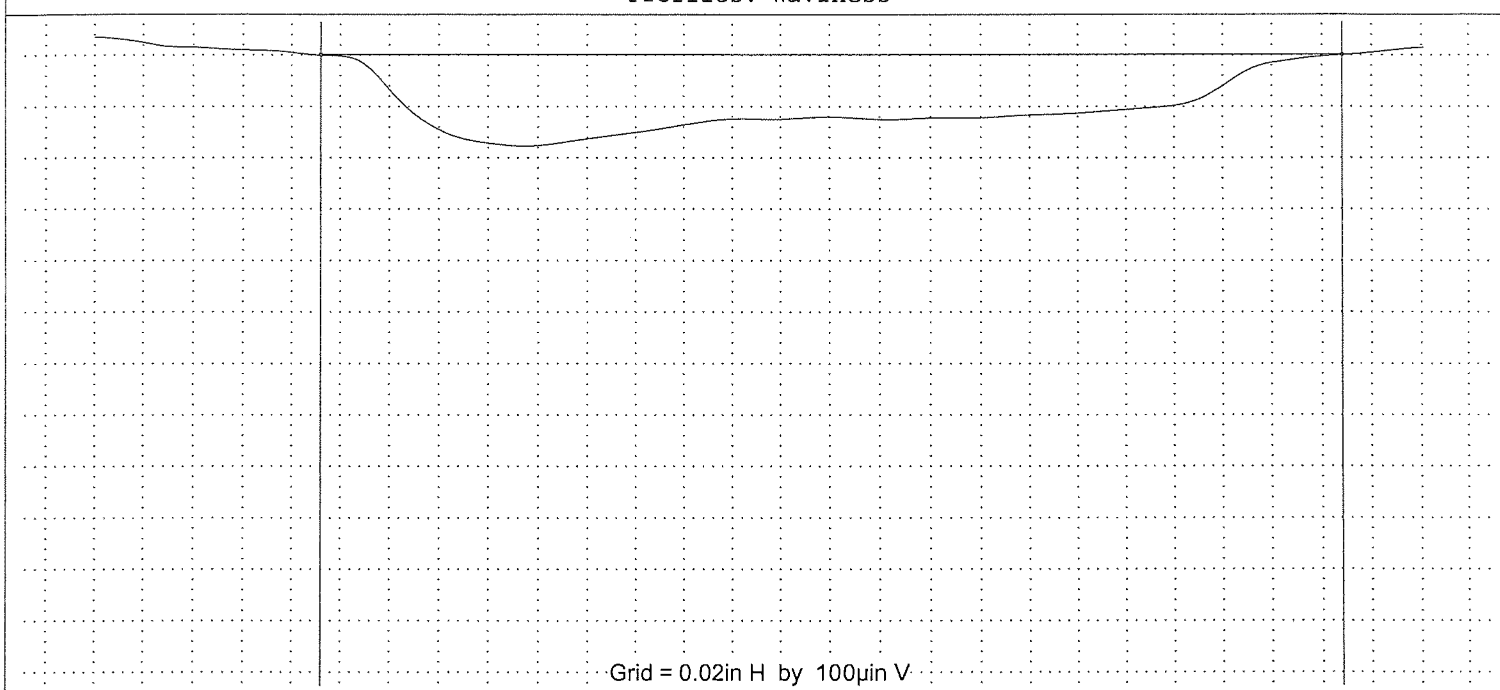
**Test Number is: Stand - Stand Run No. - Engine No. - Engine Run No.*

## Appendix A

### Roller Follower Wear Test Traces

1. Profilometer Traces 1-8 (Right and Left) (8 pages)

Profiles: Waviness



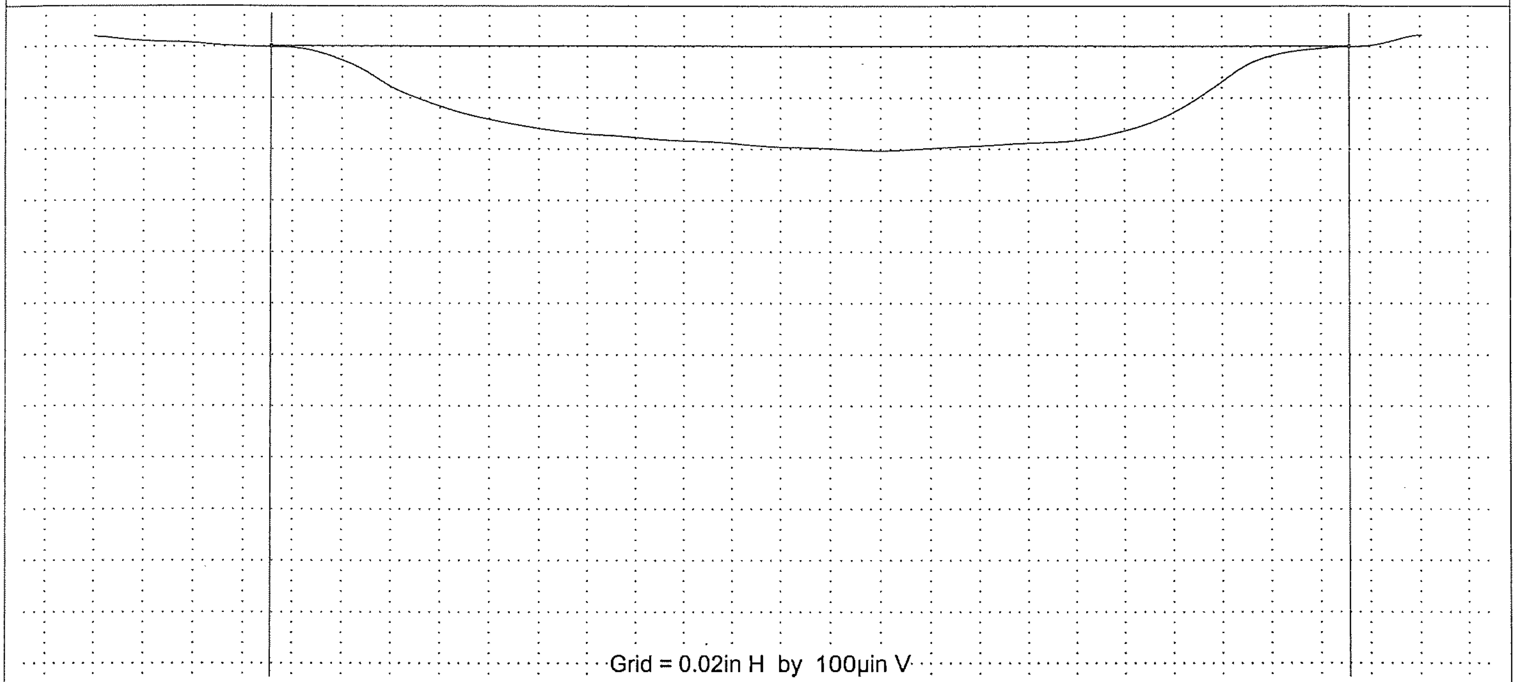

Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Mon Feb 06 09:29 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin R1
  Run 65-404-222-9
  File: C:\S-2000-2\DATA\RFWT\40422209.
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Parameters

| PARAMETER | VALUE | UNITS |
|---|---|---|
| Summary | | |
| Standards System = ANSI/ASME B46.1 1995 | | |
| Waviness Parameters: | | |
| Wt | 177.4 | µin |

Profiles: Waviness




Settings

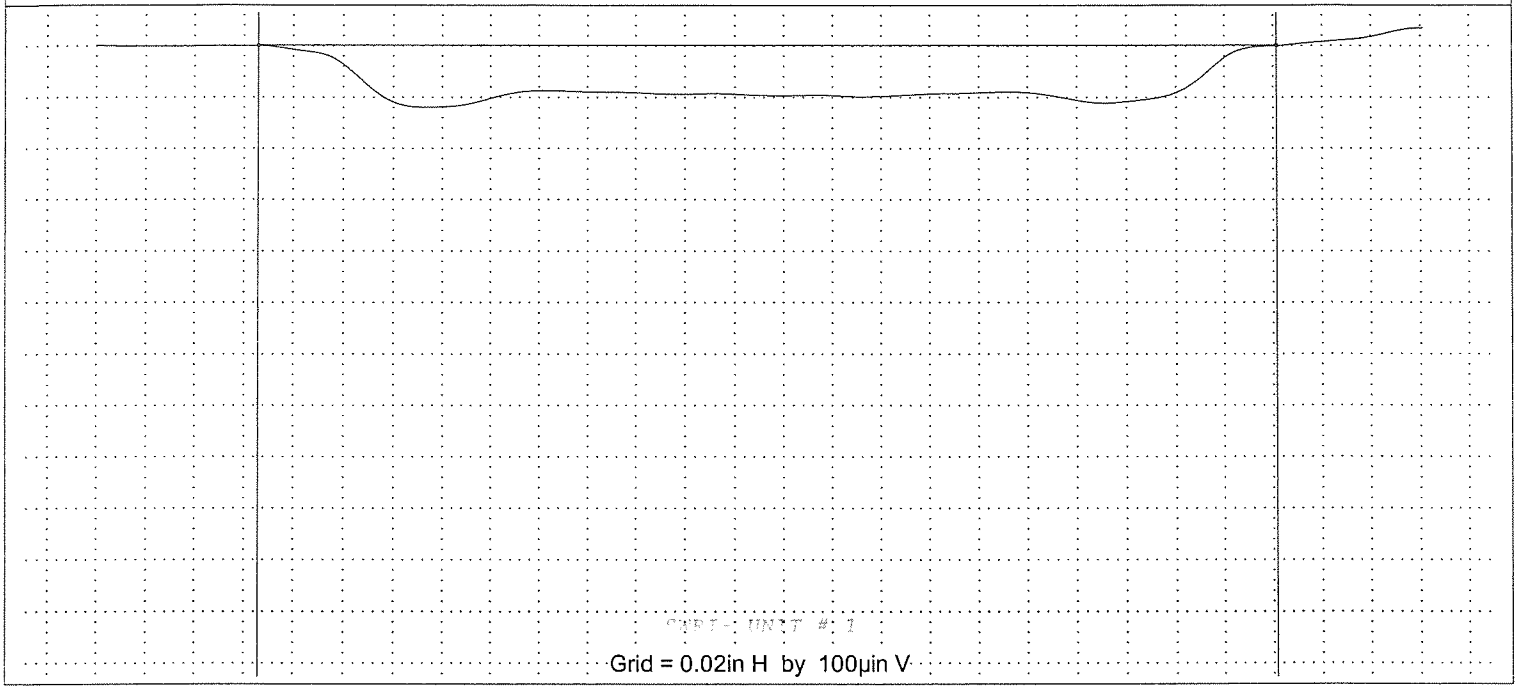
Software: 2.46; Advanced; 3.95
Data
  Collected: Mon Feb 06 09:31 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin R2
  Run 65-404-222-9
  File: C:\S-2000-2\DATA\RFWT\40422209.A
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Parameters

| PARAMETER | VALUE | UNITS |
|---|---|---|
| Summary | | |
| Standards System = ANSI/ASME B46.1 1995 | | |
| Waviness Parameters: | | |
| Wt | 203.2 | µin |

Instrument

Profiles: Waviness




Settings

```
Software: 2.46; Advanced; 3.95
Data
  Collected: Mon Feb 06 09:33 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin R3
  Run 65-404-222-9
  File: C:\S-2000-2\DATA\RFWT\40422209.
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter
```

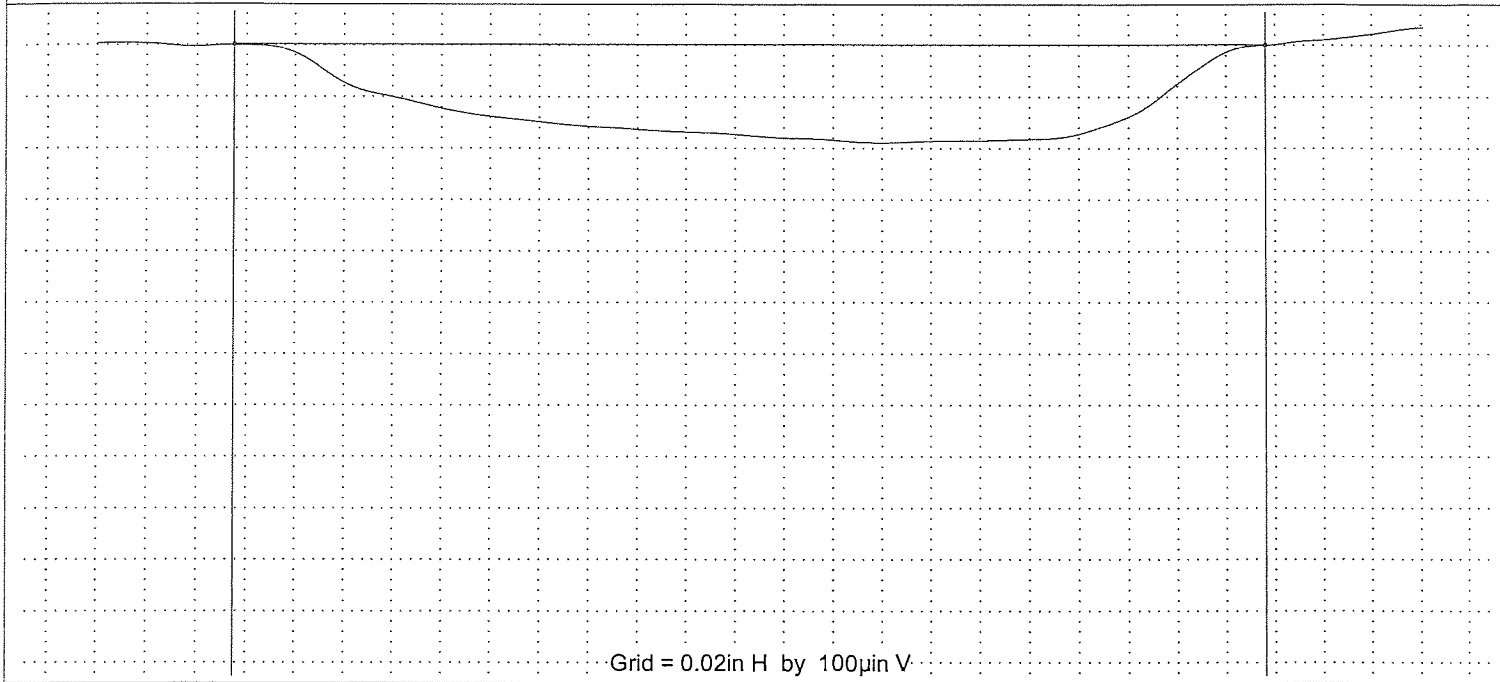
Run 65-404-222-9

Parameters

```
  PARAMETER     VALUE     UNITS
  ---------     -----     -----
Summary
  Standards System = ANSI/ASME B46.1 1995
Waviness Parameters:
  Wt            119.9     µin
```

Parameters

Profiles: Waviness



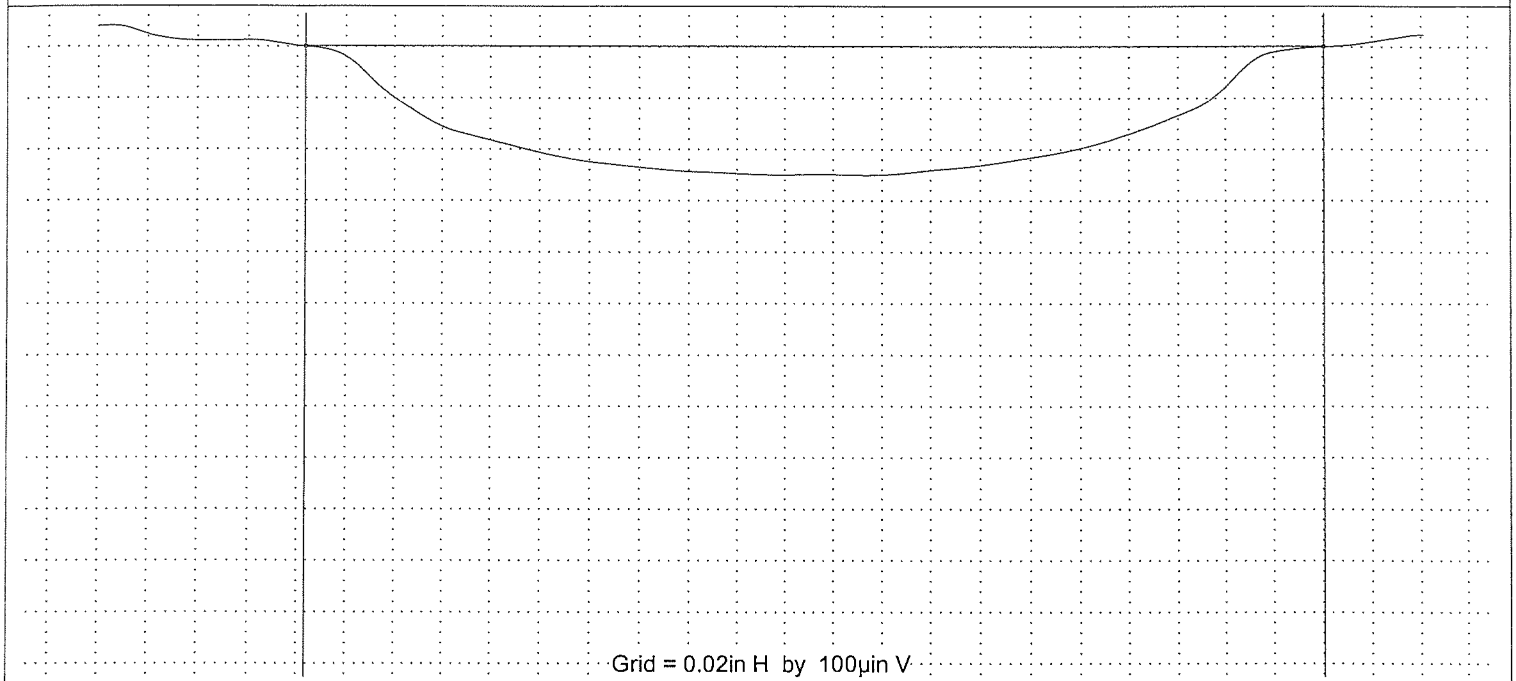

Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Mon Feb 06 09:35 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin R4
  Run 65-404-222-9
  File: C:\S-2000-2\DATA\RFWT\40422209.
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Parameters

| PARAMETER | VALUE | UNITS |
|---|---|---|
| Summary | | |
| Standards System = ANSI/ASME B46.1 1995 | | |
| Waviness Parameters: | | |
| Wt | 189.1 | µin |

Profiles: Waviness



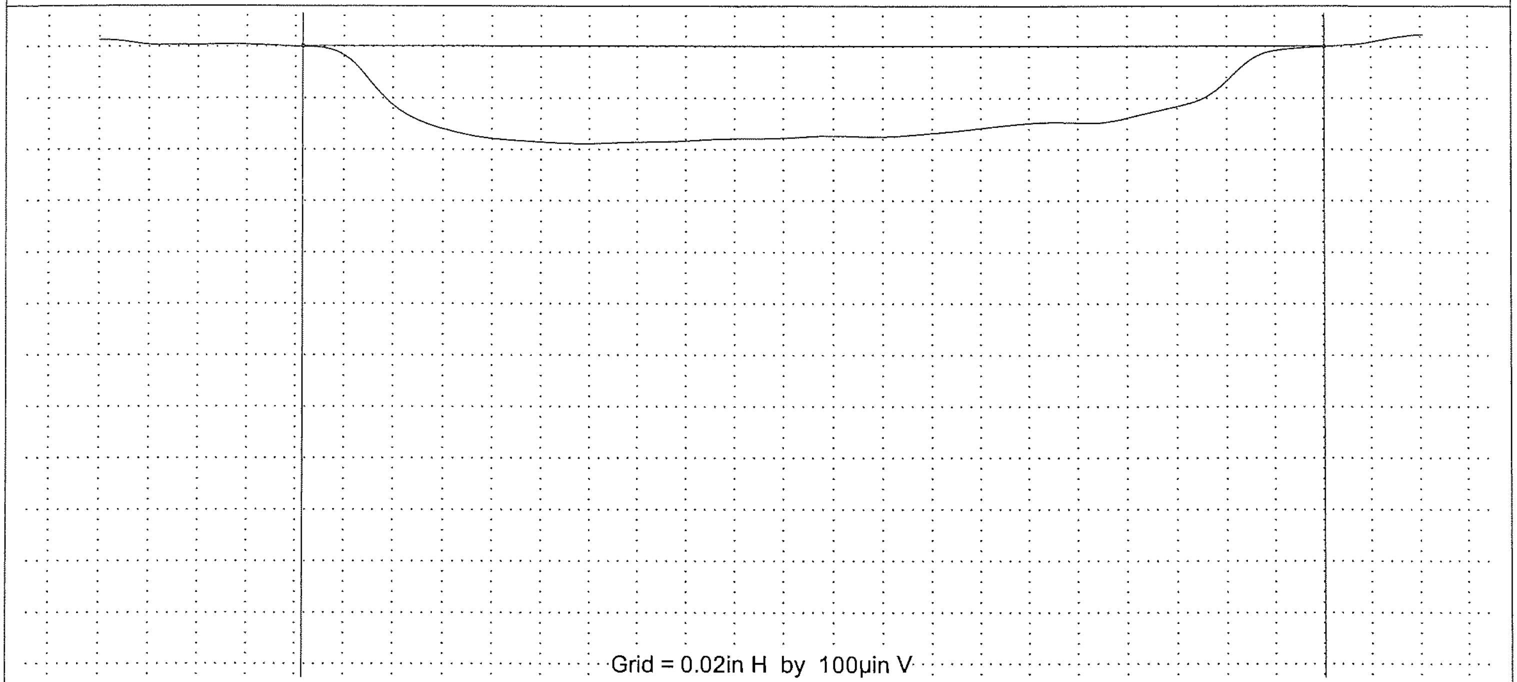

Settings

Software: 2.46; Advanced; 3.95
Data
Collected: Mon Feb 06 09:38 2012
By: Kerry McCubbin
At: SWRI- UNIT # 1
Tracer Used: PDT-2-522
Sampled Length: 0.541 in
Sample Spacing: 18.9 µin
Description
RFWT, Pin R5
Run 65-404-222-9
File: C:\S-2000-2\DATA\RFWT\40422209.
Instrument
Name: MicroAnalyzer 2000
Serial #: S-2000-3027
Current Tracer:PDT-2-522
Travel Distance: 0.541 in
Trace Velocity: 0.030 in/s
Form
Form Type: Two-Point Line
Roughness Filter
Type: Gaussian
Cutoff: 0.030 in
No Filter Width Removal at Ends
Parameter Calculation Settings
Peak Count Threshold: 19.7 µin
High Spot Count Threshold: 19.7 µin
tp Reference Percent: 5 %
tp Slice Depth: 19.7 µin
Short Wavelength Filter
Type: Gaussian
Cutoff: 0.0001 in
Waviness Filter
Type: No Filter

Parameters

| PARAMETER | VALUE | UNITS |
|---|---|---|
| Summary | | |
| Standards System = ANSI/ASME B46.1 1995 | | |
| Waviness Parameters: | | |
| Wt | 250.7 | µin |

Profiles: Waviness



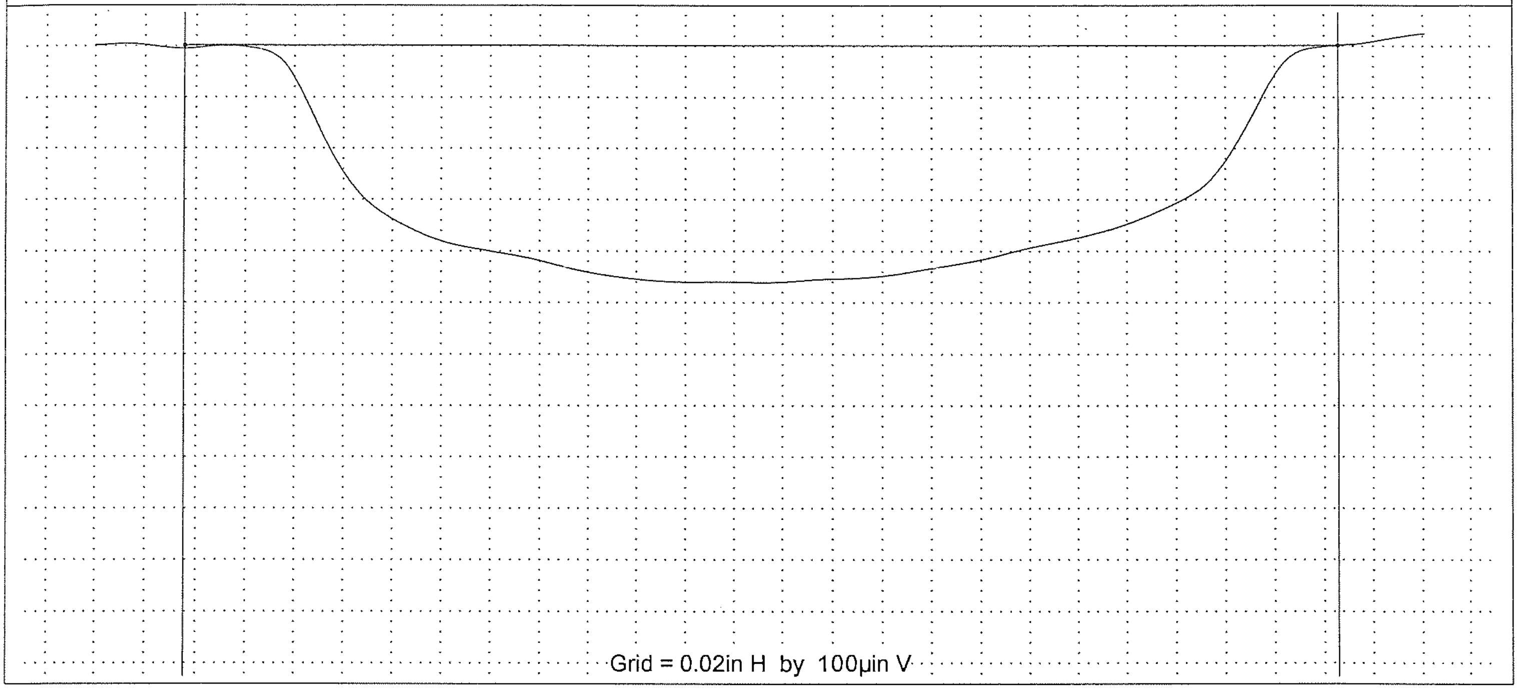

**Settings**

```
Software: 2.46; Advanced; 3.95
Data
  Collected: Mon Feb 06 09:40 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin R6
  Run 65-404-222-9
  File: C:\S-2000-2\DATA\RFWT\40422209.
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter
```

**Parameters**

```
  PARAMETER    VALUE     UNITS
  ---------    -----     -----
Summary
  Standards System = ANSI/ASME B46.1 1995
Waviness Parameters:
  Wt           188.8     µin
```

Profiles: Waviness

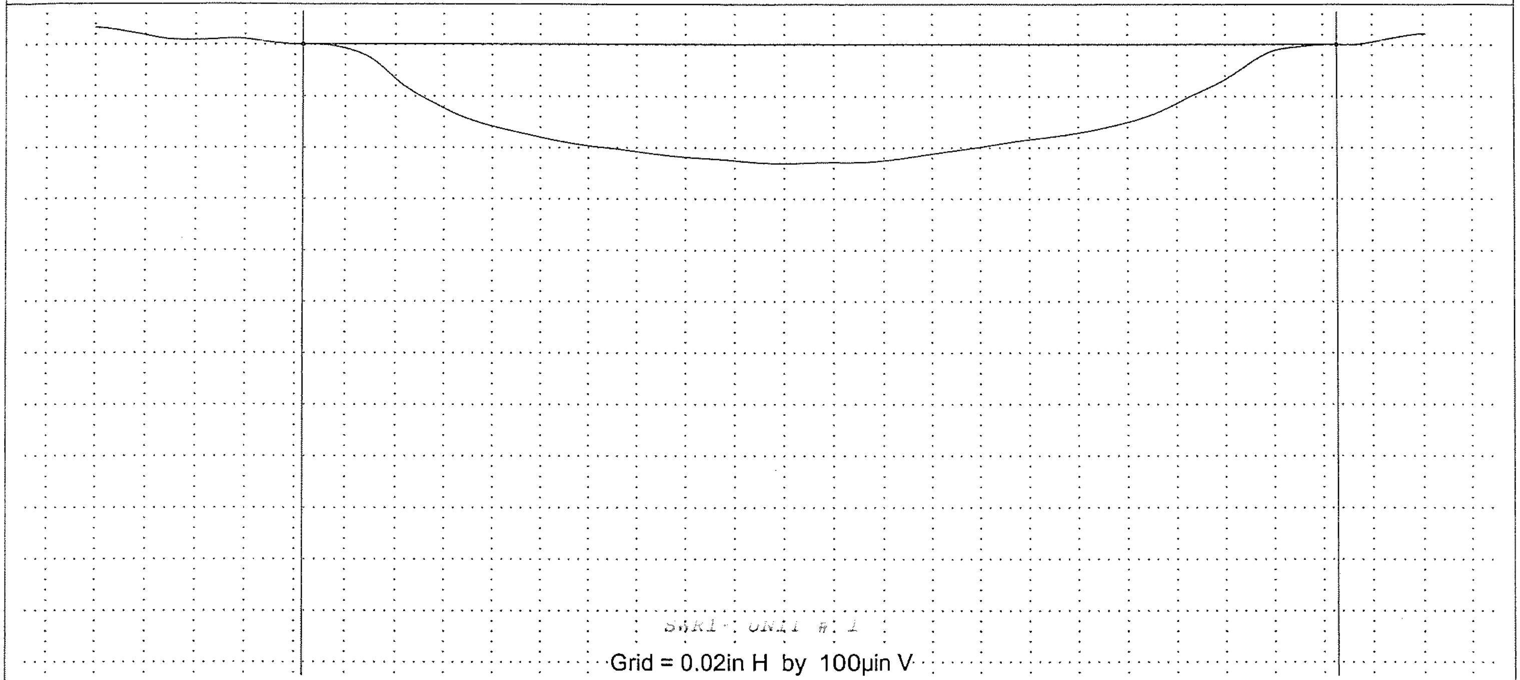



| Settings |
| --- |
| Software: 2.46; Advanced; 3.95 |
| Data |
| Collected: Mon Feb 06 09:42 2012 |
| By: Kerry McCubbin |
| At: SWRI- UNIT # 1 |
| Tracer Used: PDT-2-522 |
| Sampled Length: 0.541 in |
| Sample Spacing: 18.9 µin |
| Description |
| RFWT, Pin R7 |
| Run 65-404-222-9 |
| File: C:\S-2000-2\DATA\RFWT\40422209.I |
| Instrument |
| Name: MicroAnalyzer 2000 |
| Serial #: S-2000-3027 |
| Current Tracer:PDT-2-522 |
| Travel Distance: 0.541 in |
| Trace Velocity: 0.030 in/s |
| Form |
| Form Type: Two-Point Line |
| Roughness Filter |
| Type: Gaussian |
| Cutoff: 0.030 in |
| No Filter Width Removal at Ends |
| Parameter Calculation Settings |
| Peak Count Threshold: 19.7 µin |
| High Spot Count Threshold: 19.7 µin |
| tp Reference Percent: 5 % |
| tp Slice Depth: 19.7 µin |
| Short Wavelength Filter |
| Type: Gaussian |
| Cutoff: 0.0001 in |
| Waviness Filter |
| Type: No Filter |

Parameters

| PARAMETER | VALUE | UNITS |
| --- | --- | --- |
| Summary | | |
| Standards System = ANSI/ASME B46.1 1995 | | |
| Waviness Parameters: | | |
| Wt | 462.2 | µin |

Profiles: Waviness



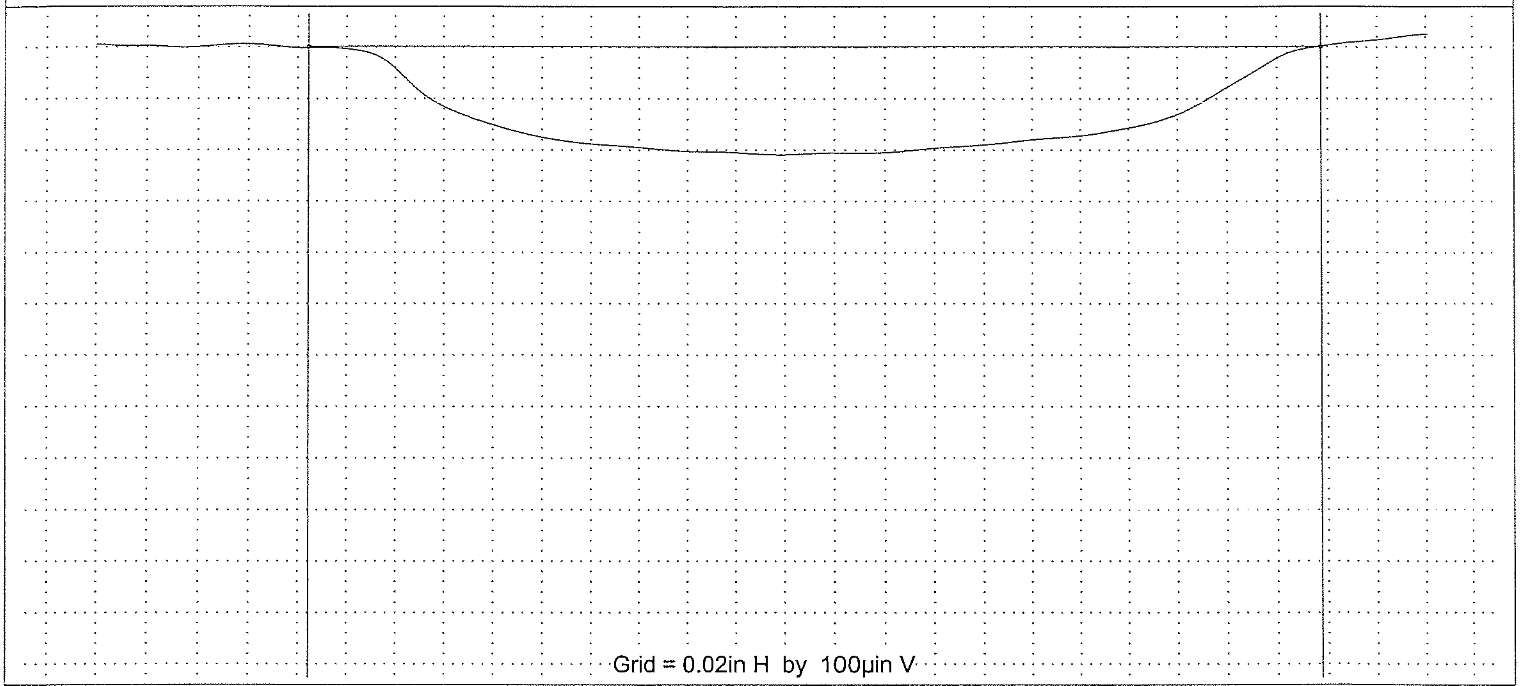

Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Mon Feb 06 09:43 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin R8
  Run 65-404-222-9
  File: C:\S-2000-2\DATA\RFWT\40422209.A
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Parameters

| PARAMETER | VALUE | UNITS |
|---|---|---|
| Summary | | |
| Standards System = ANSI/ASME B46.1 1995 | | |
| Waviness Parameters: | | |
| Wt | 231.6 | µin |

## Profiles: Waviness



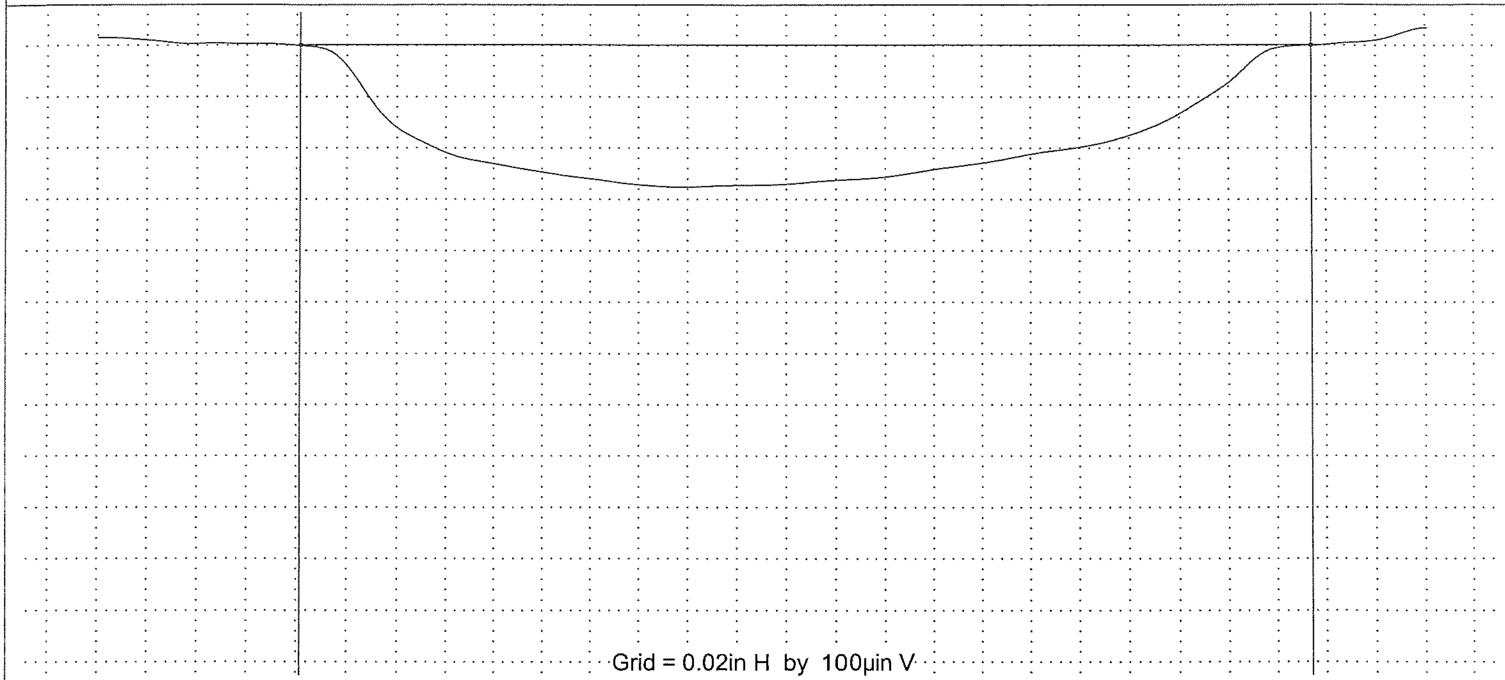

### Settings

```
Software: 2.46; Advanced; 3.95
Data
  Collected: Mon Feb 06 09:09 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin L1
  Run 65-404-222-9
  File: C:\S-2000-2\DATA\RFWT\40422209.A
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter
```

### Parameters

| PARAMETER | VALUE | UNITS |
|---|---|---|
| Summary | | |
| Standards System = ANSI/ASME B46.1 1995 | | |
| Waviness Parameters: | | |
| Wt | 210.5 | µin |

Profiles: Waviness



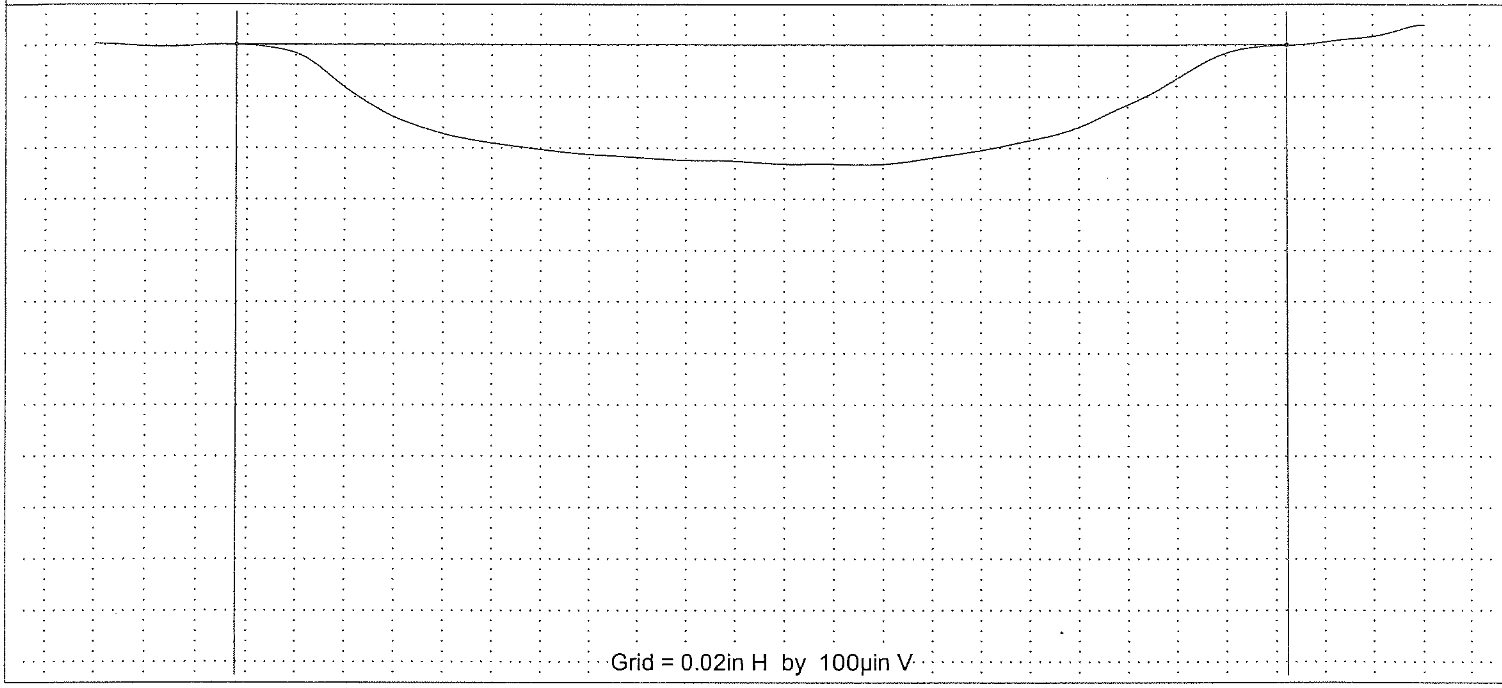

Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Mon Feb 06 09:13 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin L2
  Run 65-404-222-9
  File: C:\S-2000-2\DATA\RFWT\40422209.A
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Parameters

| PARAMETER | VALUE | UNITS |
|---|---|---|
| Summary | | |
| Standards System = ANSI/ASME B46.1 1995 | | |
| Waviness Parameters: | | |
| Wt | 276.5 | µin |

Profiles: Waviness




## Settings

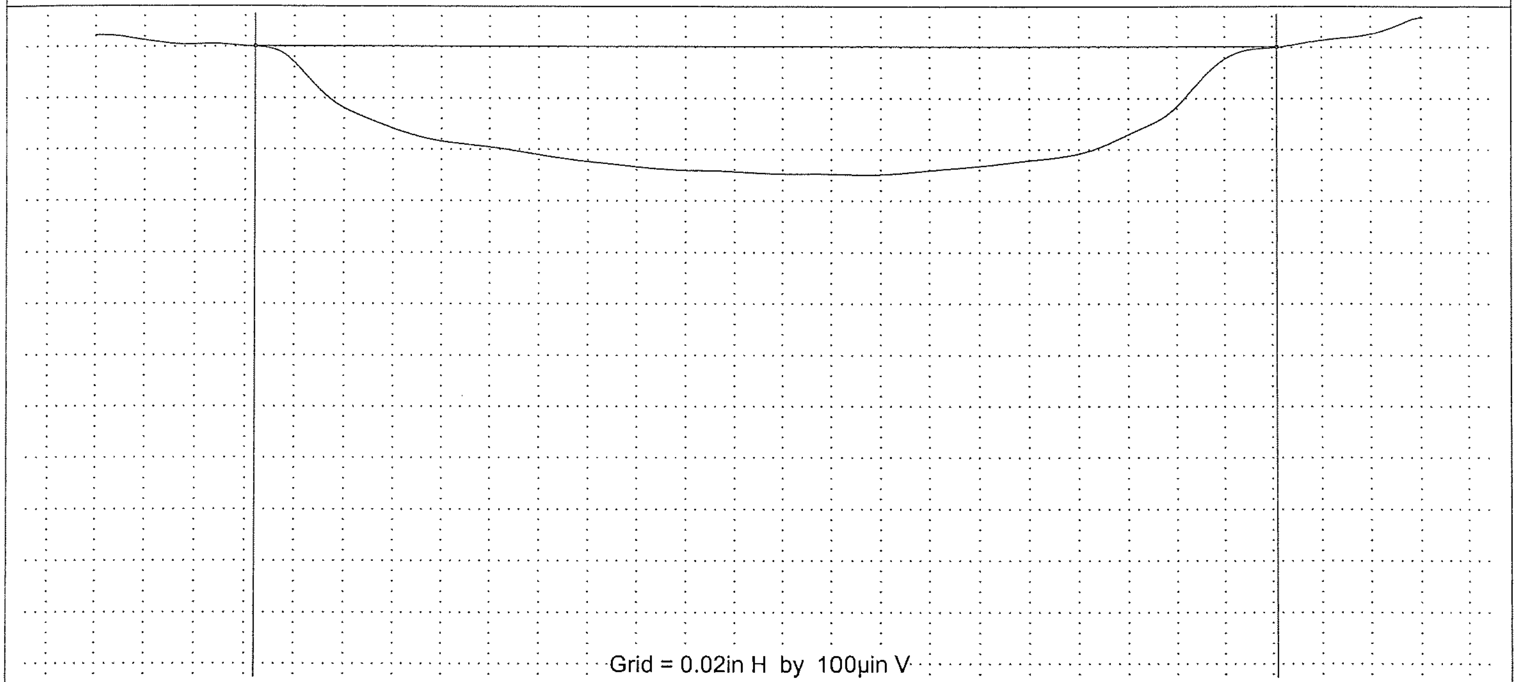
Software: 2.46; Advanced; 3.95
Data
  Collected: Mon Feb 06 09:14 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin L3
  Run 65-404-222-9
  File: C:\S-2000-2\DATA\RFWT\40422209.A
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

## Parameters

| PARAMETER | VALUE | UNITS |
|---|---|---|
| Summary | | |
| Standards System = ANSI/ASME B46.1 1995 | | |
| Waviness Parameters: | | |
| Wt | 233.2 | µin |

Wt 233.2 µin

Profiles: Waviness

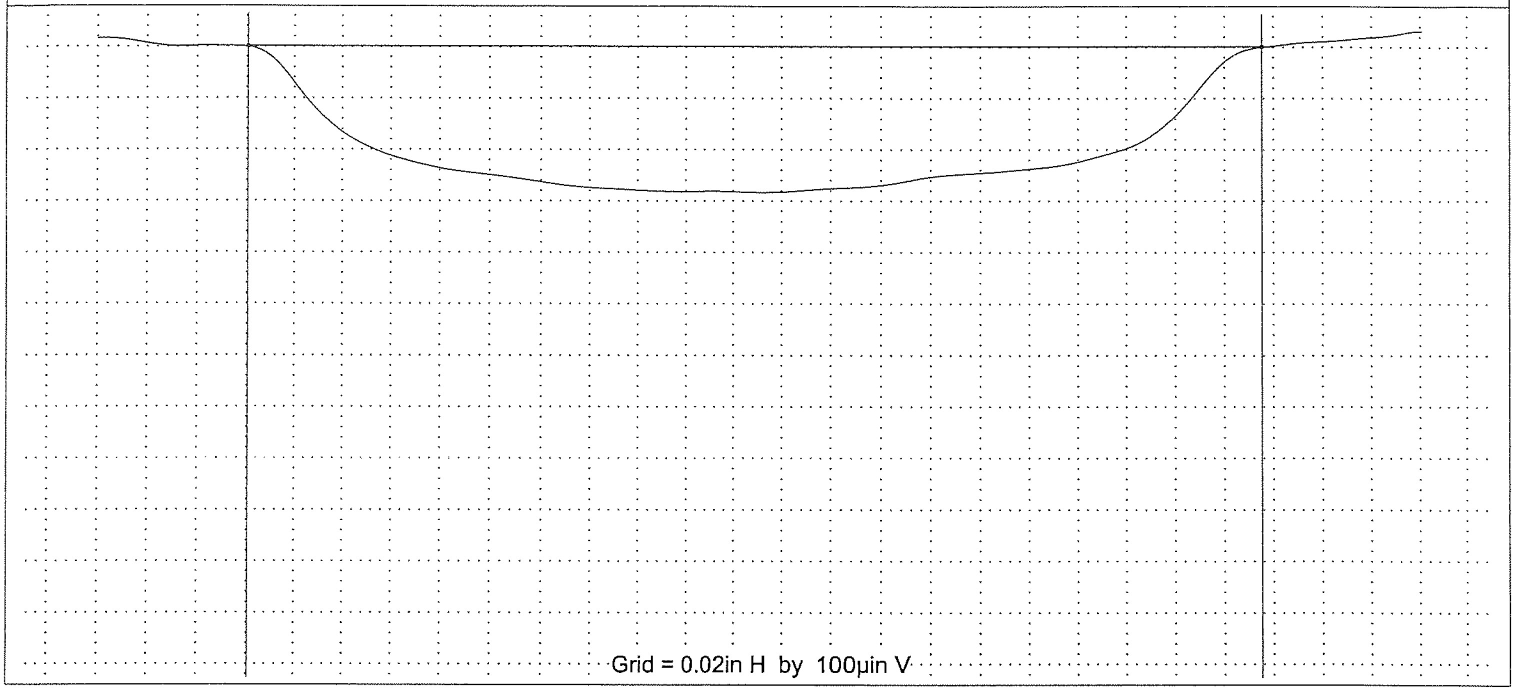



| Settings |
|---|
| Software: 2.46; Advanced; 3.95 |
| Data |
| Collected: Mon Feb 06 09:17 2012 |
| By: Kerry McCubbin |
| At: SWRI- UNIT # 1 |
| Tracer Used: PDT-2-522 |
| Sampled Length: 0.541 in |
| Sample Spacing: 18.9 μin |
| Description |
| RFWT, Pin L4 |
| Run 65-404-222-9 |
| File: C:\S-2000-2\DATA\RFWT\40422209.F |
| Instrument |
| Name: MicroAnalyzer 2000 |
| Serial #: S-2000-3027 |
| Current Tracer:PDT-2-522 |
| Travel Distance: 0.541 in |
| Trace Velocity: 0.030 in/s |
| Form |
| Form Type: Two-Point Line |
| Roughness Filter |
| Type: Gaussian |
| Cutoff: 0.030 in |
| No Filter Width Removal at Ends |
| Parameter Calculation Settings |
| Peak Count Threshold: 19.7 μin |
| High Spot Count Threshold: 19.7 μin |
| tp Reference Percent: 5 % |
| tp Slice Depth: 19.7 μin |
| Short Wavelength Filter |
| Type: Gaussian |
| Cutoff: 0.0001 in |
| Waviness Filter |
| Type: No Filter |

Parameters

| PARAMETER | VALUE | UNITS |
|---|---|---|
| Summary | | |
| Standards System = ANSI/ASME B46.1 1995 | | |
| Waviness Parameters: | | |
| Wt | 249.4 | μin |

Profiles: Waviness

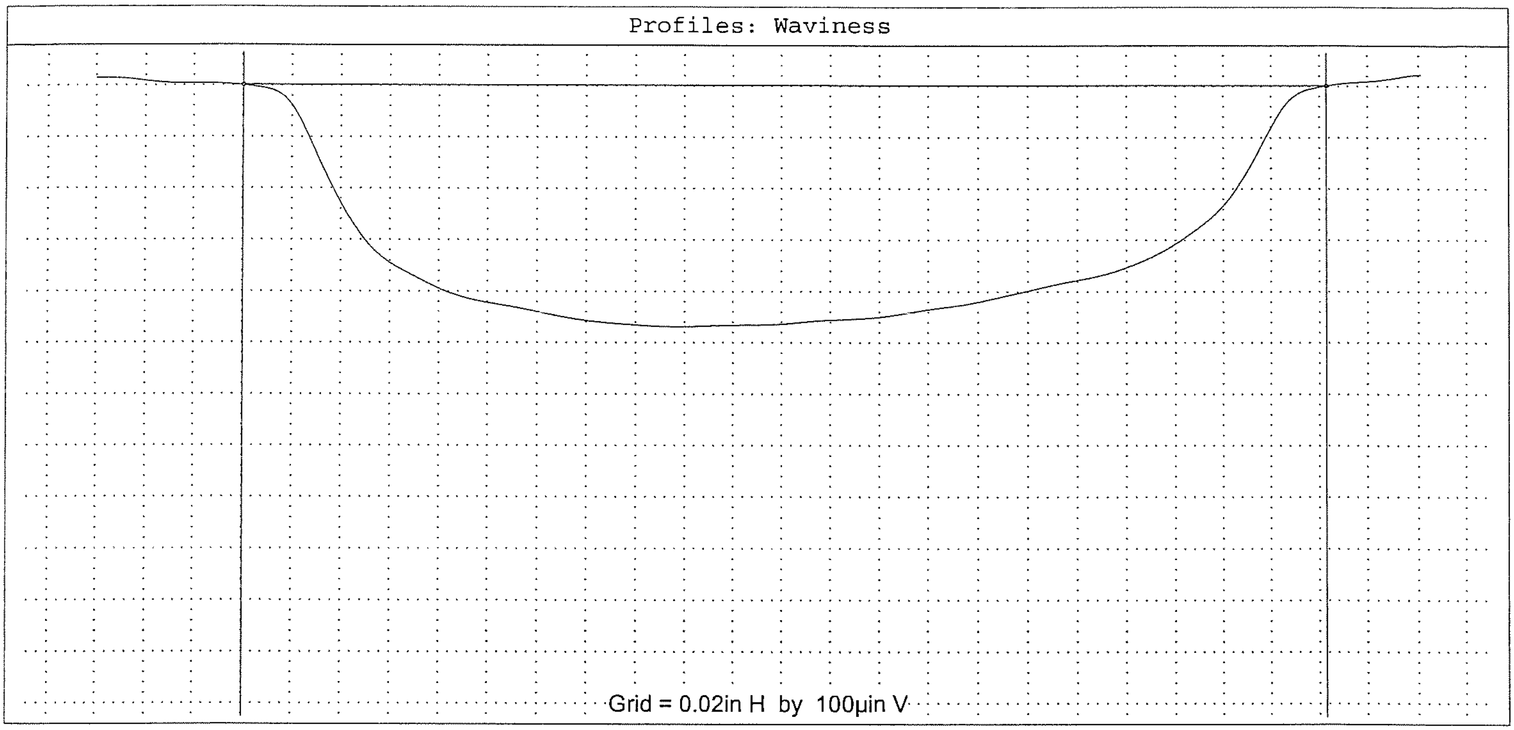



Settings

Software: 2.46; Advanced; 3.95
Data
Collected: Mon Feb 06 09:20 2012
By: Kerry McCubbin
At: SWRI- UNIT # 1
Tracer Used: PDT-2-522
Sampled Length: 0.541 in
Sample Spacing: 18.9 µin
Description
RFWT, Pin L5
Run 65-404-222-9
File: C:\S-2000-2\DATA\RFWT\40422209.
Instrument
Name: MicroAnalyzer 2000
Serial #: S-2000-3027
Current Tracer:PDT-2-522
Travel Distance: 0.541 in
Trace Velocity: 0.030 in/s
Form
Form Type: Two-Point Line
Roughness Filter
Type: Gaussian
Cutoff: 0.030 in
No Filter Width Removal at Ends
Parameter Calculation Settings
Peak Count Threshold: 19.7 µin
High Spot Count Threshold: 19.7 µin
tp Reference Percent: 5 %
tp Slice Depth: 19.7 µin
Short Wavelength Filter
Type: Gaussian
Cutoff: 0.0001 in
Waviness Filter
Type: No Filter

Parameters

| PARAMETER | VALUE | UNITS |
|---|---|---|
| Summary | | |
| Standards System = ANSI/ASME B46.1 1995 | | |
| Waviness Parameters: | | |
| Wt | 283.2 | µin |



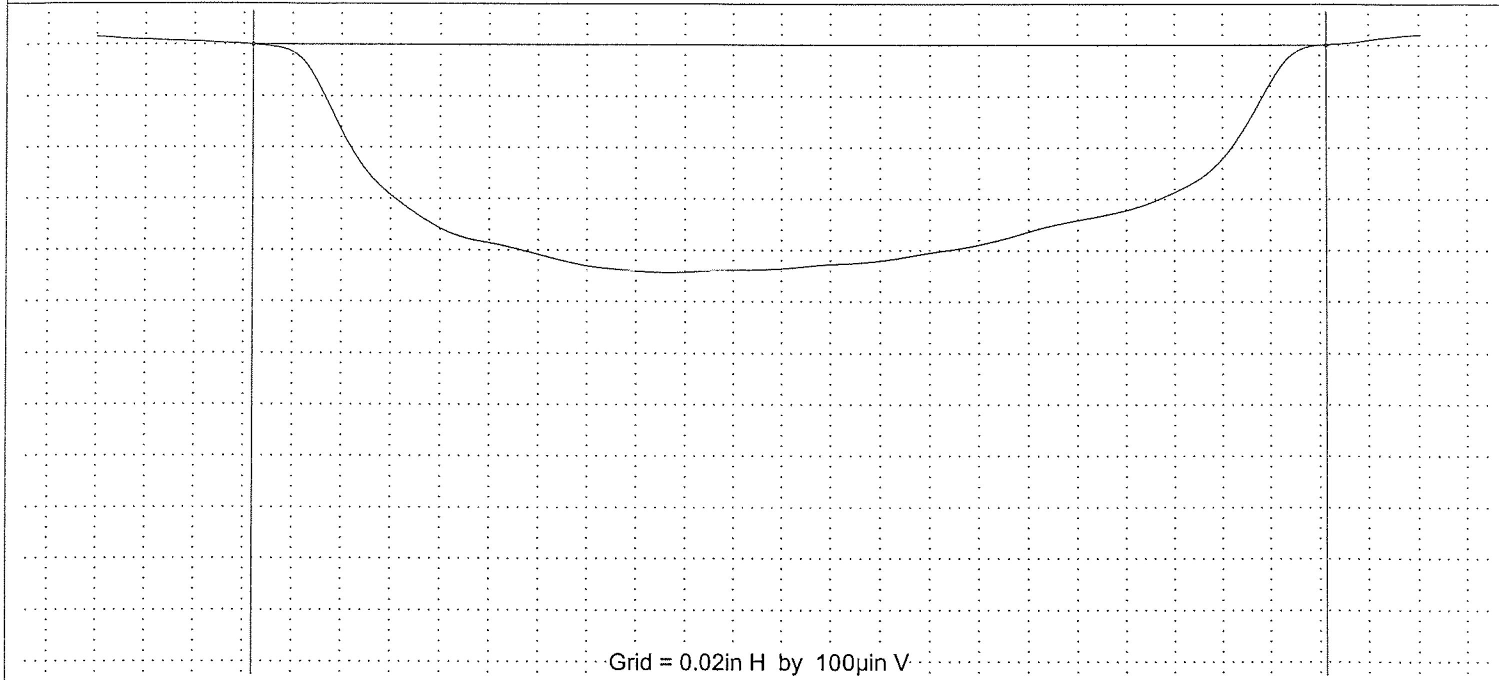

| Settings |
|---|
| Software: 2.46; Advanced; 3.95 |
| Data |
| Collected: Mon Feb 06 09:22 2012 |
| By: Kerry McCubbin |
| At: SWRI- UNIT # 1 |
| Tracer Used: PDT-2-522 |
| Sampled Length: 0.541 in |
| Sample Spacing: 18.9 µin |
| Description |
| RFWT, Pin L6 |
| Run 65-404-222-9 |
| File: C:\S-2000-2\DATA\RFWT\40422209.P |
| Instrument |
| Name: MicroAnalyzer 2000 |
| Serial #: S-2000-3027 |
| Current Tracer:PDT-2-522 |
| Travel Distance: 0.541 in |
| Trace Velocity: 0.030 in/s |
| Form |
| Form Type: Two-Point Line |
| Roughness Filter |
| Type: Gaussian |
| Cutoff: 0.030 in |
| No Filter Width Removal at Ends |
| Parameter Calculation Settings |
| Peak Count Threshold: 19.7 µin |
| High Spot Count Threshold: 19.7 µin |
| tp Reference Percent: 5 % |
| tp Slice Depth: 19.7 µin |
| Short Wavelength Filter |
| Type: Gaussian |
| Cutoff: 0.0001 in |
| Waviness Filter |
| Type: No Filter |
| RFWT, Pin L6 |

Parameters

| PARAMETER | VALUE | UNITS |
|---|---|---|
| Summary | | |
| Standards System = ANSI/ASME B46.1 1995 | | |
| Waviness Parameters: | | |
| Wt | 469.5 | µin |

Parameters

Profiles: Waviness



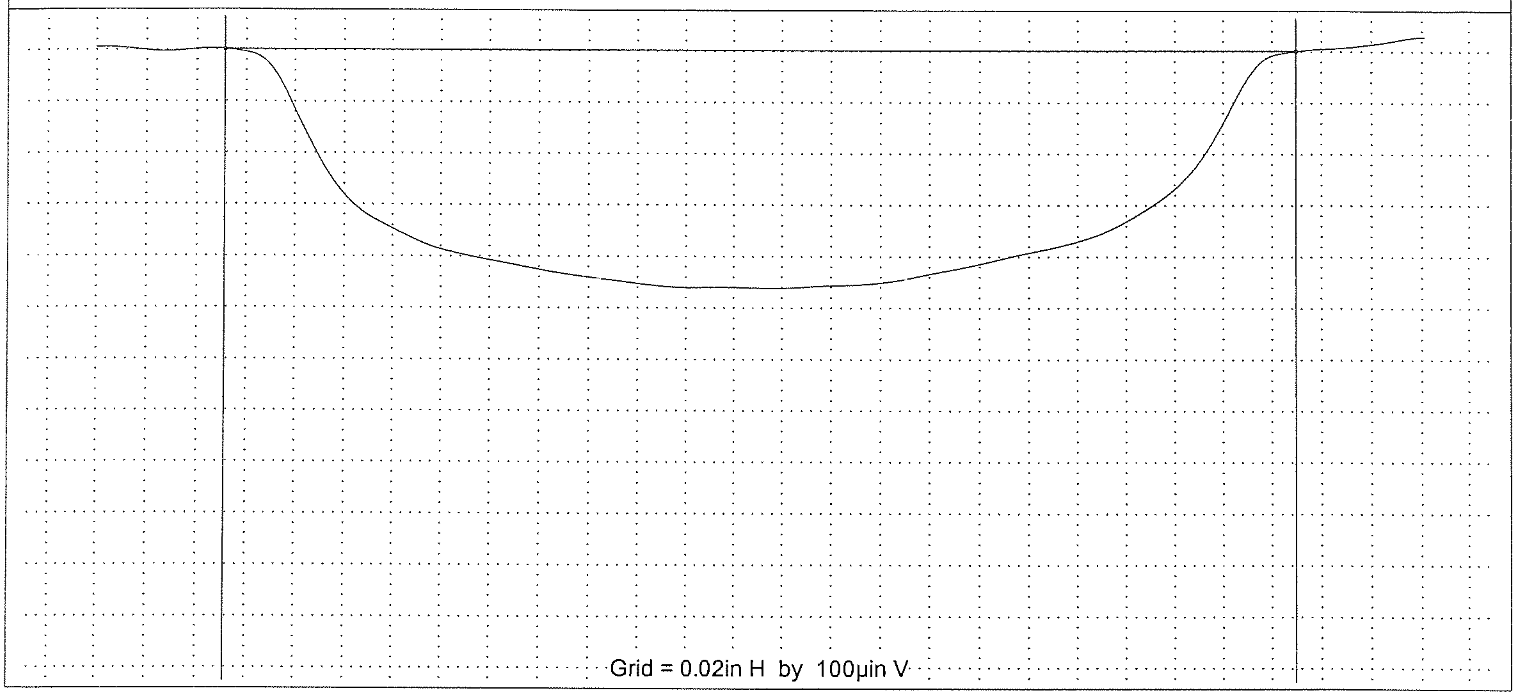

Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Mon Feb 06 09:24 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin L7
  Run 65-404-222-9
  File: C:\S-2000-2\DATA\RFWT\40422209.A
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Parameters

| PARAMETER | VALUE | UNITS |
|---|---|---|
| Summary | | |
| Standards System = ANSI/ASME B46.1 1995 | | |
| Waviness Parameters: | | |
| Wt | 444.5 | µin |

Profiles: Waviness




Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Mon Feb 06 09:26 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin L8
  Run 65-404-222-9
  File: C:\S-2000-2\DATA\RFWT\40422209.
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Parameters

| PARAMETER | VALUE | UNITS |
|---|---|---|
| Summary | | |
| Standards System = ANSI/ASME B46.1 1995 | | |
| Waviness Parameters: | | |
| Wt | 463.4 | µin |

| | |
|---|---|
| **Laboratory:** SR | **EOT Date:** 20120203 |
| **Test Number: *** 65-404-222-9 | |
| **Oil Code:** LO-268869 | |
| **Formulation / Stand Code:** | |

**Test Number is: Stand - Stand Run No. - Engine No. - Engine Run No.*

**Appendix B**

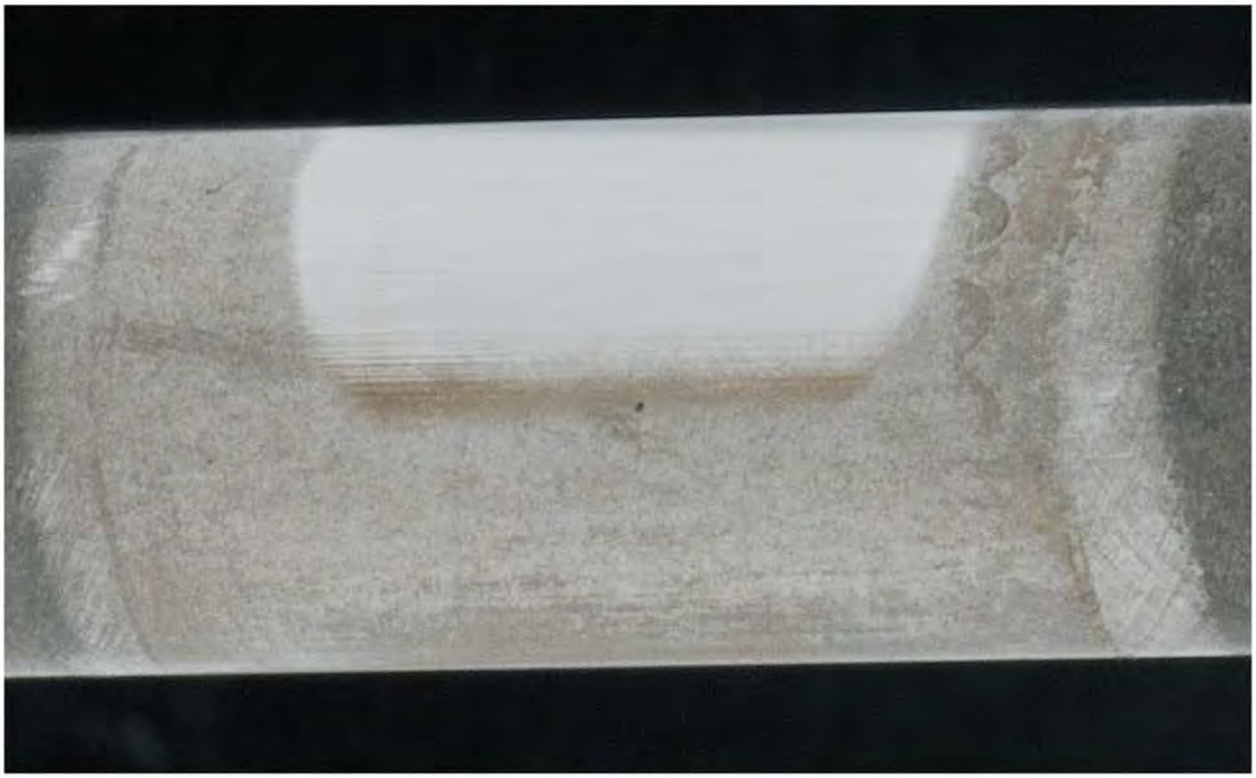
**Roller Follower Wear Test Photographs**

1. Roller Follower Axle Pin Wear Best
2. Roller Follower Axle Pin Wear Worst

## Roller Follower Wear Test

| | | | |
|---|---|---|---|
| **Laboratory:** | SR | **Oil Code:** | LO-268869 |
| **Test Stand No.:** | 65 | **Test No.:** | 65-404-222-9 |
| **Laboratory Oil Code:** | 268869 | **Test Hours:** | 50 |
| **Formulation / Stand Code:** | | | |

### Roller Axle Wear

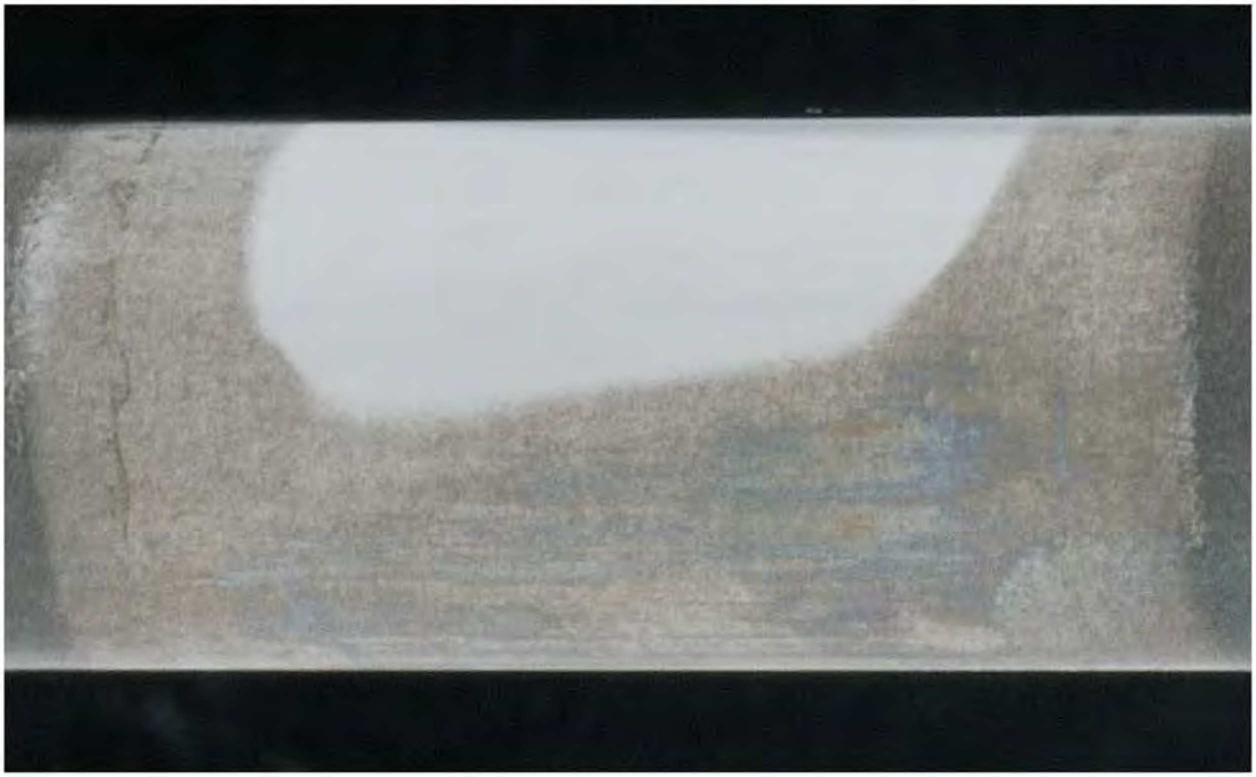


### Best 3R

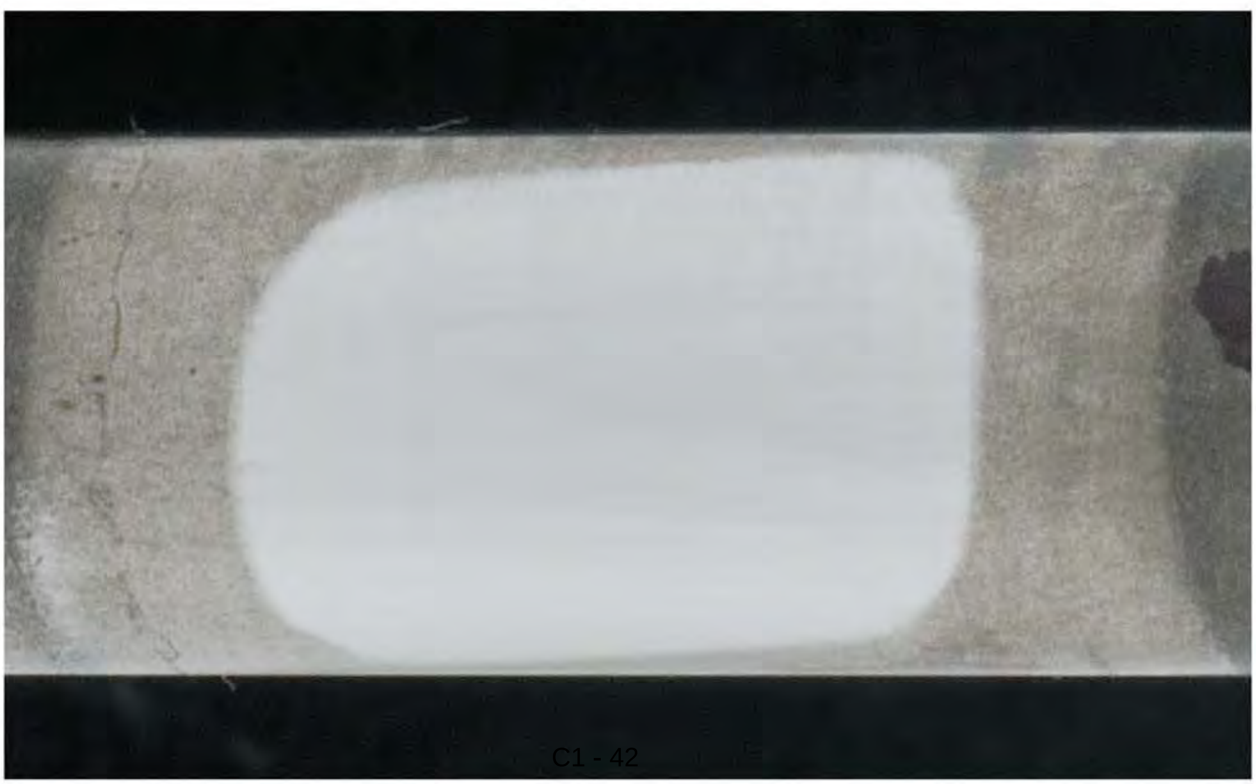
# Roller Follower Wear Test

| | | | |
|---|---|---|---|
| **Laboratory:** | SR | **Oil Code:** | LO-268869 |
| **Test Stand No.:** | 65 | **Test No.:** | 65-404-222-9 |
| **Laboratory Oil Code:** | 268869 | **Test Hours:** | 50 |
| **Formulation / Stand Code:** | | | |

## Roller Axle Wear



## Worst 6L



# APPENDIX – C2
# ROLLER FOLLOWER WEAR TEST
# LO-271510

# D 5966
# Roller Follower Wear Test

Version 20040401

**Title / Validity Declaration Page**

Conducted for

## US ARMY TARDEC

| | | |
|---|---|---|
| V | V = | Valid; The Reference Oil / Non-Reference Oil was Evaluated in Accordance with the Test Prodecure. |
| | I = | Invalid; The Reference Oil / Non-Reference Oil was Evaluated in Accordance with the Test Procedure. |

| | | | |
|---|---|---|---|
| **Stand:** 65 | **Stand Run No.:** 405 | **Engine No.:** 222 | **Engine Run No.:** 10 |
| **End of Test Date:** 20120206 | | **End of Test Time:** 05:23 CST | |
| **Oil Code:*** LO-271510 | | | |
| **Formulation / Stand Code:**[A] | | | |
| **Alternate Codes:**[B] | | | |

In my opinion this test has been conducted in a valid manner in accordance with the Test Method D 5966 and the appropriate amendments through the information letter system. The remarks included in the report describe the anomalies associated with this test.

The results of this report relate only to the items tested.

This report shall not be reproduced, except in full, without the written approval of Southwest Research Institute ®.

* *CMIR or Non-Reference Oil Code*

[A] *ACC -Registered Tests Only*

[B] *When Provided or Required by Client*

Submitted by:

**Southwest Research Institute (R)**
Testing Laboratory

Signature

**Perry Grosch**
Typed Name

**Principal Research Technologist**
Title

# D 5966
## Roller Follower Wear Test
### Test Identification Cover Sheet
### Test Lab Affidavit
Form 1

**Reference Oil Test**

| Lab | Stand | Stand Run No. | Engine | Engine Run No. |
|---|---|---|---|---|
| SR | 65 | | 222 | |

| Start Date | Date Completed | EOT of Test Time | Test Length |
|---|---|---|---|
| | | | 0 |

| CMIR | TMC Oil Code | Viscosity Grade |
|---|---|---|
| | | |

| | |
|---|---|
| Laboratory Oil Code | |
| Engine Displacement | 6.5L |
| [redacted] | |

| Average Wear (mils) | [redacted] |
|---|---|
| | |

**Non-Reference Oil Test**

| Lab | Stand | Stand Run No. | Engine | Engine Run No. |
|---|---|---|---|---|
| SR | 65 | 405 | 222 | 10 |

| Start Date | Date Completed | EOT of Test Time | Test Length |
|---|---|---|---|
| 20120204 | 20120206 | 05:23 | 50 |

| Oil Code | Viscosity Grade |
|---|---|
| LO-271510 | N/A |

| | |
|---|---|
| Laboratory Oil Code | 271510 |

| Formulation / Stand Code |
|---|
| |

| Average Wear (mils) | Severity Adjustment | Adjustment Average Wear |
|---|---|---|
| 0.15 | 0.00 | 0.15 |

C2 - 3

# D 5966
## Roller Follower Wear Test
### Summary of Roller Follower Wear
Form 2

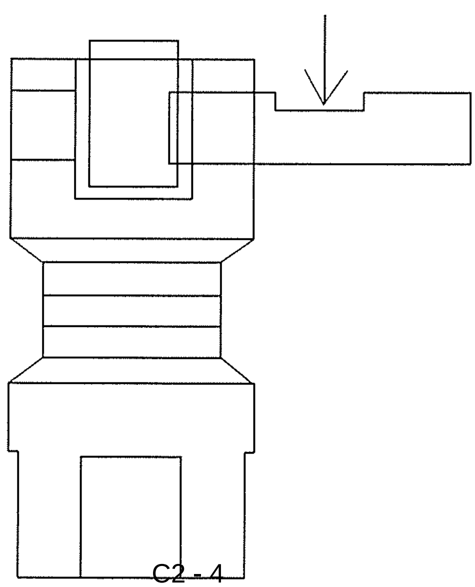
| Laboratory: SR | EOT Date: 20120206 |
|---|---|
| Test Number: * 65-405-222-10 | |
| Oil Code: LO-271510 | |
| Formulation / Stand Code: | |

*Test Number is: Stand - Stand Run No. - Engine No. - Engine Run No.*

| Lifter Part Number |
|---|
| 17109650 |

| Profilometer Wear Measurements (mils) | | | |
|---|---|---|---|
| Lifter Number | Wear (mils) | Lifter Number | Wear (mils) |
| 1L | 0.12 | 1R | 0.07 |
| 2L | 0.20 | 2R | 0.13 |
| 3L | 0.31 | 3R | 0.15 |
| 4L | 0.17 | 4R | 0.12 |
| 5L | 0.18 | 5R | 0.19 |
| 6L | 0.11 | 6R | 0.08 |
| 7L | 0.11 | 7R | 0.13 |
| 8L | 0.22 | 8R | 0.12 |
| **Wear Statistics** | | | |
| Minimum | Maximum | Average | Std. Deviation |
| 0.07 | 0.31 | 0.15 | 0.06 |

Wear is Measured at Location Shown by Arrow.



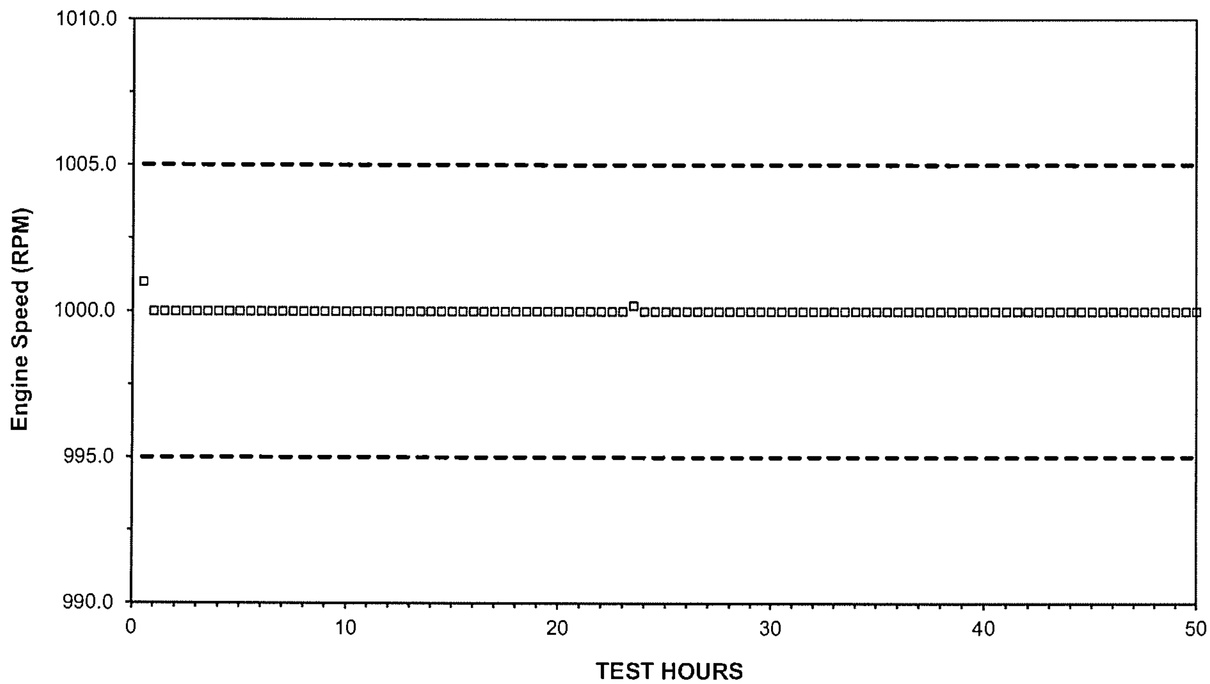
# ROLLER FOLLOWER WEAR TEST
## Operational Data Summary
## Form 3

| | |
|---|---|
| Laboratory: SR | EOT Date: 20120206 |
| Test Number: 65-405-222-10 | |
| Oil Code: LO-271510 | |
| Formulation/Stand Code: | |

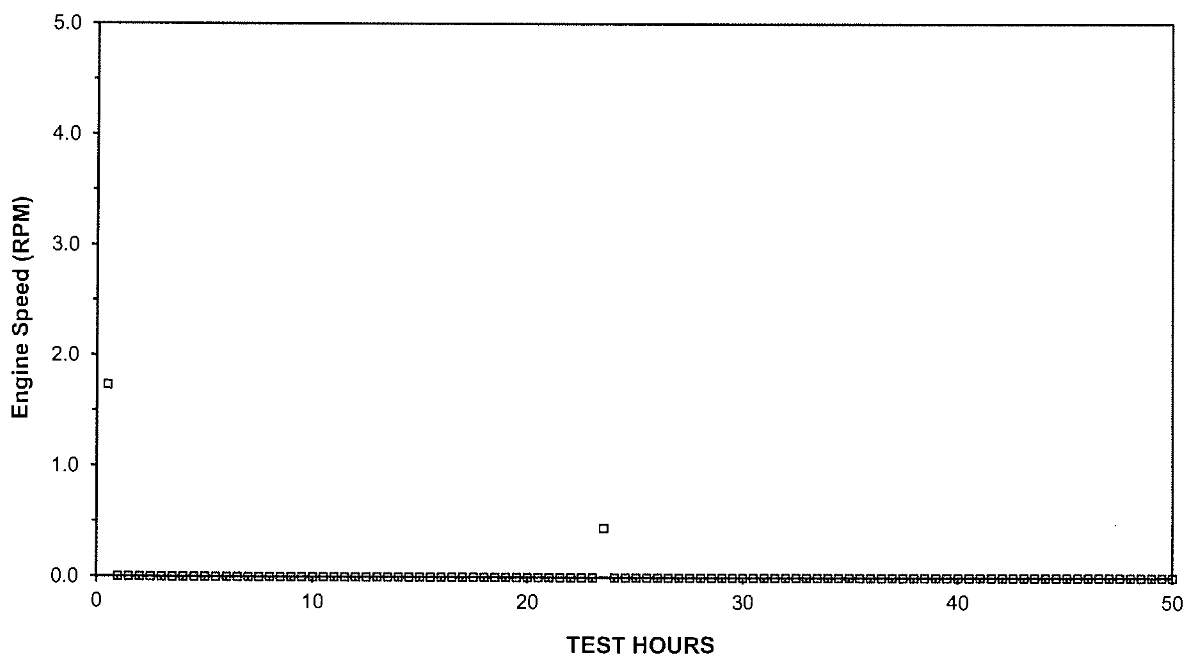
***Test Number Is: Stand - Stand Run No. - Engine No.***

ENGINE SPEED vs TEST HOURS

Process Mean
Xav = 1000.0




Process Variability (s)
Sav = 0.0




C2 - 5

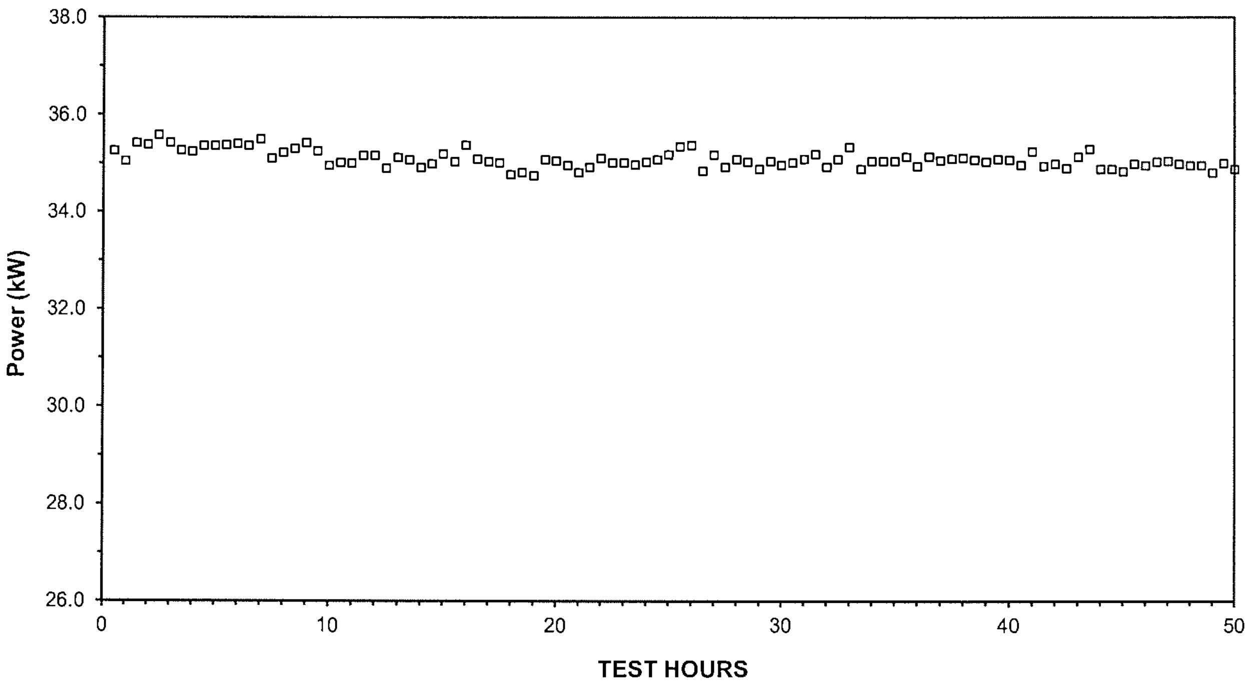
# ROLLER FOLLOWER WEAR TEST
## Operational Data Summary
## Form 4

| | |
|---|---|
| Laboratory: SR | EOT Date: 20120206 |
| Test Number: 65-405-222-10 | |
| Oil Code: LO-271510 | |
| Formulation/Stand Code: | |

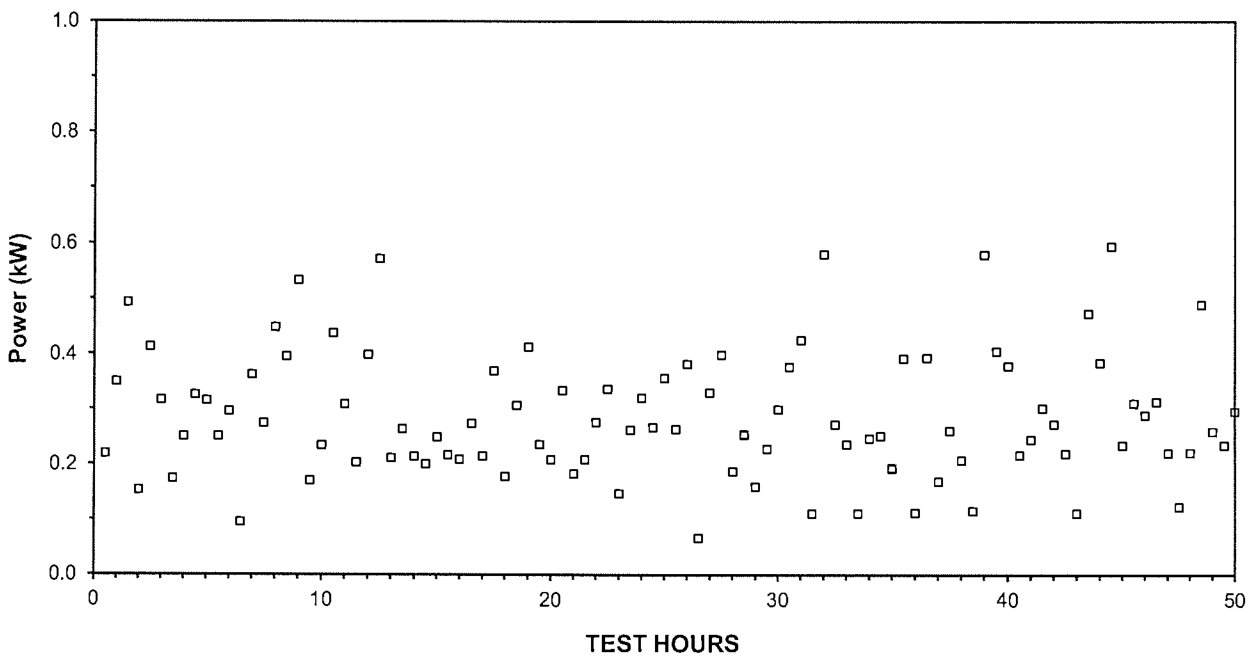
***Test Number Is: Stand - Stand Run No. - Engine No.***

POWER vs TEST HOURS

Process Mean
Xav = 35.1




Process Variability (s)
Sav = 0.3



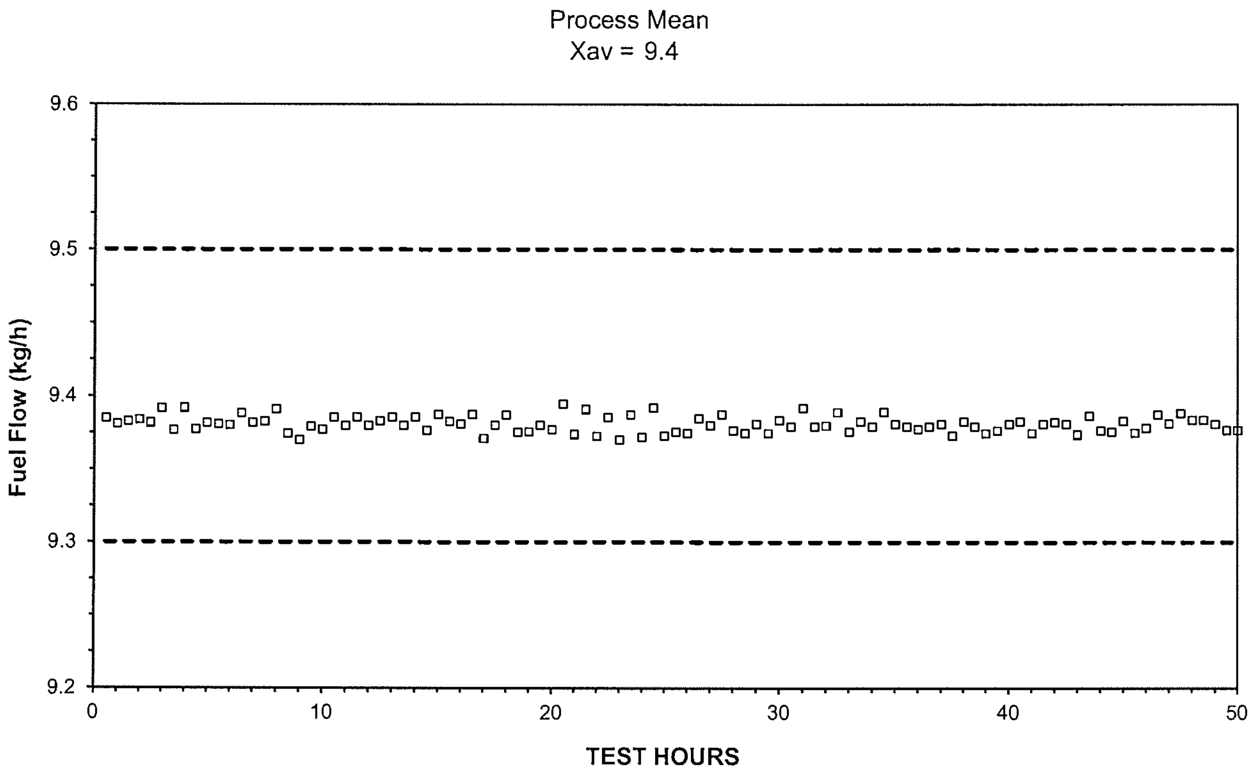

C2 - 6

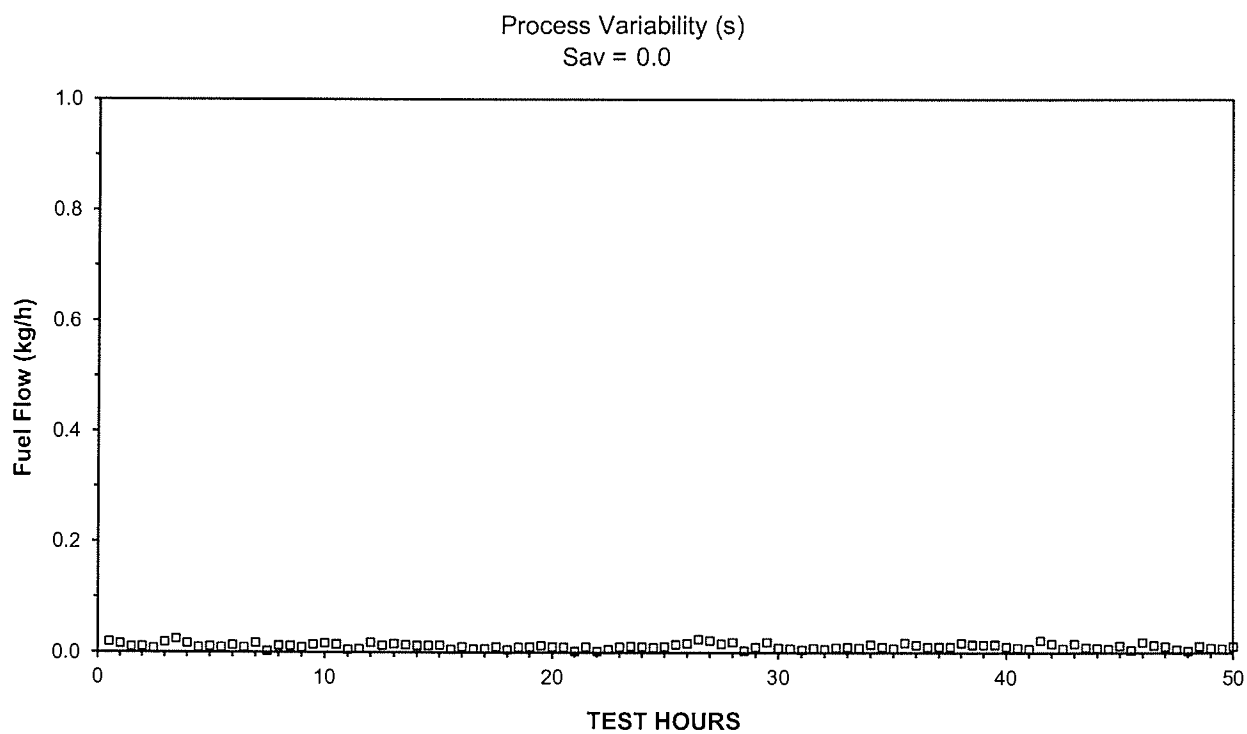
# ROLLER FOLLOWER WEAR TEST
## Operational Data Summary
## Form 5

| | |
|---|---|
| Laboratory: SR | EOT Date: 20120206 |
| Test Number: 65-405-222-10 | |
| Oil Code: LO-271510 | |
| Formulation/Stand Code: | |

***Test Number Is: Stand - Stand Run No. - Engine No.**

FUEL FLOW vs TEST HOURS




C2 - 7

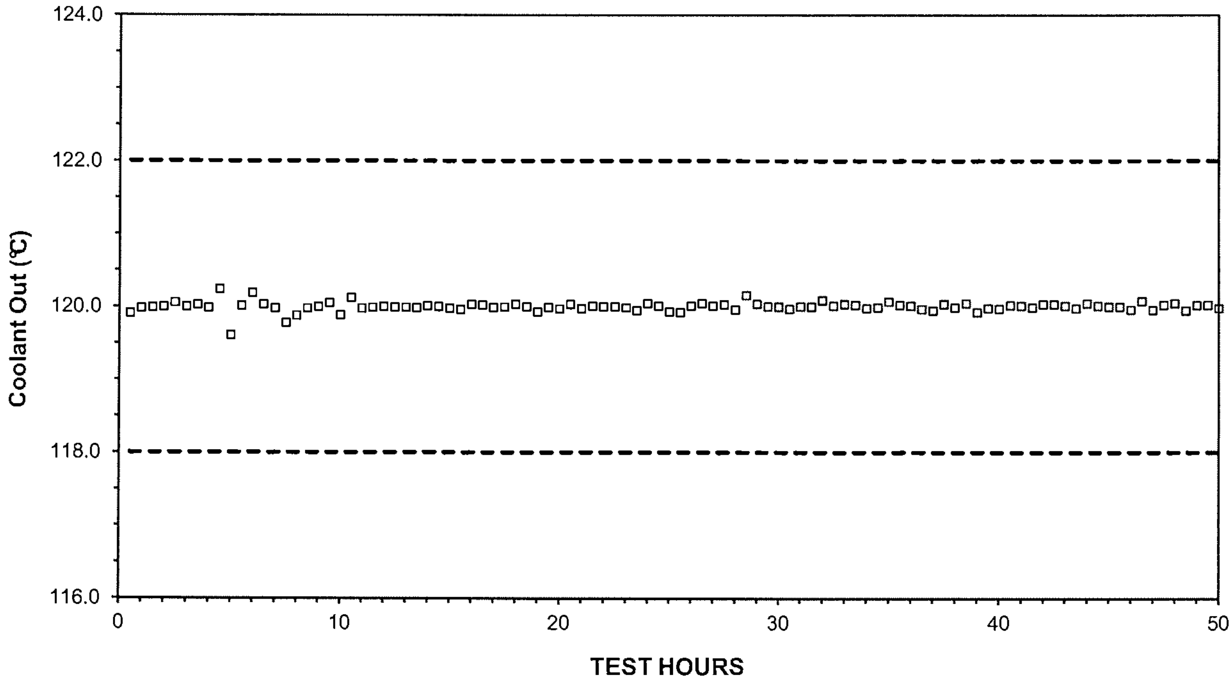
# ROLLER FOLLOWER WEAR TEST
## Operational Data Summary
## Form 6

| | |
|---|---|
| Laboratory: SR | EOT Date: 20120206 |
| Test Number: 65-405-222-10 | |
| Oil Code: LO-271510 | |
| Formulation/Stand Code: | |

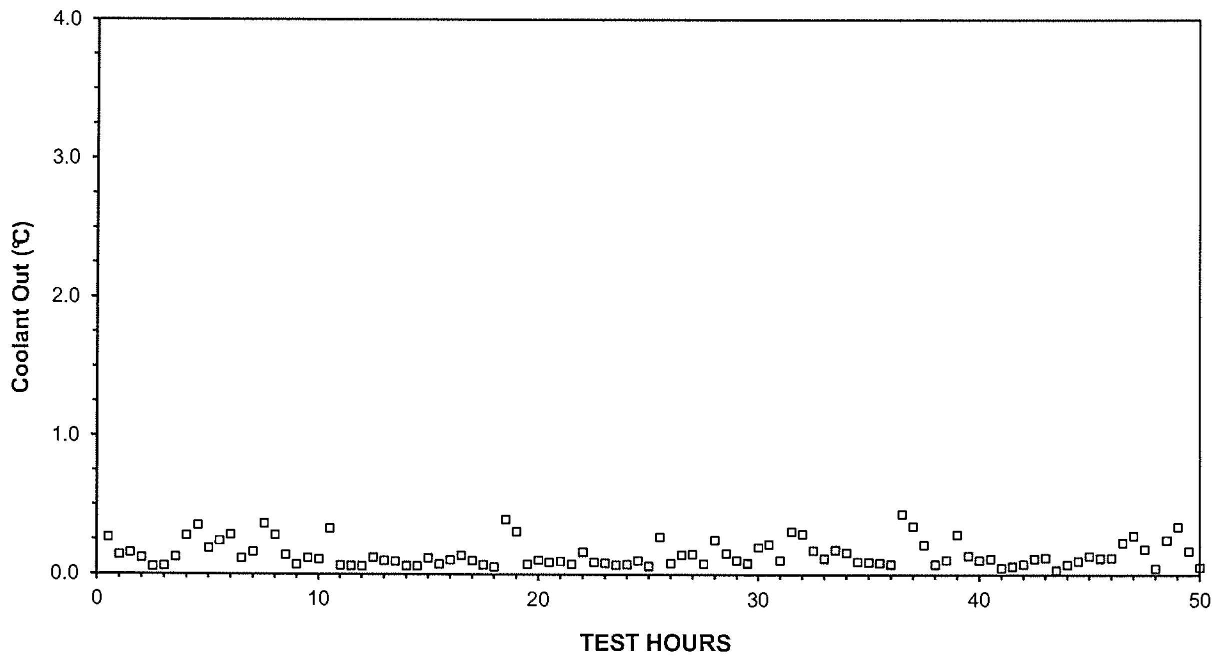
***Test Number Is: Stand - Stand Run No. - Engine No.***

COOLANT OUT TEMPERATURE vs TEST HOURS

Process Mean
Xav = 120.0




Process Variability (s)
Sav = 0.1




C2 - 8

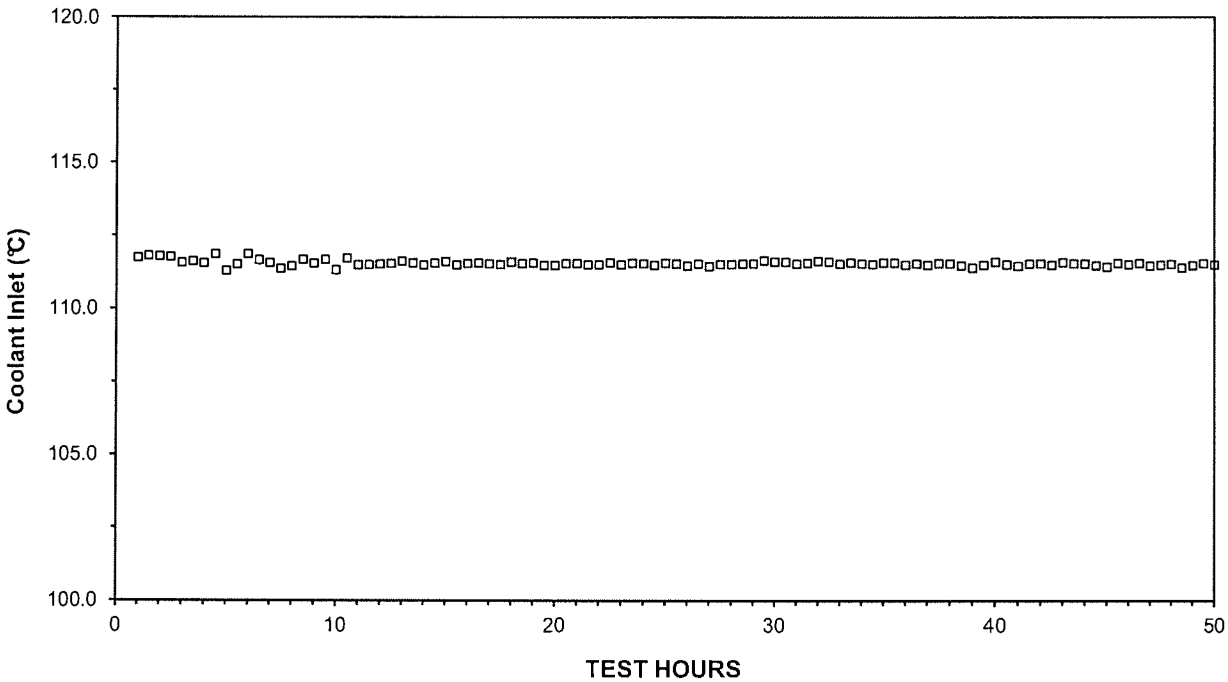
# ROLLER FOLLOWER WEAR TEST
## Operational Data Summary
## Form 7

| | |
|---|---|
| Laboratory: SR | EOT Date: 20120206 |
| Test Number: 65-405-222-10 | |
| Oil Code: LO-271510 | |
| Formulation/Stand Code: | |

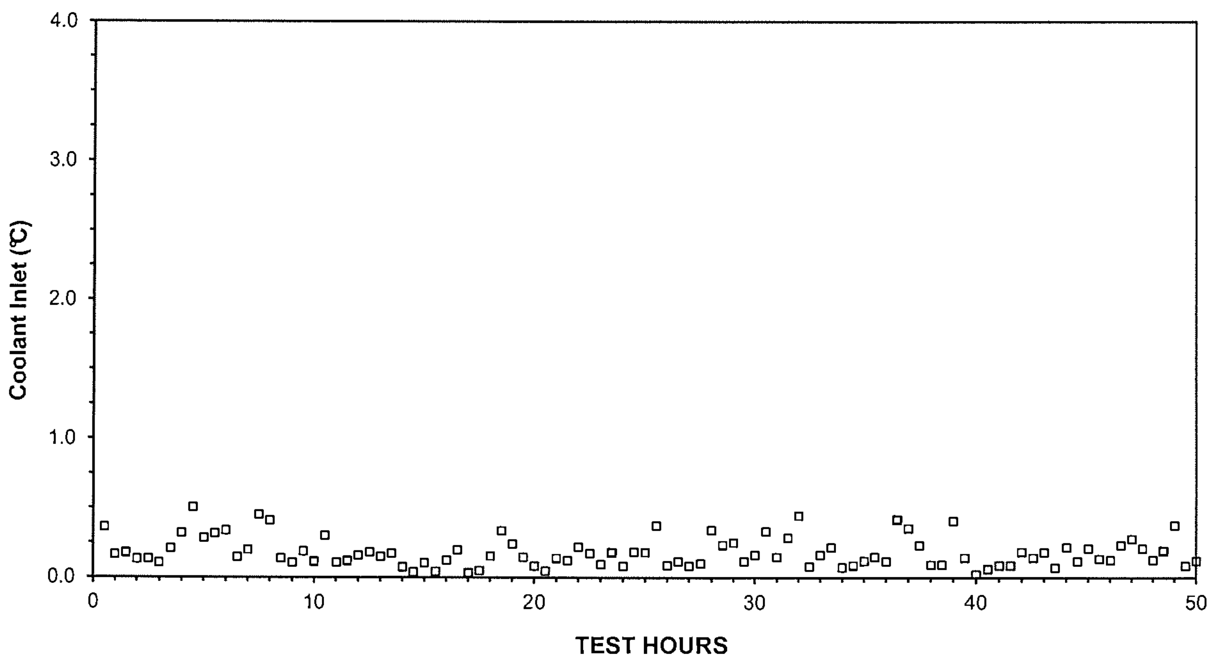
***Test Number Is: Stand - Stand Run No. - Engine No.***

COOLANT INLET TEMPERATURE vs TEST HOURS

Process Mean
Xav = 111.6




Process Variability (s)
Sav = 0.2




C2 - 9

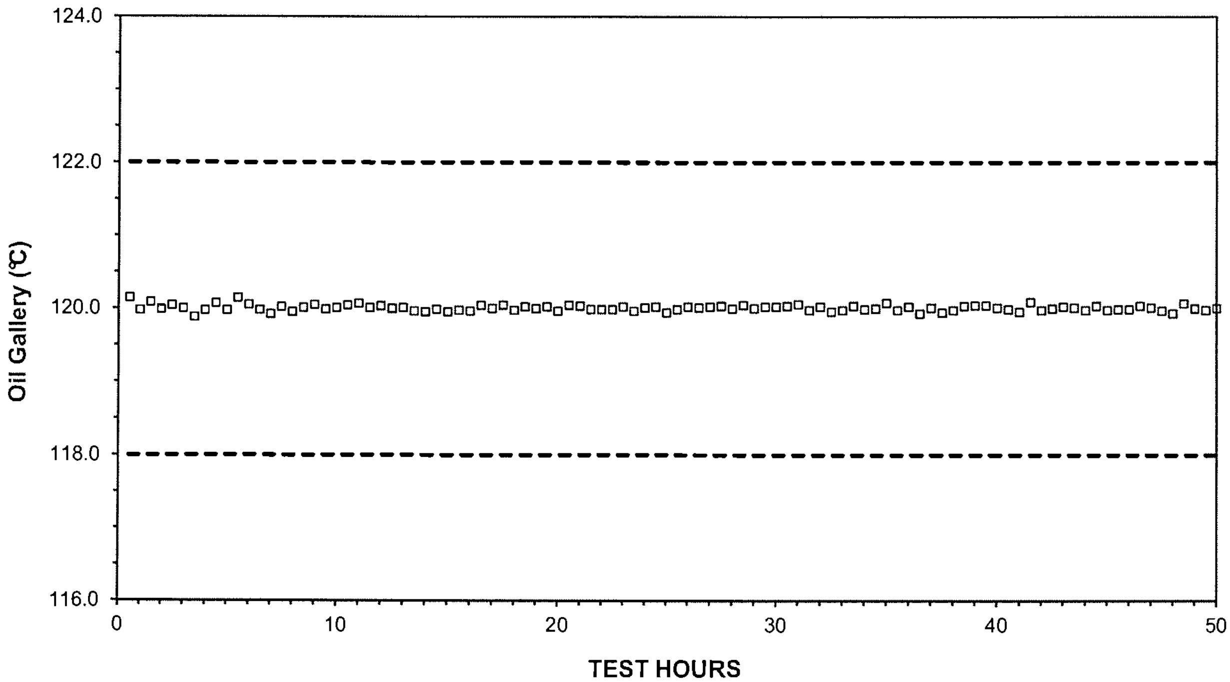
# ROLLER FOLLOWER WEAR TEST
## Operational Data Summary
## Form 8

| | |
|---|---|
| Laboratory: SR | EOT Date: 20120206 |
| Test Number: 65-405-222-10 | |
| Oil Code: LO-271510 | |
| Formulation/Stand Code: | |

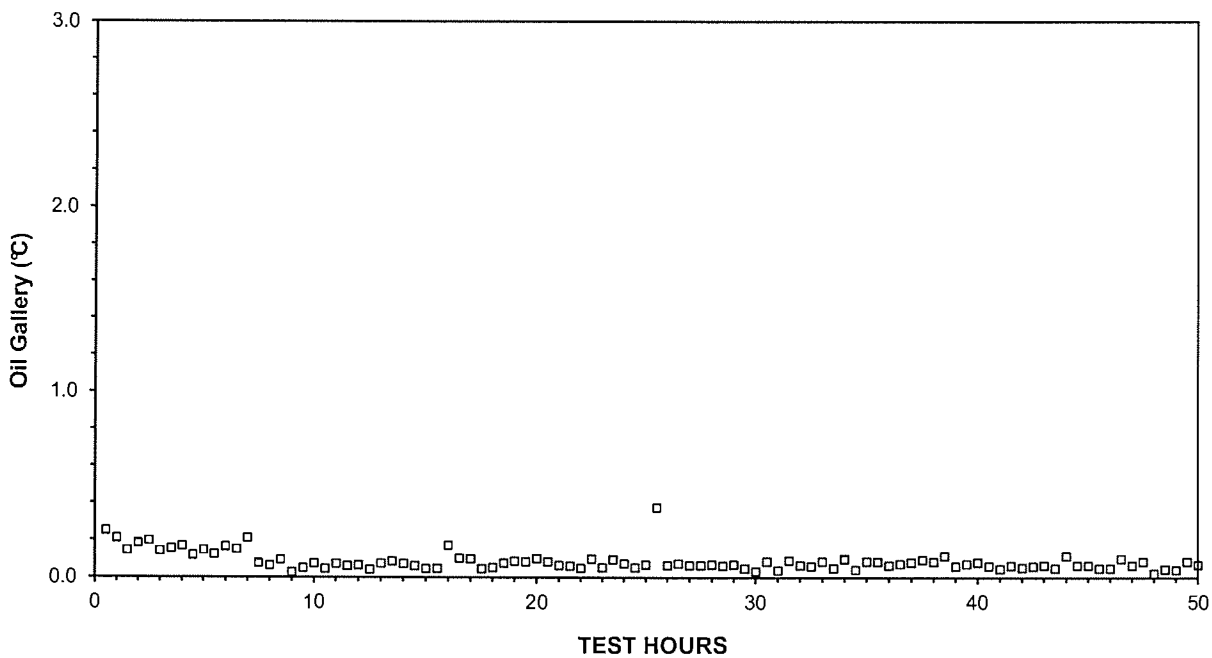
***Test Number Is: Stand - Stand Run No. - Engine No.***

OIL GALLERY TEMPERATURE vs TEST HOURS

Process Mean
Xav = 120.0




Process Variability (s)
Sav = 0.1




C2 - 10

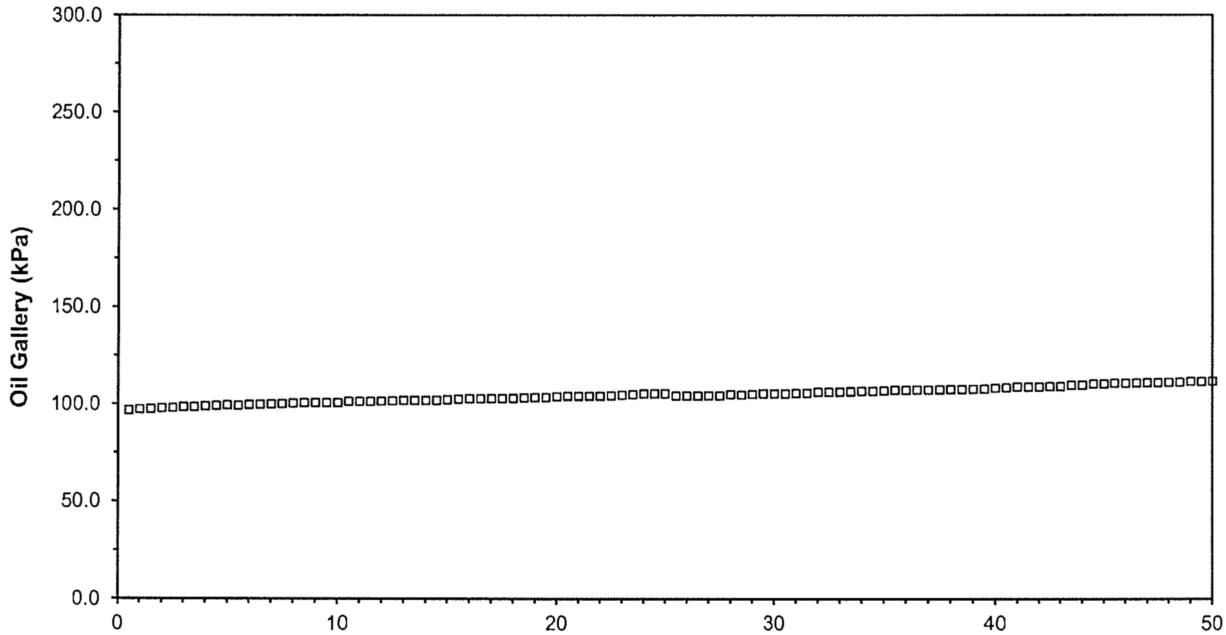
# ROLLER FOLLOWER WEAR TEST
## Operational Data Summary
## Form 9

| | |
|---|---|
| Laboratory: SR | EOT Date: 20120206 |
| Test Number: 65-405-222-10 | |
| Oil Code: LO-271510 | |
| Formulation/Stand Code: | |

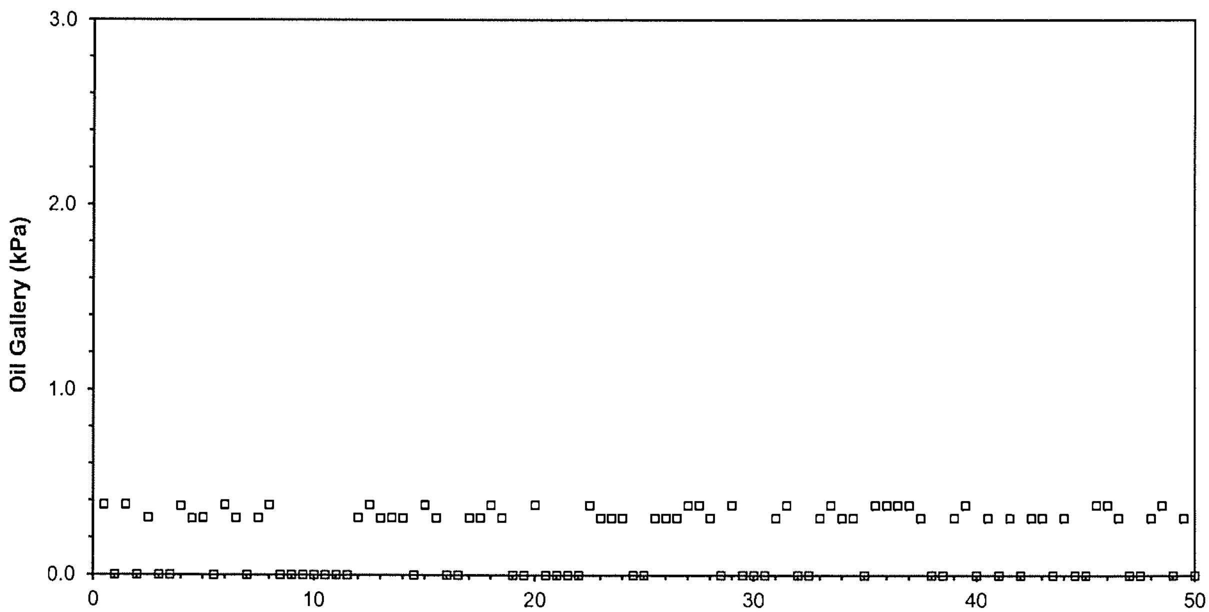
***Test Number Is: Stand - Stand Run No. - Engine No.***

OIL GALLERY PRESSURE vs TEST HOURS

Process Mean
Xav = 104.7




Process Variability (s)
Sav = 0.2




C2 - 11

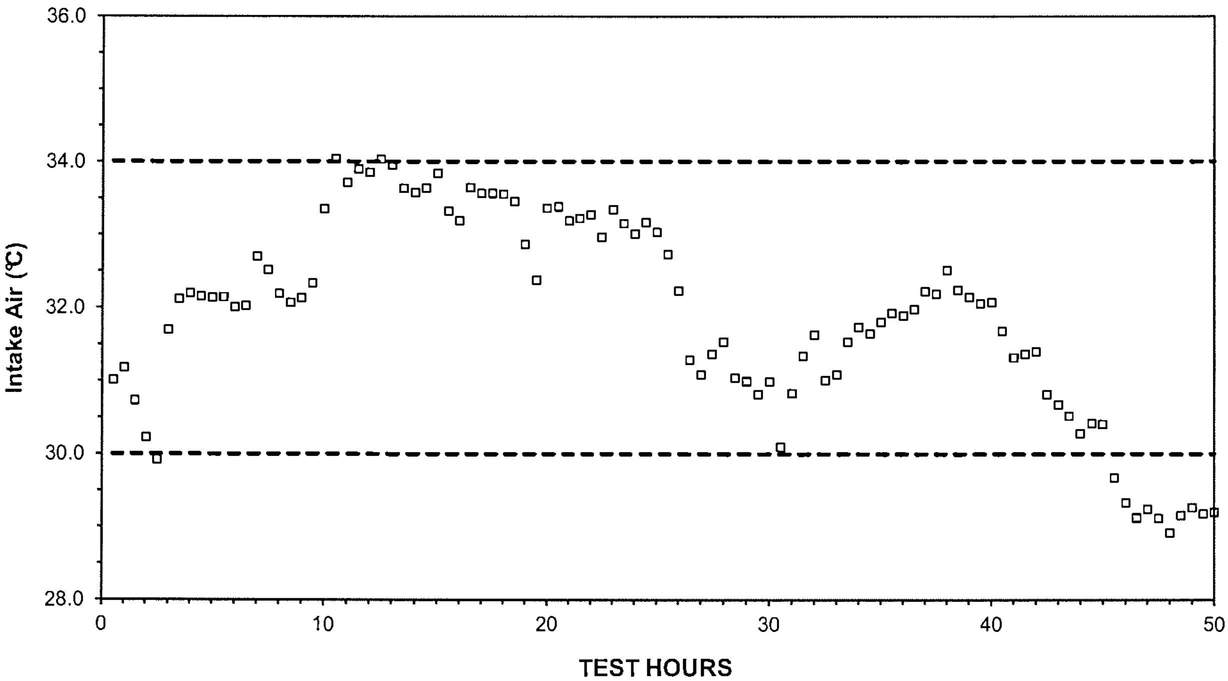
# ROLLER FOLLOWER WEAR TEST
## Operational Data Summary
## Form 10

| | |
|---|---|
| Laboratory: SR | EOT Date: 20120206 |
| Test Number: 65-405-222-10 | |
| Oil Code: LO-271510 | |
| Formulation/Stand Code: | |

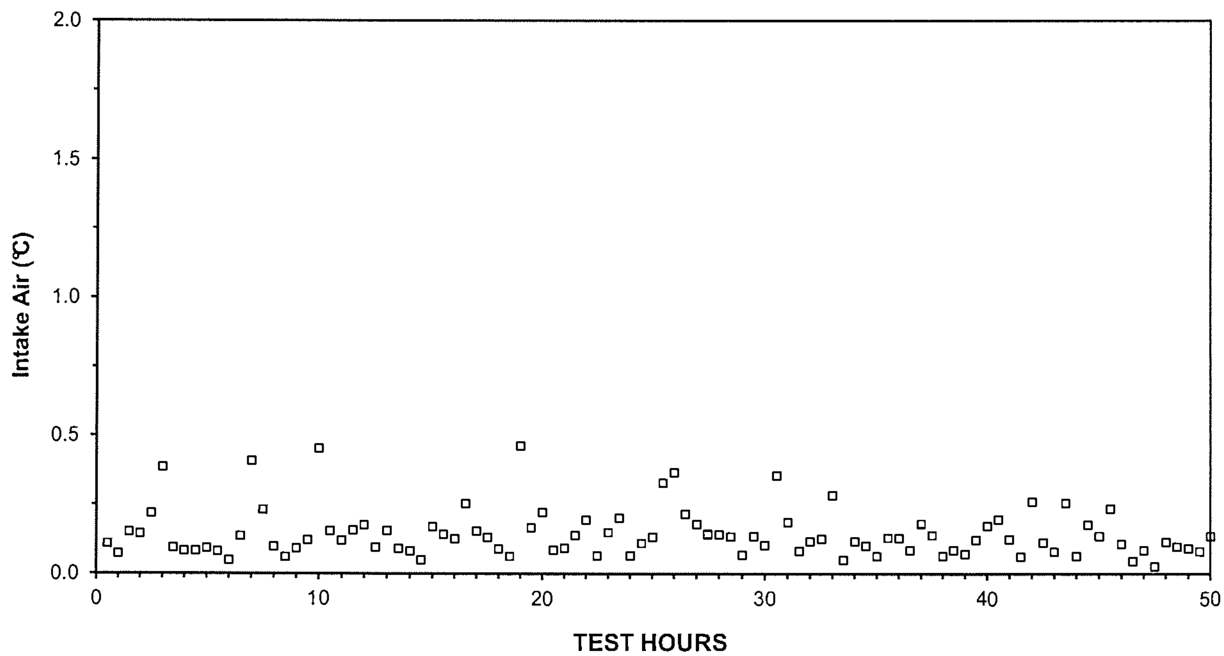
***Test Number Is: Stand - Stand Run No. - Engine No.***

INTAKE AIR TEMPERATURE vs TEST HOURS

Process Mean
Xav = 31.9




Process Variability (s)
Sav = 0.1




C2 - 12

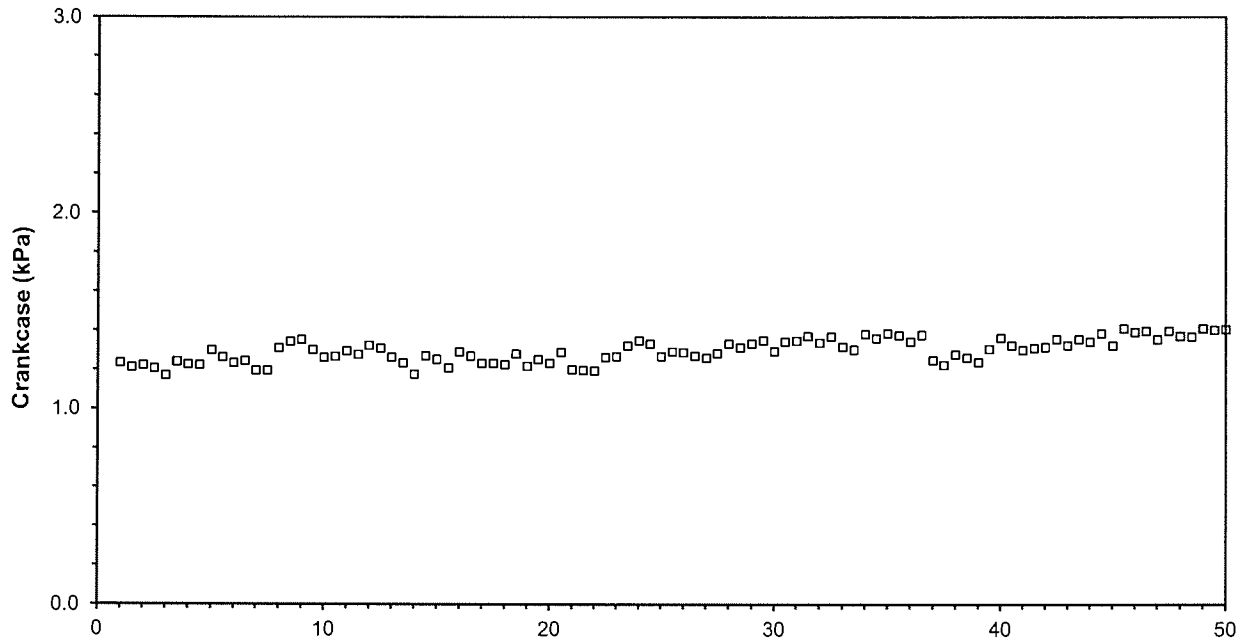
# ROLLER FOLLOWER WEAR TEST
## Operational Data Summary
## Form 11

| | | | |
|---|---|---|---|
| Laboratory: | SR | EOT Date: | 20120206 |
| Test Number: | 65-405-222-10 | | |
| Oil Code: | LO-271510 | | |
| Formulation/Stand Code: | | | |

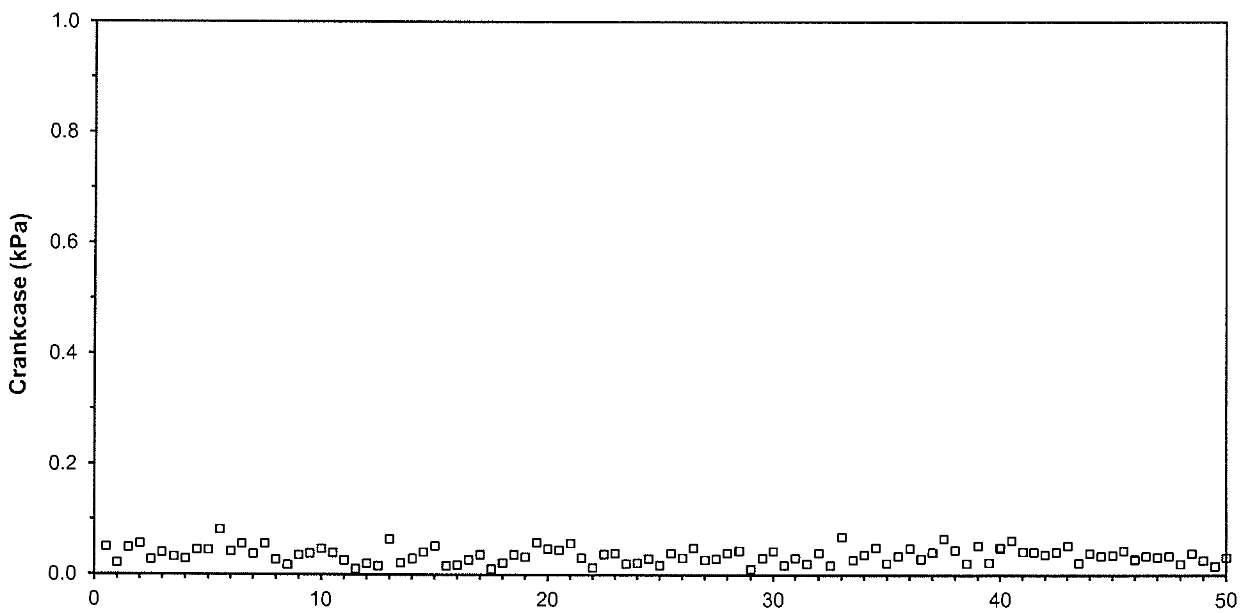
***Test Number Is: Stand - Stand Run No. - Engine No.***

CRANKCASE PRESSURE vs TEST HOURS

Process Mean
Xav = 1.3




Process Variability (s)
Sav = 0.0




C2 - 13

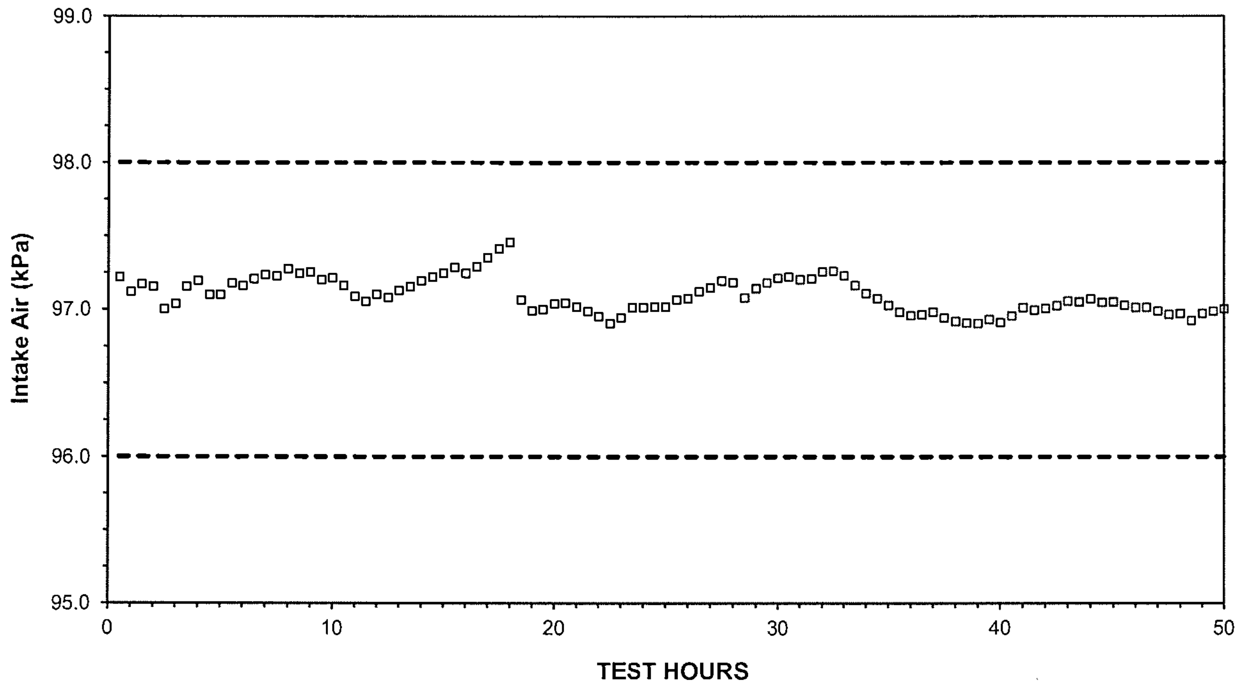
# ROLLER FOLLOWER WEAR TEST
## Operational Data Summary
## Form 12

| | |
|---|---|
| Laboratory: SR | EOT Date: 20120206 |
| Test Number: 65-405-222-10 | |
| Oil Code: LO-271510 | |
| Formulation/Stand Code: | |

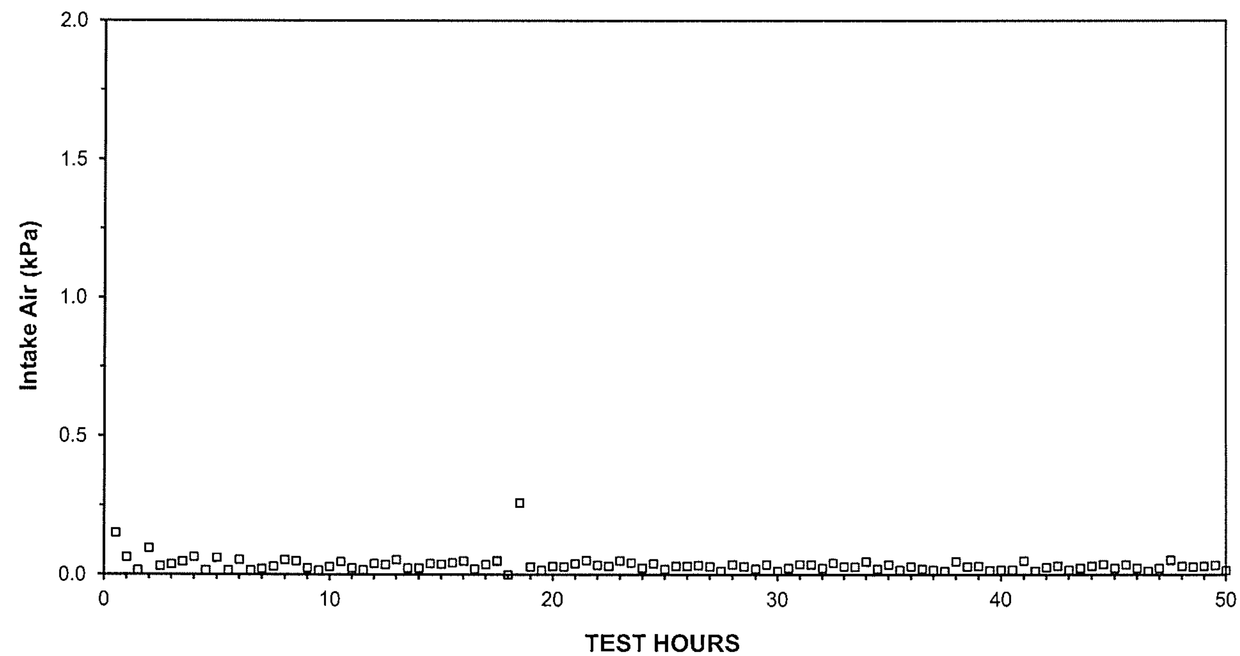
***Test Number Is: Stand - Stand Run No. - Engine No.***

INTAKE AIR PRESSURE vs TEST HOURS

Process Mean
Xav = 97.1




Process Variability (s)
Sav = 0.0



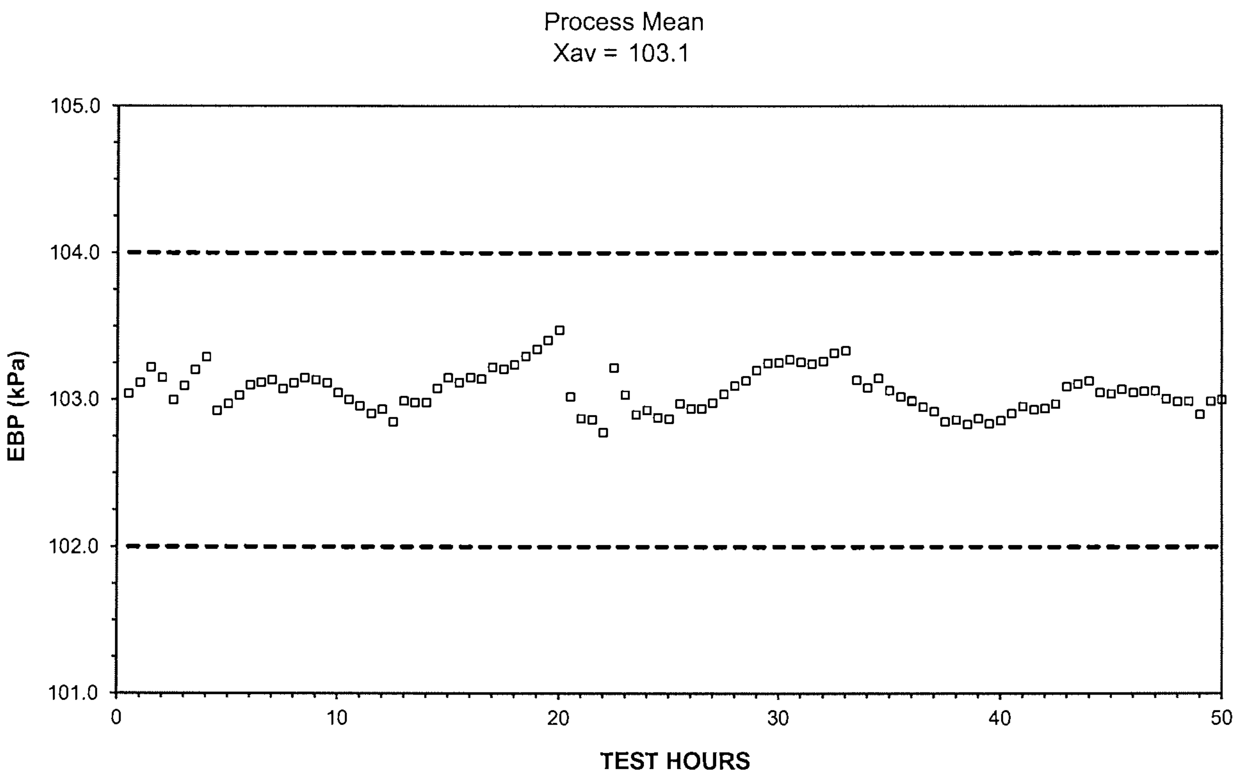

C2 - 14

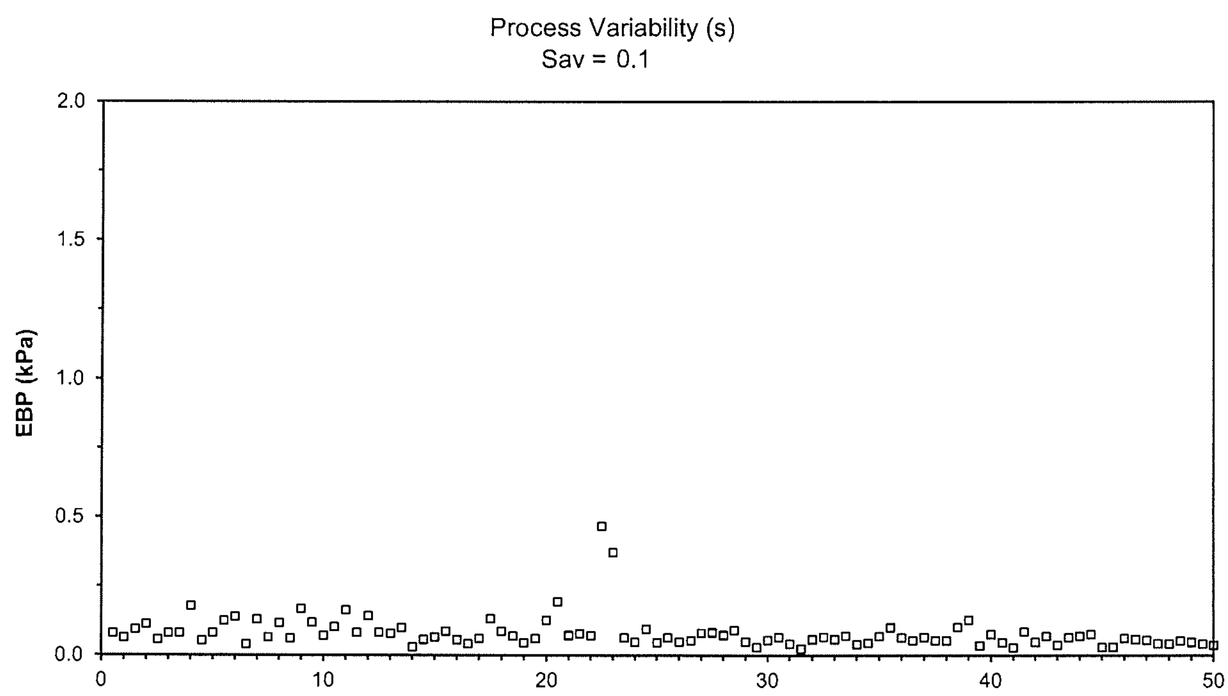
# ROLLER FOLLOWER WEAR TEST
## Operational Data Summary
## Form 13

| | |
|---|---|
| Laboratory: SR | EOT Date: 20120206 |
| Test Number: 65-405-222-10 | |
| Oil Code: LO-271510 | |
| Formulation/Stand Code: | |

***Test Number Is: Stand - Stand Run No. - Engine No.***

EXHAUST BACK PRESSURE vs TEST HOURS



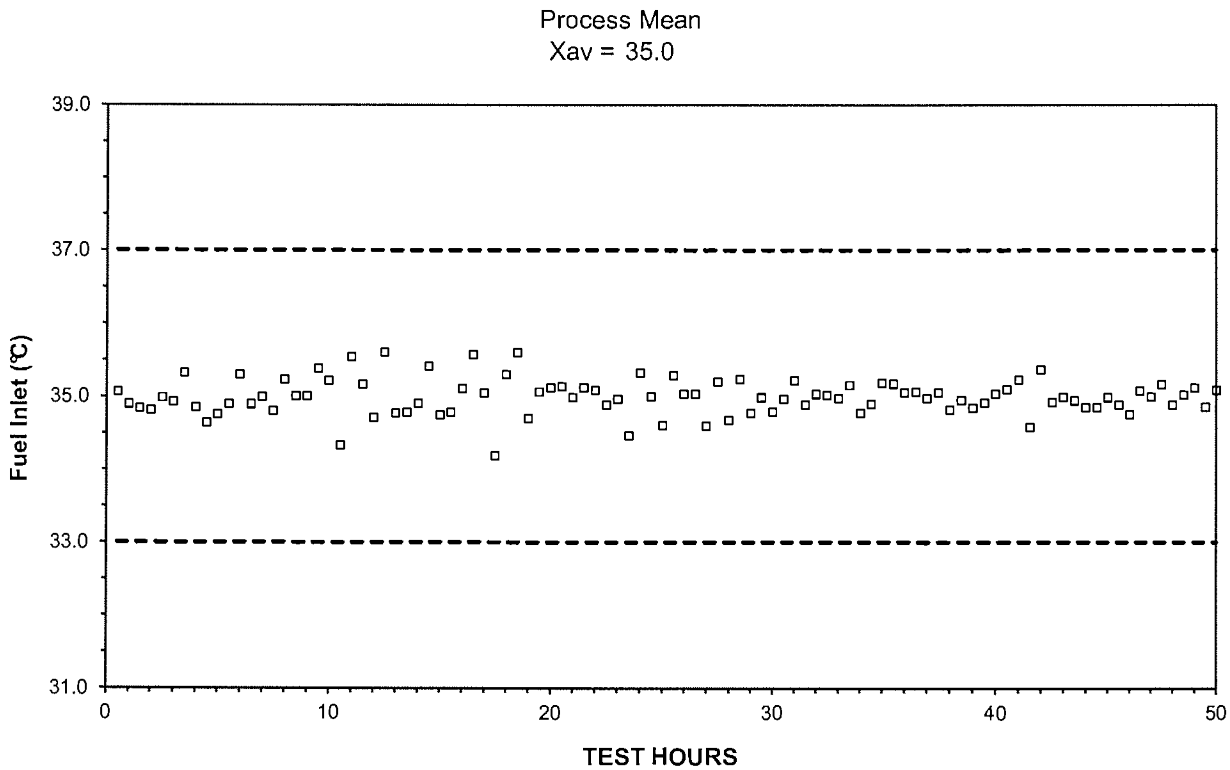

C2 - 15

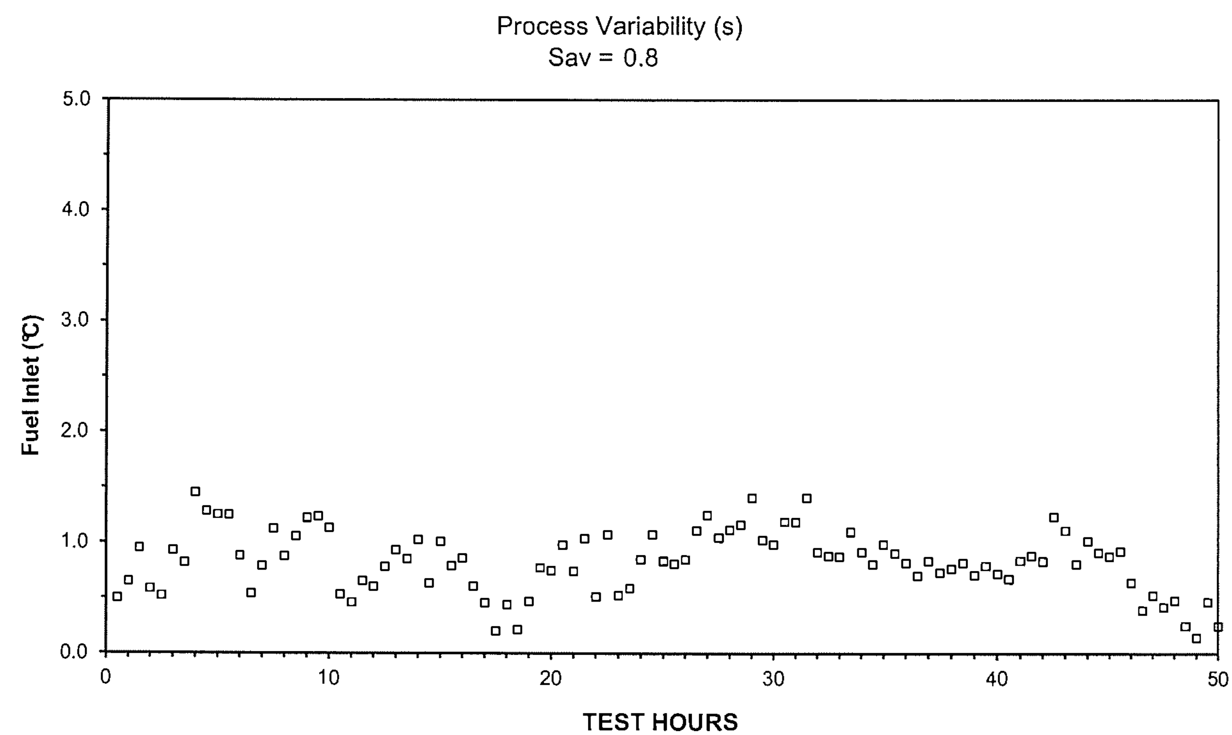
# ROLLER FOLLOWER WEAR TEST
## Operational Data Summary
## Form 14

| | |
|---|---|
| Laboratory: SR | EOT Date: 20120206 |
| Test Number: 65-405-222-10 | |
| Oil Code: LO-271510 | |
| Formulation/Stand Code: | |

***Test Number Is: Stand - Stand Run No. - Engine No.***

FUEL INLET TEMPERATURE vs TEST HOURS




C2 - 16

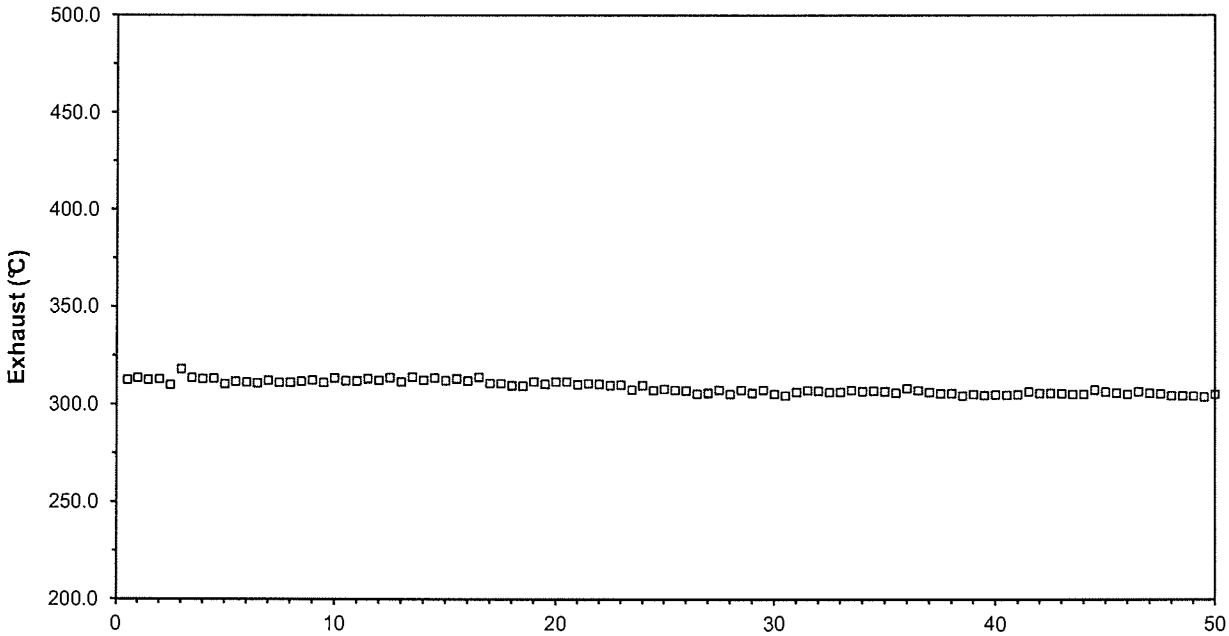
# ROLLER FOLLOWER WEAR TEST
## Operational Data Summary
## Form 15

| | |
|---|---|
| Laboratory: SR | EOT Date: 20120206 |
| Test Number: 65-405-222-10 | |
| Oil Code: LO-271510 | |
| Formulation/Stand Code: | |

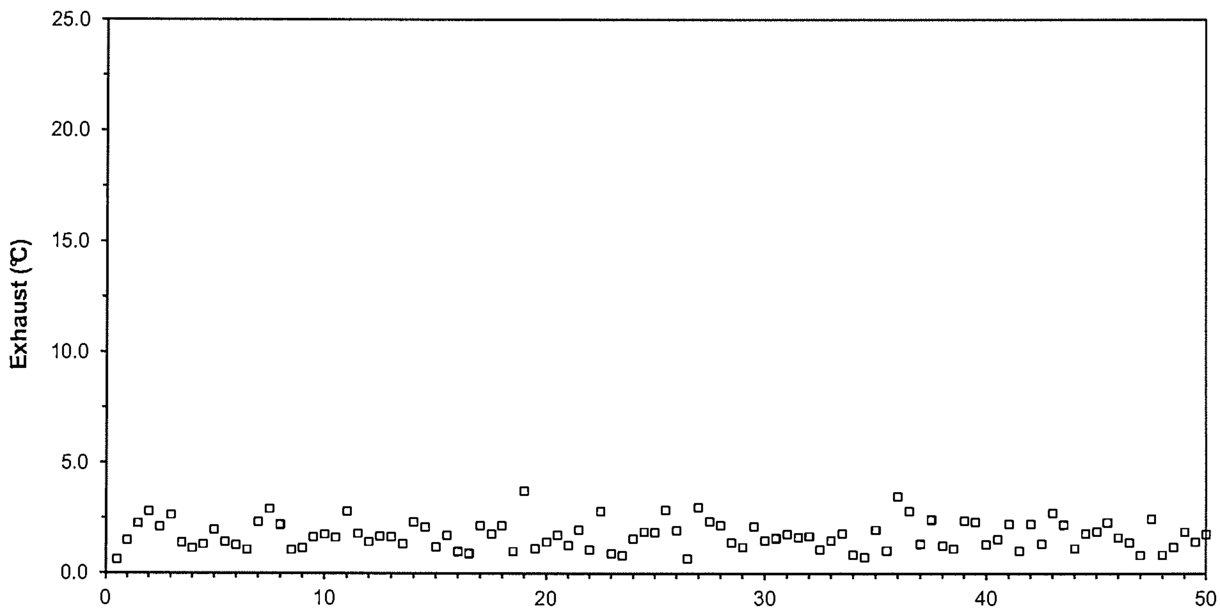
***Test Number Is: Stand - Stand Run No. - Engine No.***

EXHAUST TEMPERATURE vs TEST HOURS

Process Mean
Xav = 308.9




Process Variability (s)
Sav = 1.7




C2 - 17

# D 5966
# Roller Follower Wear Test
## Operational Summary
Form 16

| | |
|---|---|
| **Laboratory:** SR | **EOT Date:** 20120206 |
| **Test Number: *** 65-405-222-10 | |
| **Oil Code:** LO-271510 | |
| **Formulation / Stand Code:** | |

**Test Number is: Stand - Stand Run No. - Engine No. - Engine Run No.*

| Test Parameter | Specification | | Average | Std. Dev. | Minimum | Maximum |
|---|---|---|---|---|---|---|
| Engine Speed, r/min | 6.2L Engine 1000 ± 5 | 6.5L Engine 1000 ± 5 | 1000.0 | 0.1 | 1000.0 | 1001.0 |
| Torque, N-m | Record | Record | 335.8 | 1.6 | 332.6 | 340.4 |
| Fuel Flow, kg/h | 9.0 ± 0.1 | 9.4 ± 0.1 | 9.4 | 0.0 | 9.4 | 9.4 |
| Total Oil Consumption, kg | Record | Record | 3.9 | | | |

| Test Parameter | Specification | Average | Std. Dev. | Minimum | Maximum |
|---|---|---|---|---|---|
| Coolant Out, °C | 120 ± 2 | 120.0 | 0.1 | 119.6 | 120.2 |
| Coolant In, °C | Report Only | 111.6 | 0.1 | 111.3 | 111.9 |
| Main Oil Gallery, °C | 120 ± 2 | 120.0 | 0.0 | 119.9 | 120.1 |
| Fuel In, °C | 35 ± 2 | 35.0 | 0.2 | 34.2 | 35.6 |
| Intake Air, °C | 32 ± 2 | 31.9 | 1.4 | 28.9 | 34.0 |
| Oil Sump, °C | Report | 128.2 | 0.3 | 127.5 | 128.7 |
| Exhaust, °C | Report | 308.9 | 3.2 | 304.0 | 318.1 |

| Pressures | Specification | Average | Std. Dev. | Minimum | Maximum |
|---|---|---|---|---|---|
| Crankcase, kPa | Report | 1.3 | 0.1 | 1.4 | 1.2 |
| Back Pressure, kPa | 103 ± 1 | 103.1 | 0.1 | 102.8 | 103.5 |
| Intake Air, kPa | 97 ± 1 | 97.1 | 0.1 | 96.9 | 97.5 |

# D 5966
## Roller Follower Wear Test
### Oil Analysis
Form 17

| Laboratory: SR | EOT Date: 20120206 |
|---|---|
| Test Number: * 65-405-222-10 | |
| Oil Code: LO-271510 | |
| Formulation / Stand Code: | |

**Test Number is: Stand - Stand Run No. - Engine No. - Engine Run No.*

| Hours | Viscosity, cSt @ 100°C | % SOOT |
|---|---|---|
| NEW | 8.61 | 0.2 |
| 025 | 10.29 | 2.6 |
| 050 | 11.65 | 4.5 |

| Hours | Elements | | | | | | |
|---|---|---|---|---|---|---|---|
| | Al | Cr | Cu | Fe | Pb | Si | Sn |
| NEW | 1 | 0 | 0 | 1 | 0 | 6 | 0 |
| 025 | 2 | 2 | 2 | 70 | 5 | 6 | 0 |
| 050 | 2 | 4 | 3 | 151 | 11 | 7 | 1 |

| | |
|---|---|
| Average Bosch Smokes | 6.5 |
| Average BSFC | 0.268 kg/kW-h |

# D 5966
## Roller Follower Wear Test
### Unscheduled Downtime & Maintenance Summary
Form 18

| | |
|---|---|
| **Laboratory:** SR | **EOT Date:** 20120206 |
| **Test Number: *** 65-405-222-10 | |
| **Oil Code:** LO-271510 | |
| **Formulation / Stand Code:** | |

**Test Number is: Stand - Stand Run No. - Engine No. - Engine Run No.*

**Number of Downtime Occurrences:** 0

| Test | Date | Downtime | Reasons |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| **Total Downtime** | | 0:00 | |

**Other Comments**

**Number of Comment Lines:** 0

# D 5966
## Roller Follower Wear Test
### Test Fuel Analysis (Last Batch)
Form 21

| | | | |
|---|---|---|---|
| **Laboratory:** | SR | **EOT Date:** | 20120206 |
| **Test Number:** * | 65-405-222-10 | | |
| **Oil Code:** | LO-271510 | | |
| **Formulation / Stand Code:** | | | |
| **Supplier:** | Chevron Phillips | **Batch Identifiers:** | 11JPPC901 |

**Test Number is: Stand - Stand Run No. - Engine No. - Engine Run No.*

| Measurement | Specifications | Analysis | Test Method |
|---|---|---|---|
| Total Sulfur, % Weight | 0.03 - 0.05 | 0.04 | D 2622 |
| Gravity, °API | 32 - 36 | 35.1 | D 287 |
| **Hydrocarbon Composition** | | | |
| Aromatics, % Vol. | 28 - 35 | 30.7 | D 5186 |
| Olefin | Report | 4.3 | D 1319 |
| Saturates | Report | 65.0 | D 1319 |
| Cetane Index | 42 - 48 | 44.0 | D 4737 |
| Cetane No. | 42 - 48 | 46.0 | D 613 |
| Copper Strip Corrosion | 3 Maximum | 1A | D 130 |
| Flash Point, °C | 54 Minimum | 63 | D 92 |
| Cloud Point, °C | -12 Maximum | -21 | D 2500 |
| Pour Point, °C | -18 Maximum | -27 | D 97 |
| Carbon Residue on 10% Residuum, % | 0.35 Maximum | 0.10 | D 524 (10% Bottoms) |
| Water & Sediment, % Vol. | 0.05 Maximum | 0.00 | D 2709 |
| Ash, % Wgt. | 0.01 Maximum | 0.000 | D 482 |
| Viscosity, cSt @ 40°C | 2.0 - 3.2 | 2.4 | D 445 |
| **Distillation, °C** | | | |
| IBP | 177 - 199 | 173 | D 86 |
| 10% | 210 - 232 | 206 | D 86 |
| 50% | 249 - 277 | 252 | D 86 |
| 90% | 299 - 327 | 326 | D 86 |
| EP | 327 - 360 | 361 | D 86 |

# D 5966
## Roller Follower Wear Test
### Characteristics of the Data Acquisition System
Form 22

| | |
|---|---|
| **Laboratory:** SR | **EOT Date:** 20120206 |
| **Test Number:** * 65-405-222-10 | |
| **Oil Code:** LO-271510 | |
| **Formulation / Stand Code:** | |

**Test Number is: Stand - Stand Run No. - Engine No. - Engine Run No.*

| Parameter (1) | Sensing Device (2) | Calibration Frequency (3) | Record Device (4) | Observation Frequency (5) | Record Frequency (6) | Log Frequency (7) | System Response (8) |
|---|---|---|---|---|---|---|---|
| Temperatures | | | | | | | |
| Main Oil G. | Thermocouple | Every ref test | C/D | 0 | 0 | 1 per min | 2.0s |
| Fuel In. | Thermocouple | Every ref test | C/D | 0 | 0 | 1 per min | 2.0s |
| Intake Air | Thermocouple | Every ref test | C/D | 0 | 0 | 1 per min | 2.0s |
| Oil Sump | Thermocouple | Every ref test | C/D | 0 | 0 | 1 per min | 2.0s |
| Exhaust | Thermocouple | Every ref test | C/D | 0 | 0 | 1 per min | 2.0s |
| Coolant Out | Thermocouple | Every ref test | C/D | 0 | 0 | 1 per min | 2.0s |
| **Other** | | | | | | | |
| Fuel Flow | Mass Flow | Every ref test | C/D | 0 | 0 | 1 per min | 2.5s |
| Engine RPM | Magnetic | Every ref test | C/D | 0 | 0 | 1 per min | 0.5s |
| Load | Strain Gage | Every ref test | C/D | 0 | 0 | 1 per min | 0.5s |
| Intake Press. | Mechanical | Every ref test | C/D | 0 | 0 | 1 per min | N/A |
| Exhaust Press. | Mechanical | Every ref test | C/D | 0 | 0 | 1 per min | N/A |
| Oil Gallery Press. | Mechanical | Every ref test | C/D | 0 | 0 | 1 per min | N/A |

**Legend:**

(1) Operating Parameter
(2) The Type of Device Used to Measure Temperature, Pressure or Flow
T/C - Thermocouple
(3) Frequency at Which the Measurement System is Calibrated
(4) The Type of Device Where Data is Recorded
LG - Handlog Sheet
DL - Automatic Data Logger
SC - Strip Chart Recorded
C/M - Computer, Using Manual Data Entry
C/D - Computer, Using Direct I/O Entry
(5) Data are Observed but Only if Recorded Off Spec.
(6) Data are Recorded but are not Retained at EOT
(7) Data are Logged as Permanent Record, Note Specify if:
SS - Snapshot Taken at Specified Frequency
AG/X Average of X Data Points at Specified Frequency
(8) Time for the Output to Reach 63.2% of Final Value for Step Change at Input

| | |
|---|---|
| **Laboratory:** SR | **EOT Date:** 20120206 |
| **Test Number: *** 65-405-222-10 | |
| **Oil Code:** LO-271510 | |
| **Formulation / Stand Code:** | |

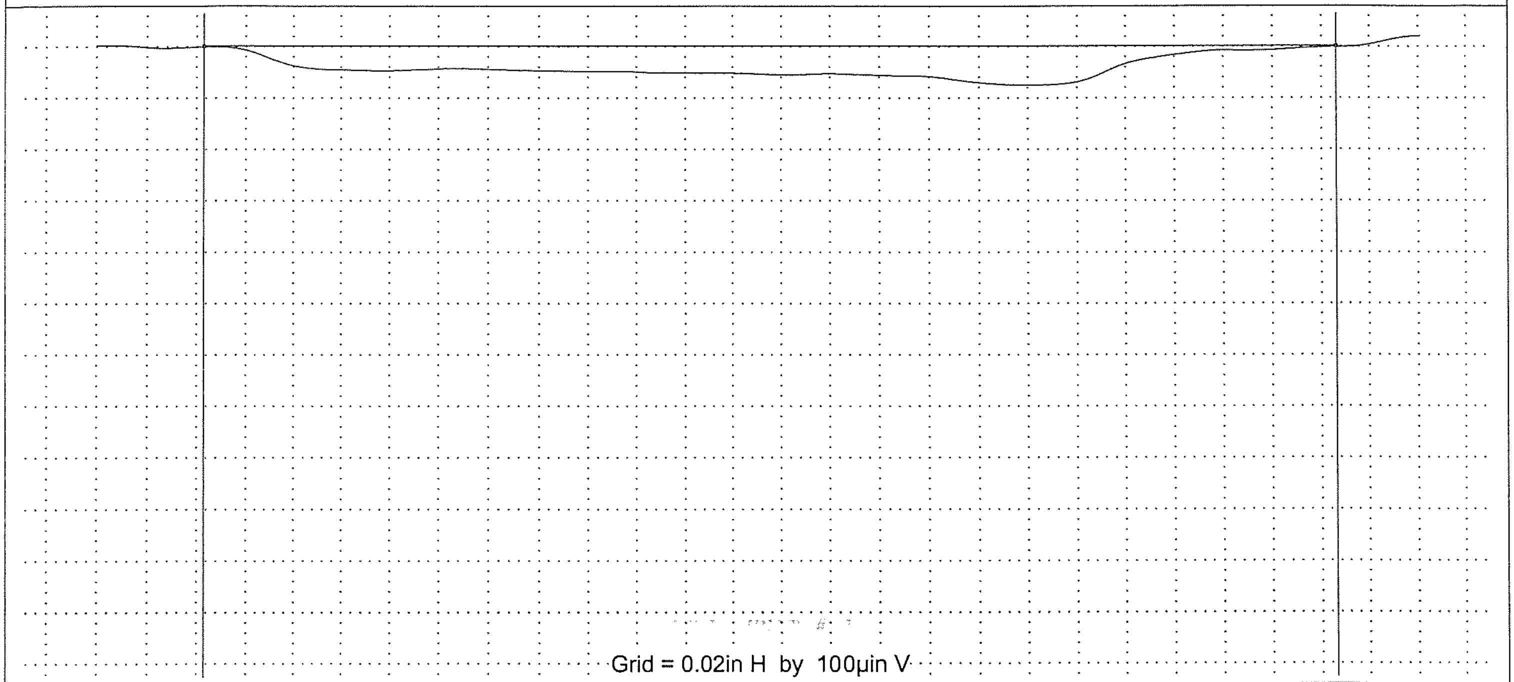
**Test Number is:* *Stand - Stand Run No. - Engine No. - Engine Run No.*

## Appendix A

### Roller Follower Wear Test Traces

1. Profilometer Traces 1-8 (Right and Left) (8 pages)

Profiles: Waviness




Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Tue Feb 07 10:13 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin R1
  Run 65-405-222-10
  *
  File: C:\S-2000-2\DATA\RFWT\40522210.A
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

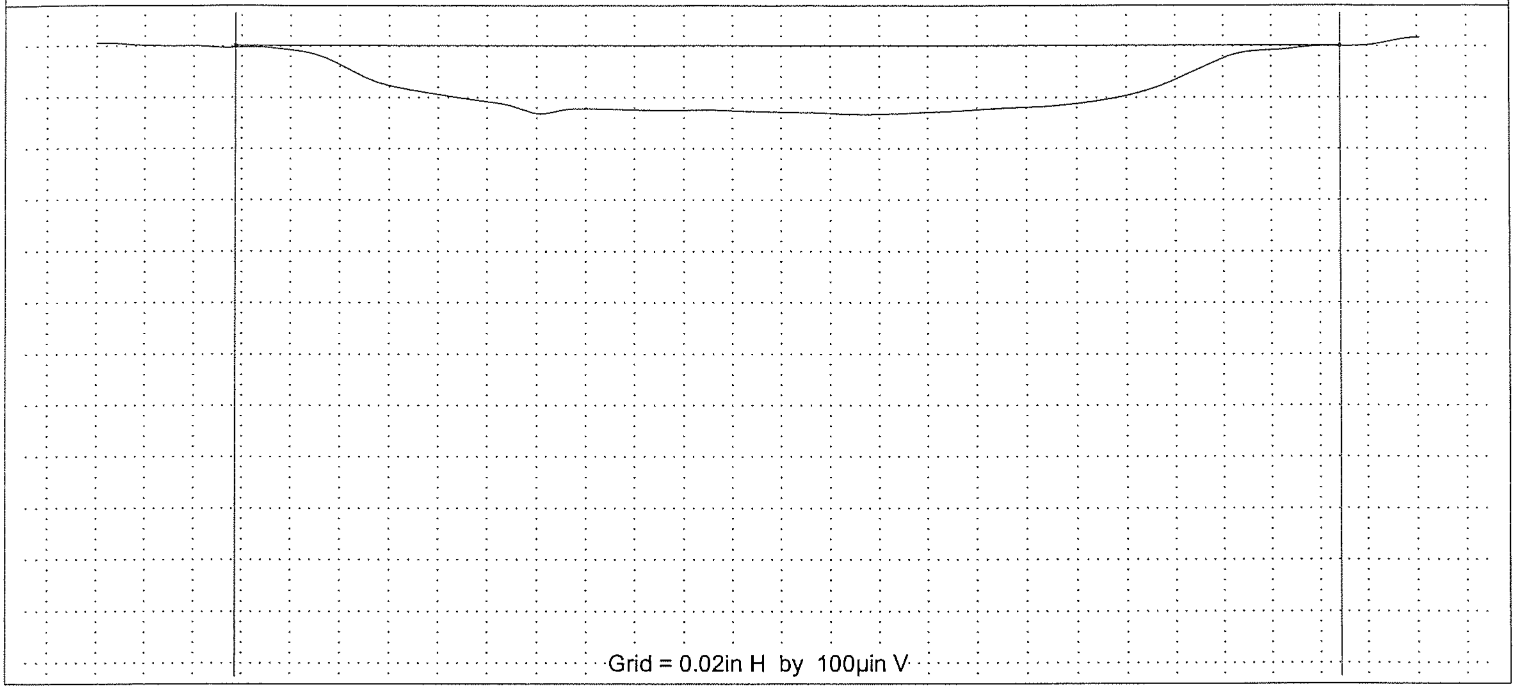
Run 65-405-222-10

Parameters

| PARAMETER | VALUE | UNITS |
|---|---|---|
| Summary | | |
| Standards System = ANSI/ASME B46.1 1995 | | |
| Waviness Parameters: | | |
| Wt | 75.2 | µin |

Parameters

Profiles: Waviness




Settings

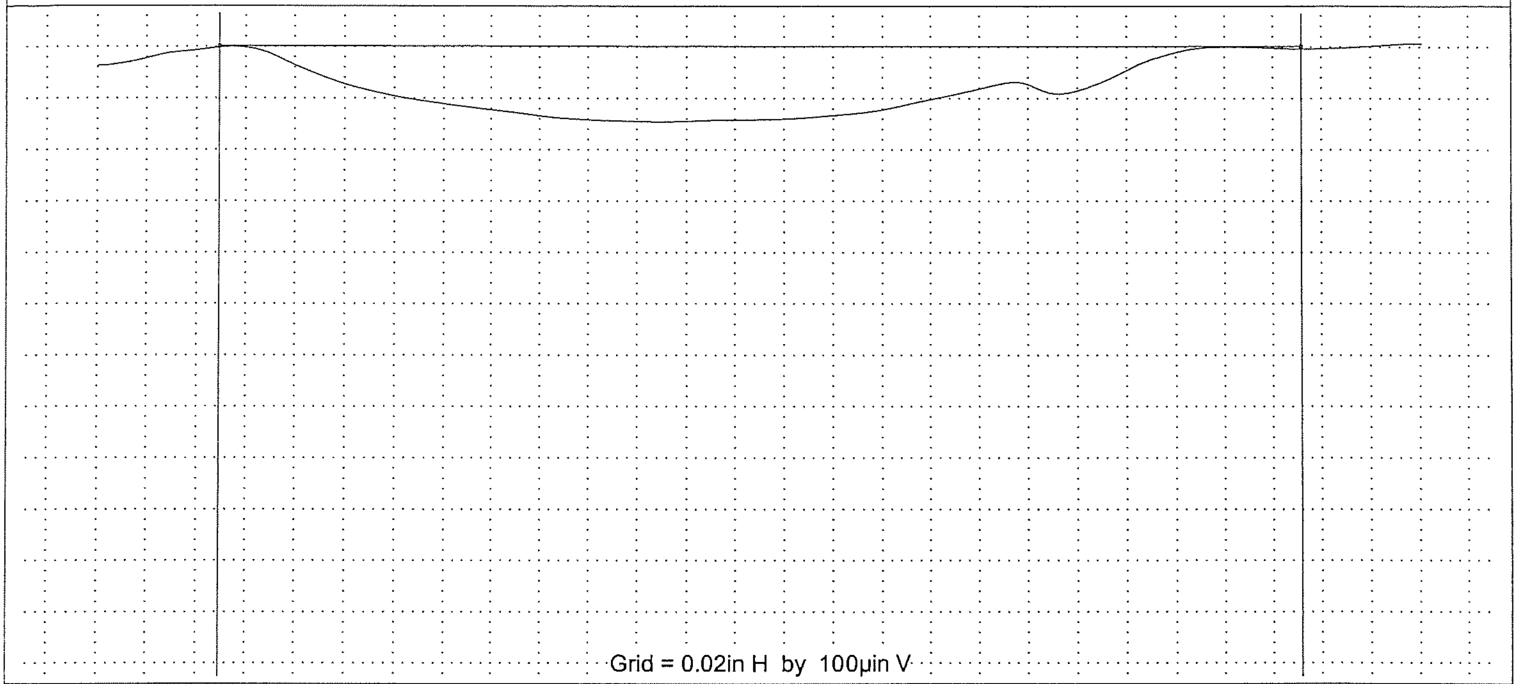
Software: 2.46; Advanced; 3.95
Data
  Collected: Tue Feb 07 10:15 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin R2
  Run 65-405-222-10
  *
  File: C:\S-2000-2\DATA\RFWT\40522210.A
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Description

Parameters

| PARAMETER | VALUE | UNITS |
|---|---|---|
| Summary | | |
| Standards System = ANSI/ASME B46.1 1995 | | |
| Waviness Parameters: | | |
| Wt | 133.3 | µin |

Profiles: Waviness



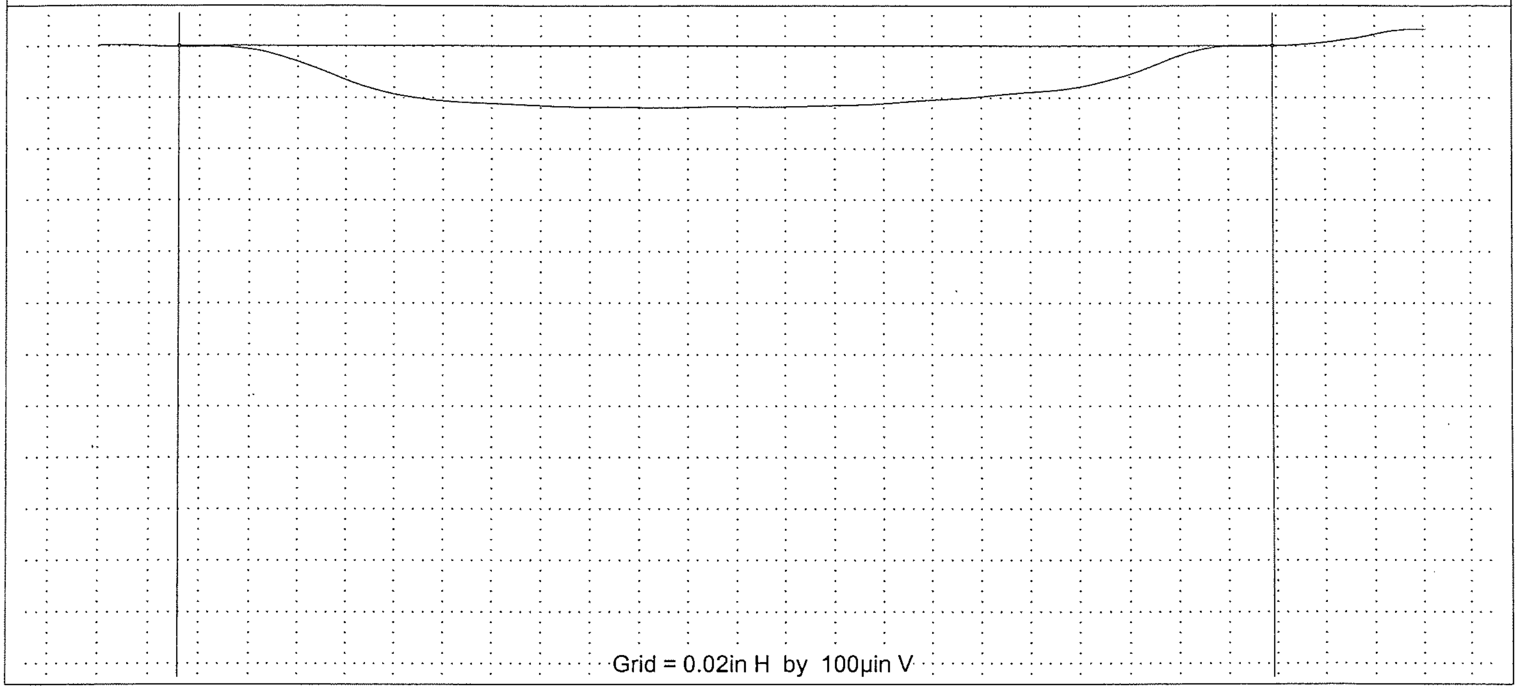

Settings

```
Software: 2.46; Advanced; 3.95
Data
  Collected: Tue Feb 07 10:17 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin R3
  Run 65-405-222-10
  *
  File: C:\S-2000-2\DATA\RFWT\40522210.A
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter
```

Parameters

```
  PARAMETER    VALUE     UNITS
  ---------    -----     -----
Summary
  Standards System = ANSI/ASME B46.1 1995
Waviness Parameters:
  Wt           145.9     µin
```

Profiles: Waviness



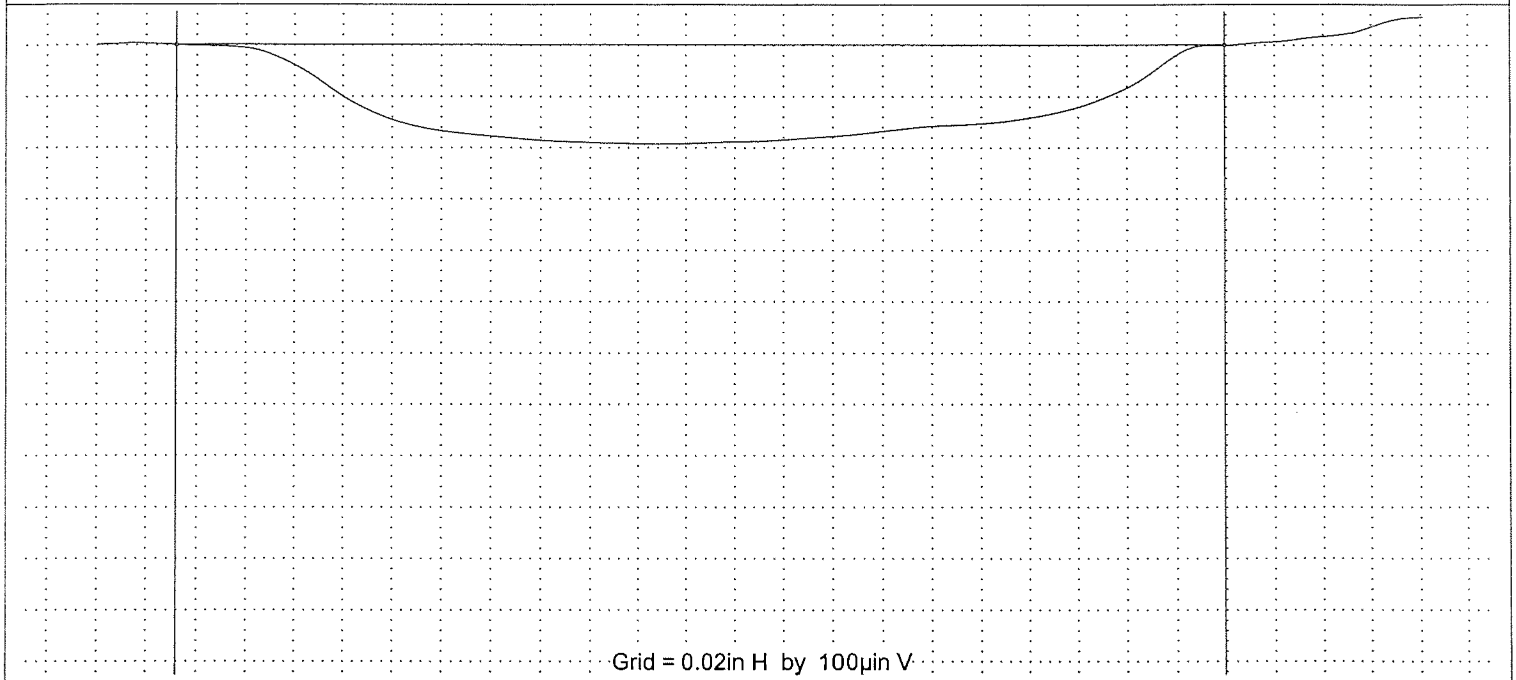

Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Tue Feb 07 10:19 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin R4
  Run 65-405-222-10
  *
  File: C:\S-2000-2\DATA\RFWT\40522210.
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Parameters

| PARAMETER | VALUE | UNITS |
|---|---|---|
| Summary | | |
| Standards System = ANSI/ASME B46.1 1995 | | |
| Waviness Parameters: | | |
| Wt | 120.5 | µin |

Profiles: Waviness



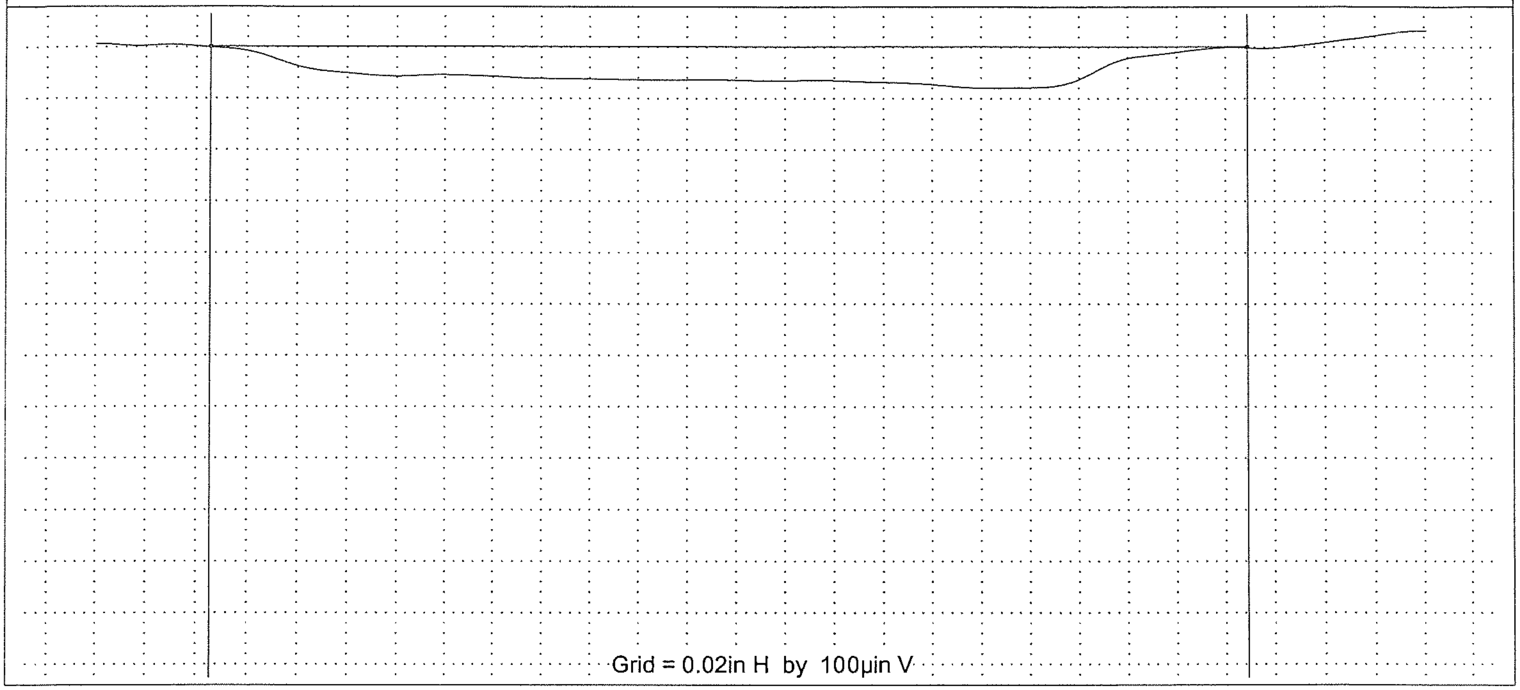

Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Tue Feb 07 10:22 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin R5
  Run 65-405-222-10
  *
  File: C:\S-2000-2\DATA\RFWT\40522210.A
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Parameters

| PARAMETER | VALUE | UNITS |
|---|---|---|
| Summary | | |
| Standards System = ANSI/ASME B46.1 1995 | | |
| Waviness Parameters: | | |
| Wt | 193.6 | µin |

Profiles: Waviness




Settings

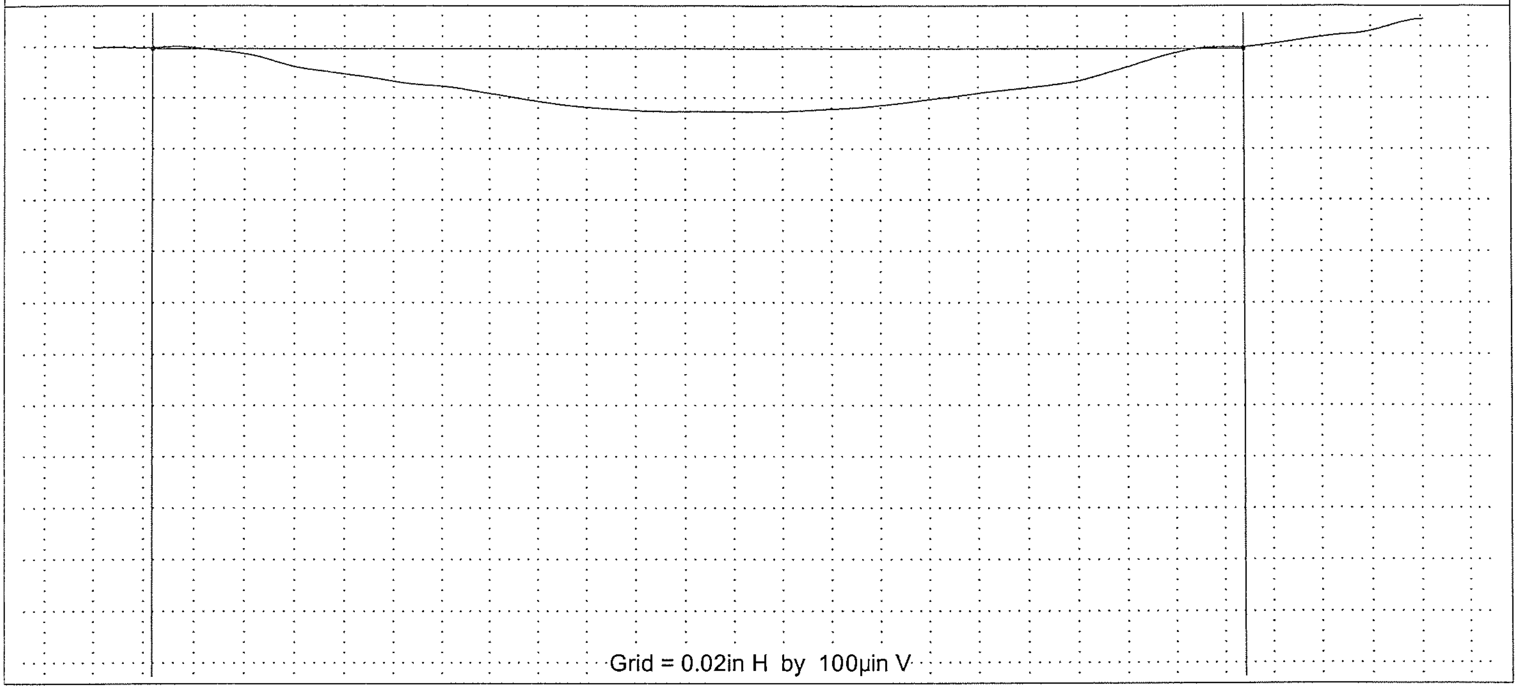
Software: 2.46; Advanced; 3.95
Data
  Collected: Tue Feb 07 10:24 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin R6
  Run 65-405-222-10
  *
  File: C:\S-2000-2\DATA\RFWT\40522210.A
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

RFWT, Pin R6

Parameters

| PARAMETER | VALUE | UNITS |
|---|---|---|
| Summary | | |
| Standards System = ANSI/ASME B46.1 1995 | | |
| Waviness Parameters: | | |
| Wt | 79.9 | µin |

Profiles: Waviness



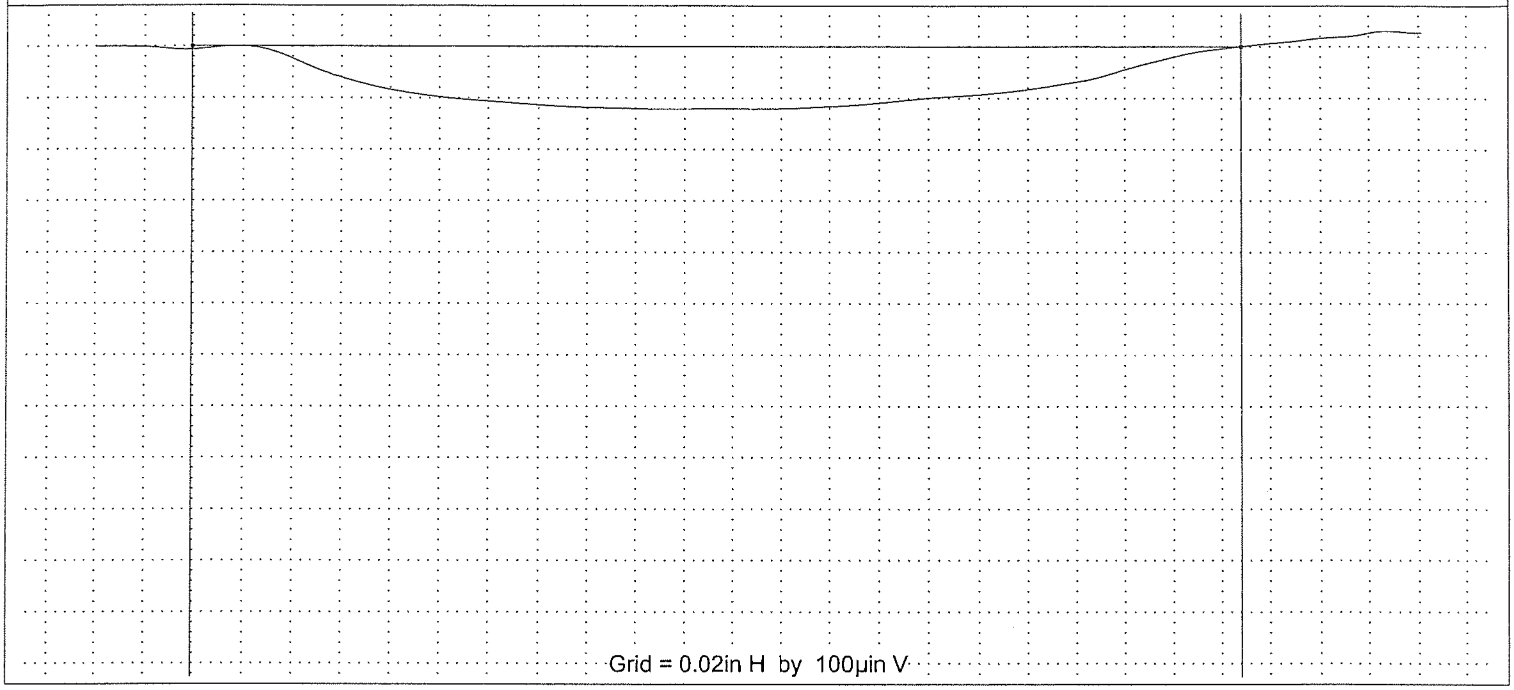

**Settings**

Software: 2.46; Advanced; 3.95
Data
  Collected: Tue Feb 07 10:27 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin R7
  Run 65-405-222-10
  *
  File: C:\S-2000-2\DATA\RFWT\40522210.P
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

**Parameters**

| PARAMETER | VALUE | UNITS |
|---|---|---|
| Summary | | |
| Standards System = ANSI/ASME B46.1 1995 | | |
| Waviness Parameters: | | |
| Wt | 127.8 | µin |

Profiles: Waviness



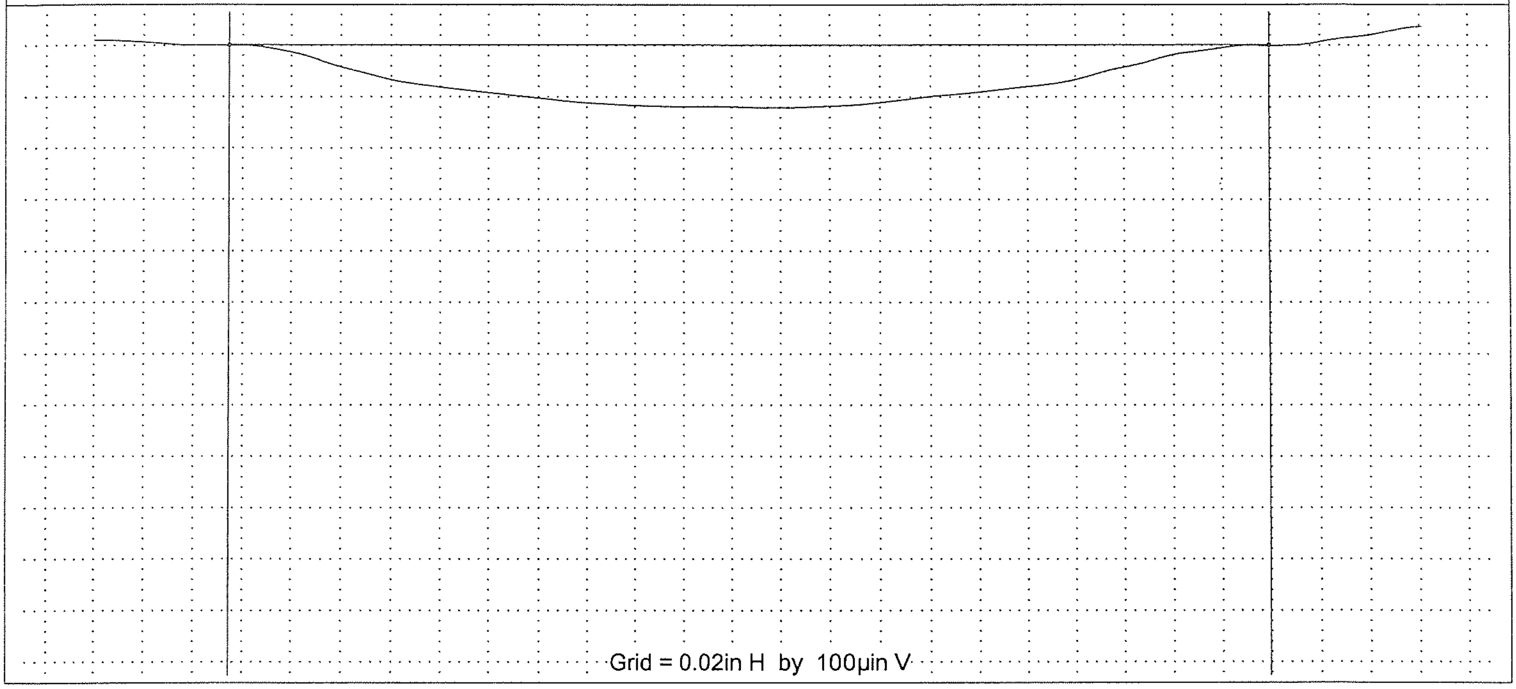

## Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Tue Feb 07 10:29 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin R8
  Run 65-405-222-10
  *
  File: C:\S-2000-2\DATA\RFWT\40522210.P
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

## Parameters

| PARAMETER | VALUE | UNITS |
|---|---|---|
| Summary | | |
| Standards System = ANSI/ASME B46.1 1995 | | |
| Waviness Parameters: | | |
| Wt | 121.7 | µin |

Profiles: Waviness




Settings

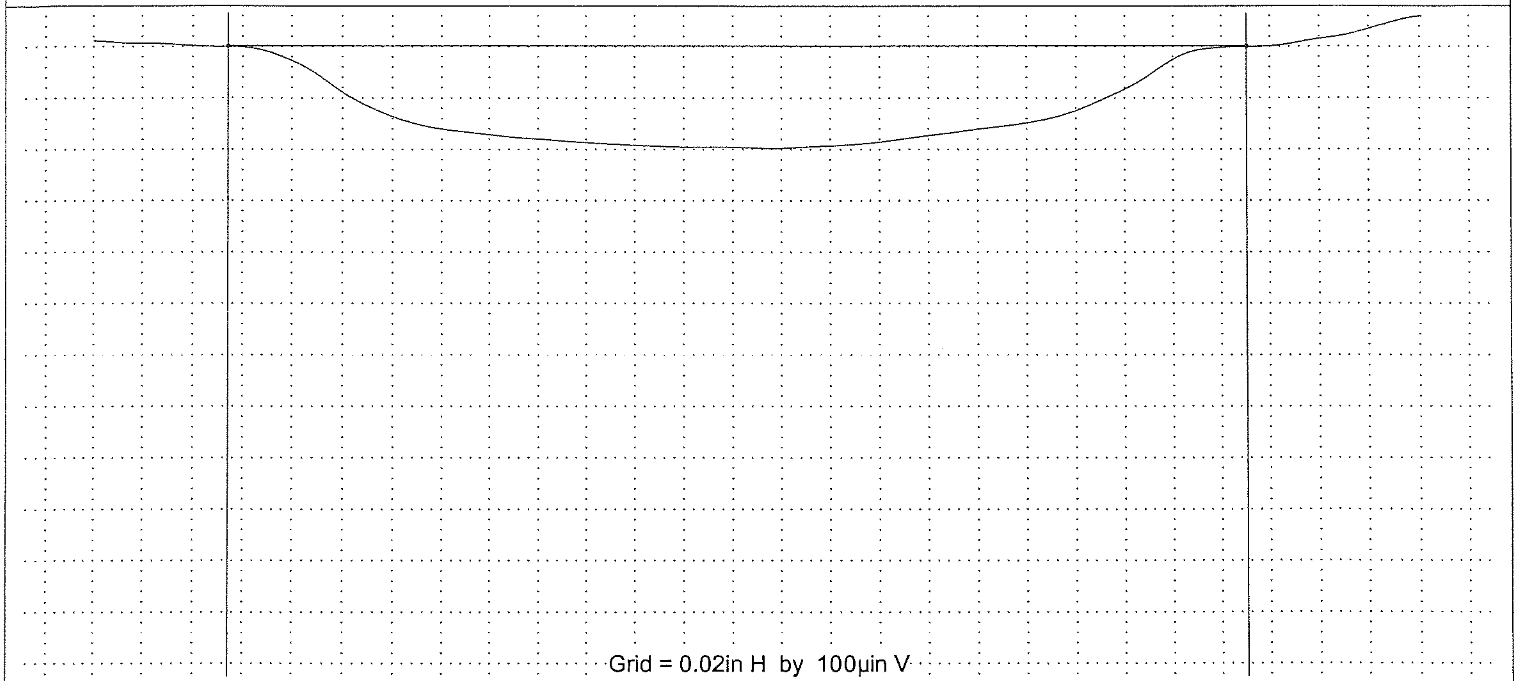
Software: 2.46; Advanced; 3.95
Data
  Collected: Tue Feb 07 09:30 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin L1
  Run 65-405-222-10
  *
  File: C:\S-2000-2\DATA\RFWT\40522210.F
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Description

Parameters

| PARAMETER | VALUE | UNITS |
|---|---|---|
| Summary | | |
| Standards System = ANSI/ASME B46.1 1995 | | |
| Waviness Parameters: | | |
| Wt | 121.3 | µin |

Profiles: Waviness



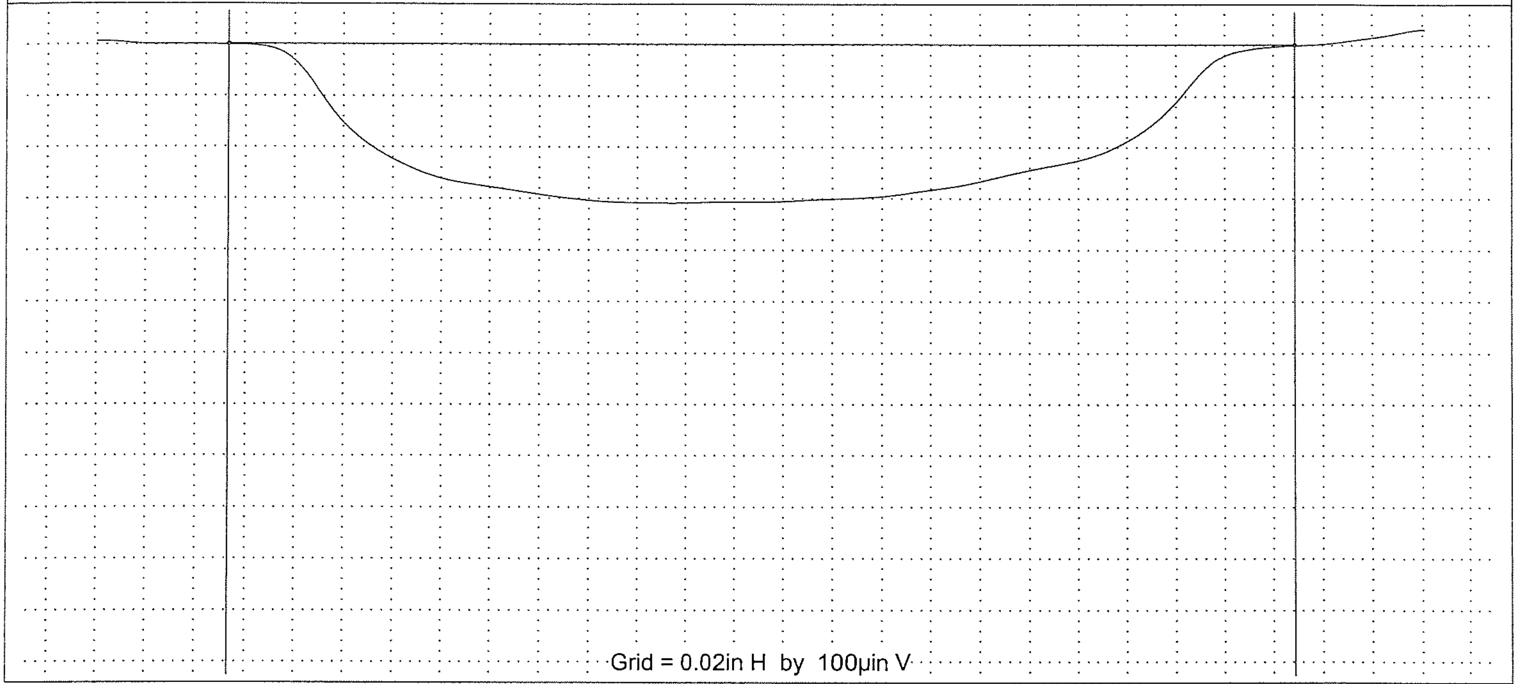

### Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Tue Feb 07 09:34 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin L2
  Run 65-405-222-10
  *
  File: C:\S-2000-2\DATA\RFWT\40522210.I
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

### Parameters

| PARAMETER | VALUE | UNITS |
|---|---|---|
| Summary | | |
| Standards System = ANSI/ASME B46.1 1995 | | |
| Waviness Parameters: | | |
| Wt | 197.8 | µin |

Profiles: Waviness



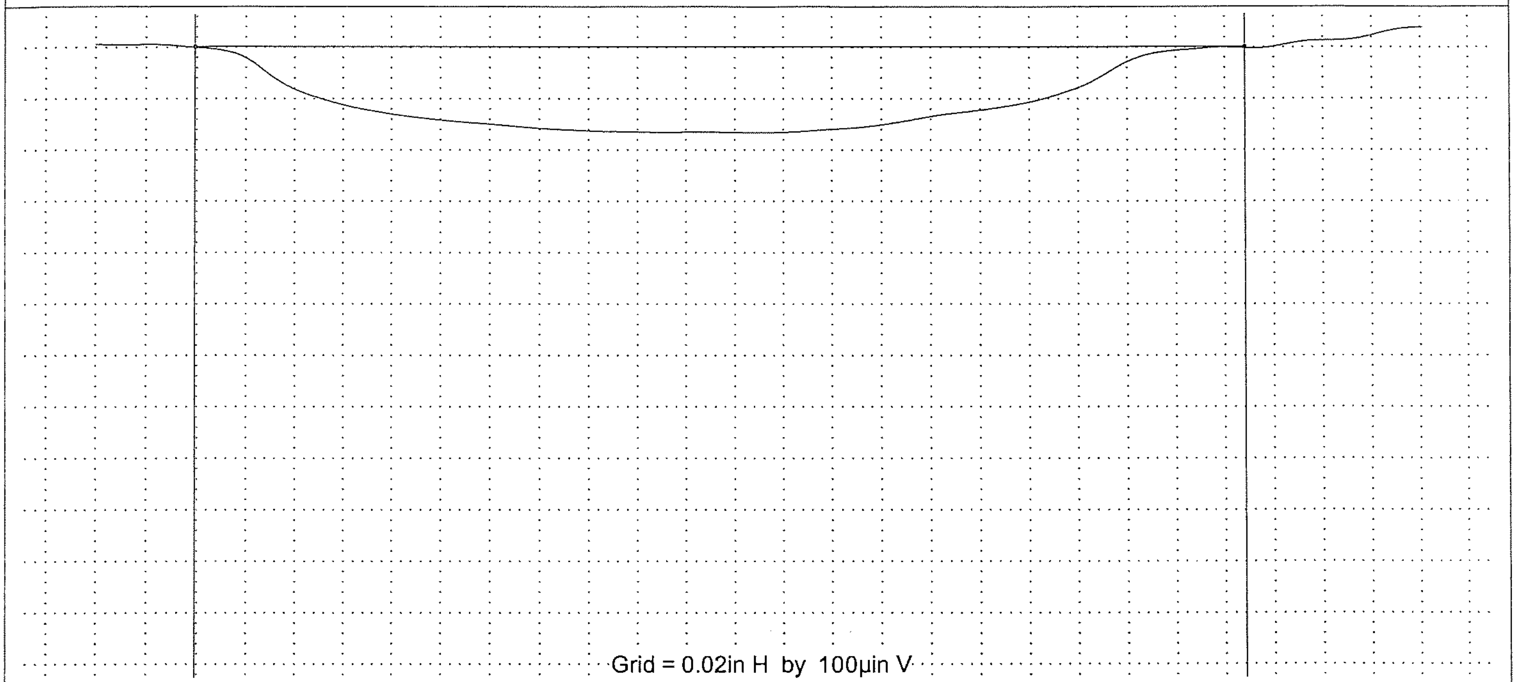

Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Tue Feb 07 09:35 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin L3
  Run 65-405-222-10
  *
  File: C:\S-2000-2\DATA\RFWT\40522210.A
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Parameters

| PARAMETER | VALUE | UNITS |
|---|---|---|
| Summary | | |
| Standards System = ANSI/ASME B46.1 1995 | | |
| Waviness Parameters: | | |
| Wt | 308.3 | µin |

Profiles: Waviness



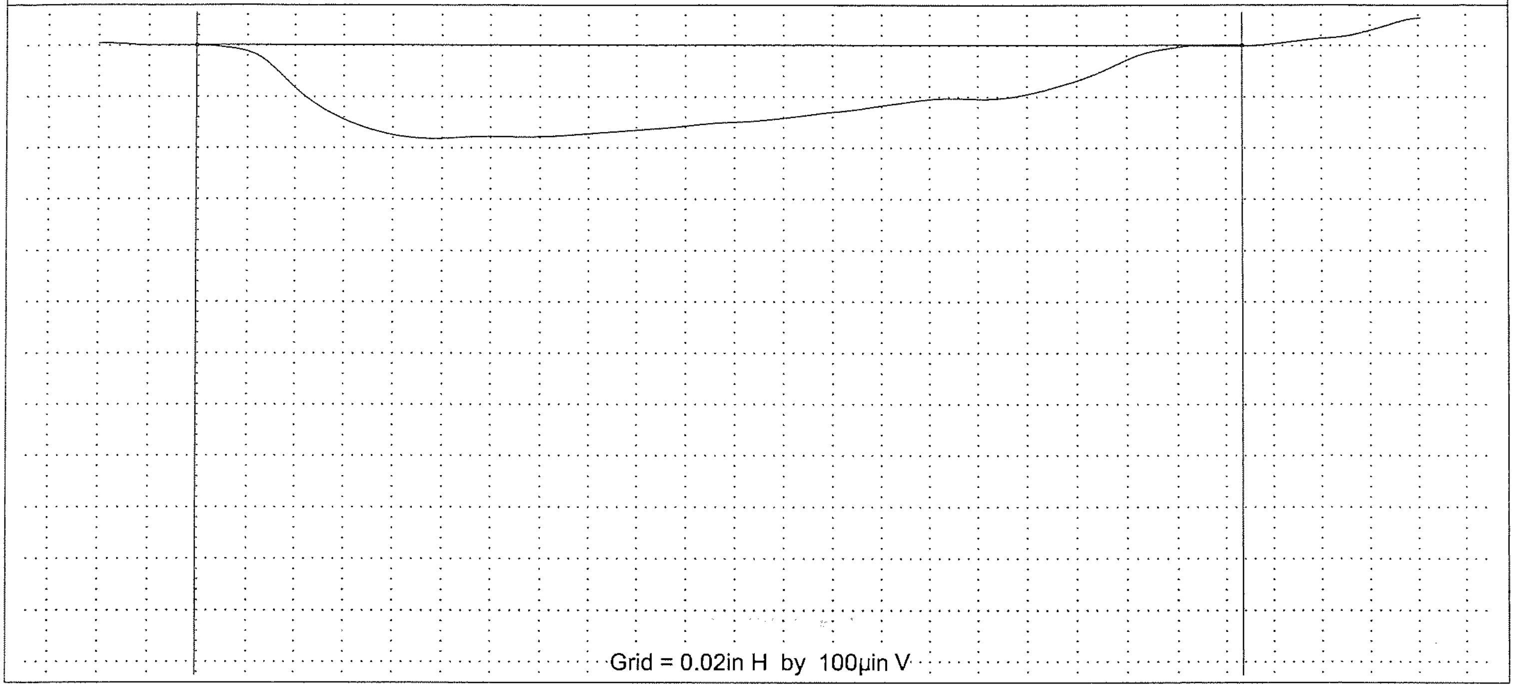

Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Tue Feb 07 09:37 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin L4
  Run 65-405-222-10
  *
  File: C:\S-2000-2\DATA\RFWT\40522210.A
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Parameters

| PARAMETER | VALUE | UNITS |
|---|---|---|
| Summary | | |
| Standards System = ANSI/ASME B46.1 1995 | | |
| Waviness Parameters: | | |
| Wt | 166.2 | µin |

Profiles: Waviness



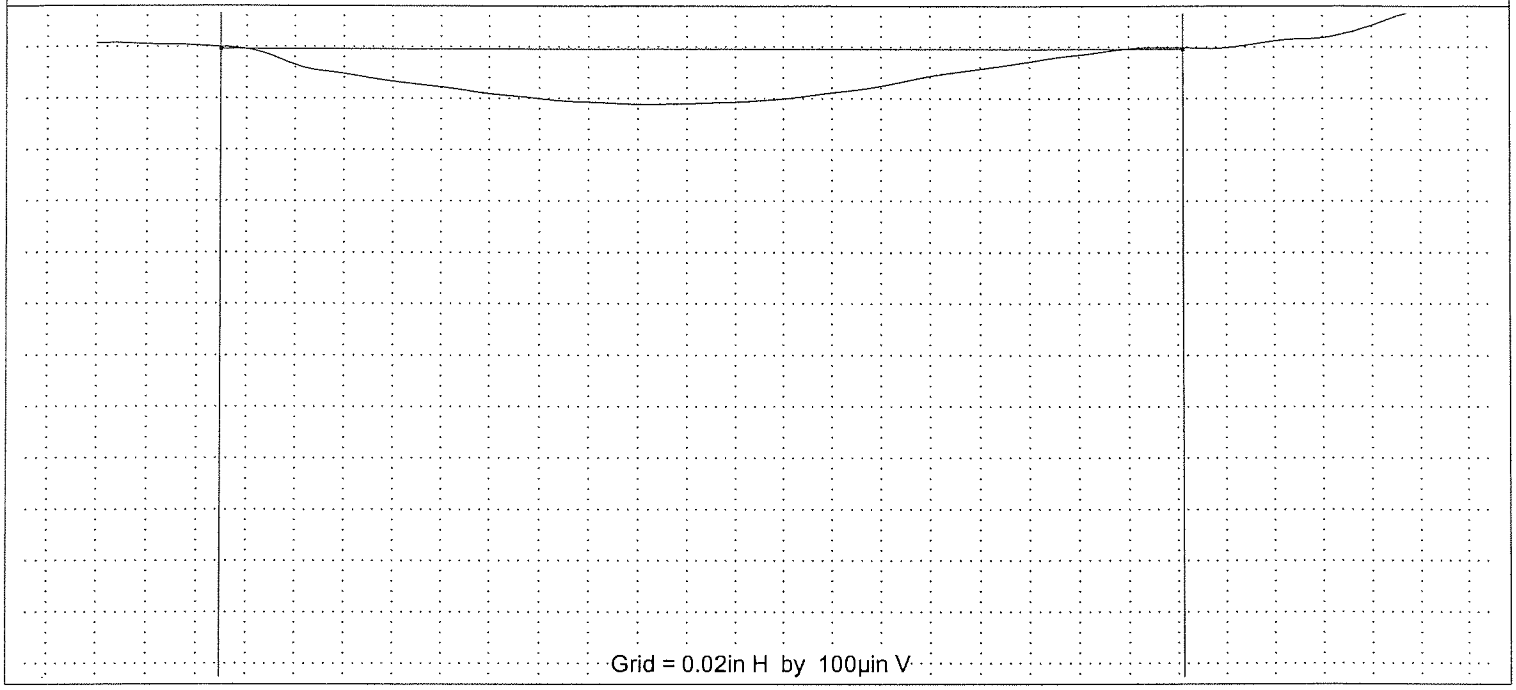

## Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Tue Feb 07 09:40 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin L5
  Run 65-405-222-10
  *
  File: C:\S-2000-2\DATA\RFWT\40522210.
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

## Parameters

| PARAMETER | VALUE | UNITS |
|---|---|---|
| Summary | | |
| Standards System = ANSI/ASME B46.1 1995 | | |
| Waviness Parameters: | | |
| Wt | 182.4 | µin |

Profiles: Waviness



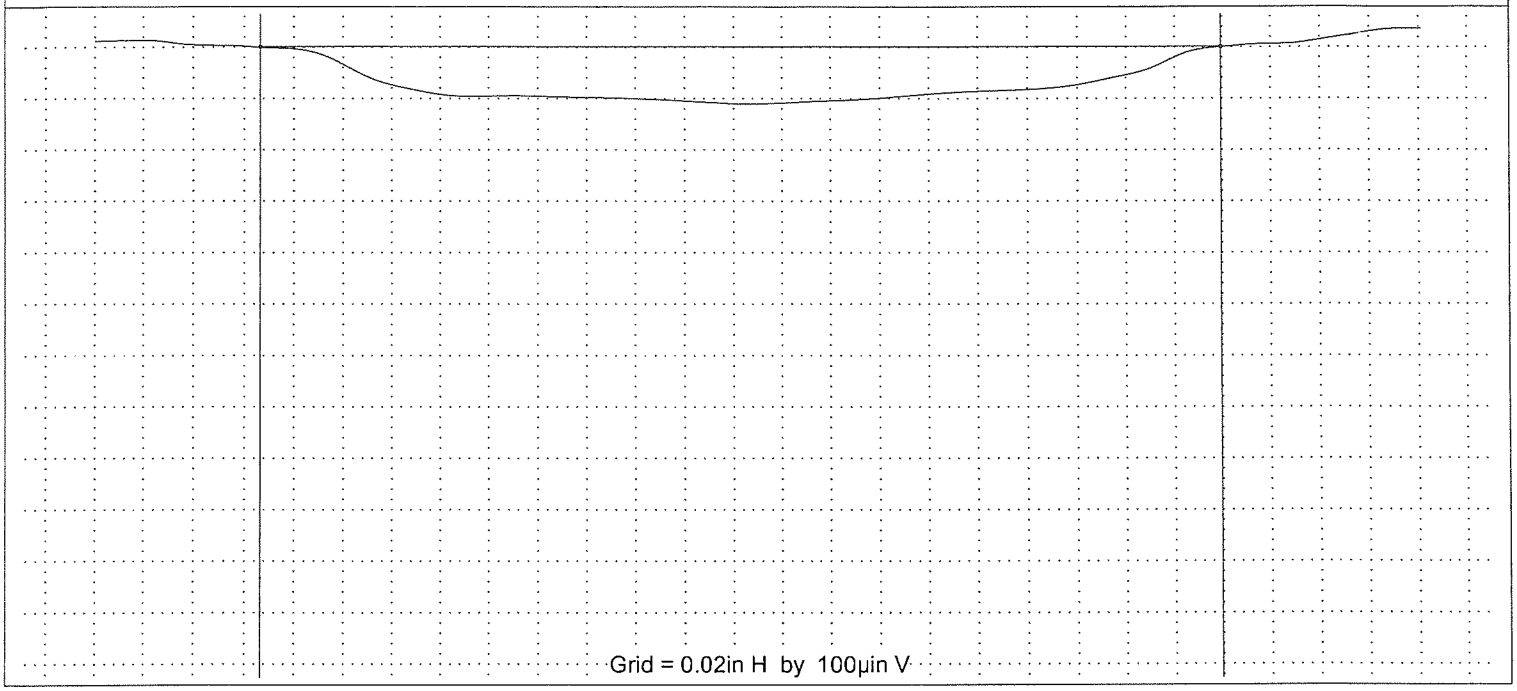

Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Tue Feb 07 09:44 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin L6
  Run 65-405-222-10
  *
  File: C:\S-2000-2\DATA\RFWT\40522210.A
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Parameters

| PARAMETER | VALUE | UNITS |
|---|---|---|
| Summary | | |
| Standards System = ANSI/ASME B46.1 1995 | | |
| Waviness Parameters: | | |
| Wt | 111.7 | µin |

Profiles: Waviness



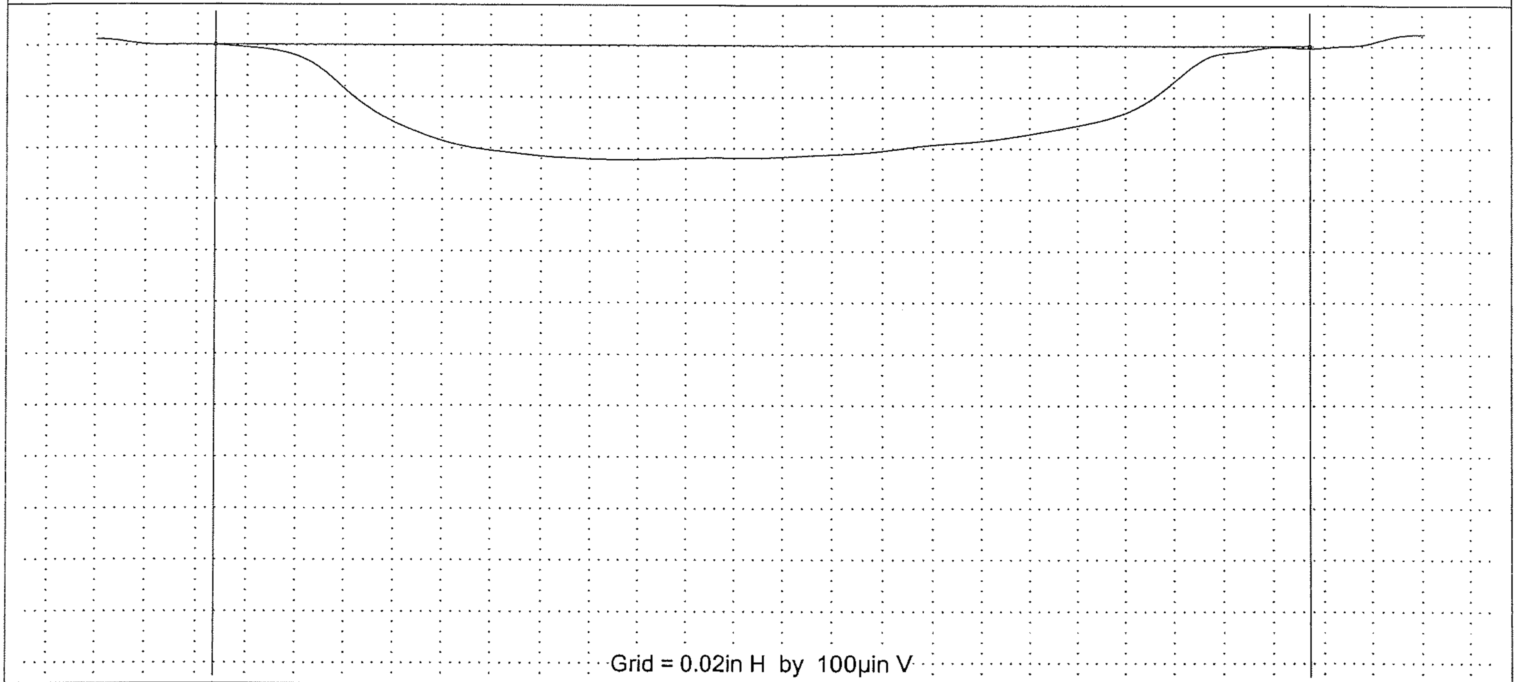

## Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Tue Feb 07 09:45 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin L7
  Run 65-405-222-10
  *
  File: C:\S-2000-2\DATA\RFWT\40522210.P
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

## Parameters

| PARAMETER | VALUE | UNITS |
|---|---|---|
| Summary | | |
| Standards System = ANSI/ASME B46.1 1995 | | |
| Waviness Parameters: | | |
| Wt | 111.1 | µin |

Profiles: Waviness




Settings

Software: 2.46; Advanced; 3.95
Data
  Collected: Tue Feb 07 10:10 2012
  By: Kerry McCubbin
  At: SWRI- UNIT # 1
  Tracer Used: PDT-2-522
  Sampled Length: 0.541 in
  Sample Spacing: 18.9 µin
Description
  RFWT, Pin L8
  Run 65-405-222-10
  *
  File: C:\S-2000-2\DATA\RFWT\40522210.
Instrument
  Name: MicroAnalyzer 2000
  Serial #: S-2000-3027
  Current Tracer:PDT-2-522
  Travel Distance: 0.541 in
  Trace Velocity: 0.030 in/s
Form
  Form Type: Two-Point Line
Roughness Filter
  Type: Gaussian
  Cutoff: 0.030 in
  No Filter Width Removal at Ends
Parameter Calculation Settings
  Peak Count Threshold: 19.7 µin
  High Spot Count Threshold: 19.7 µin
  tp Reference Percent: 5 %
  tp Slice Depth: 19.7 µin
Short Wavelength Filter
  Type: Gaussian
  Cutoff: 0.0001 in
Waviness Filter
  Type: No Filter

Parameters

| PARAMETER | VALUE | UNITS |
|---|---|---|
| Summary | | |
| Standards System = ANSI/ASME B46.1 1995 | | |
| Waviness Parameters: | | |
| Wt | 222.4 | µin |

| | |
|---|---|
| Laboratory: SR | EOT Date: 20120206 |
| Test Number: * 65-405-222-10 | |
| Oil Code: LO-271510 | |
| Formulation / Stand Code: | |

*Test Number is: Stand - Stand Run No. - Engine No. - Engine Run No.*

**Appendix B**

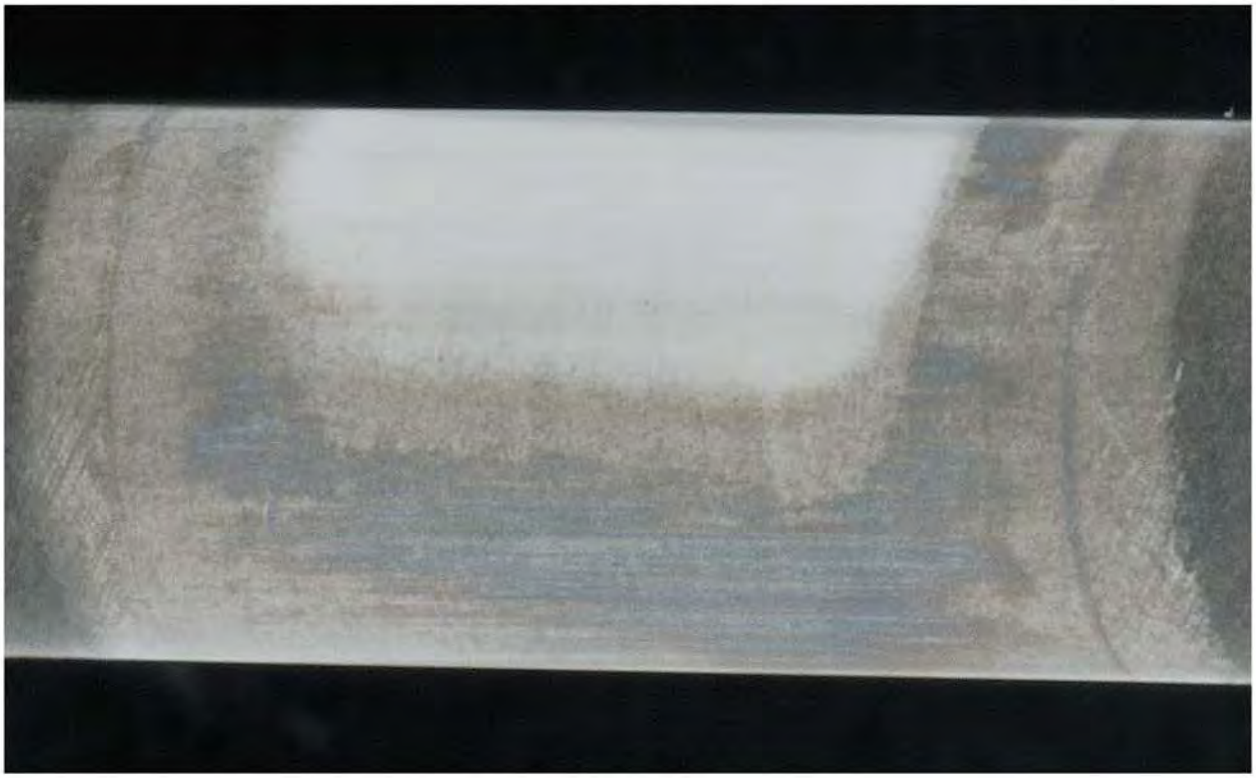
**Roller Follower Wear Test Photographs**

1. Roller Follower Axle Pin Wear Best
2. Roller Follower Axle Pin Wear Worst

# Roller Follower Wear Test

| | | | |
|---|---|---|---|
| **Laboratory:** | SR | **Oil Code:** | LO-271510 |
| **Test Stand No.:** | 65 | **Test No.:** | 65-405-222-10 |
| **Laboratory Oil Code:** | 271510 | **Test Hours:** | 50 |
| **Formulation / Stand Code:** | | | |

## Roller Axle Wear



## Best 1R

# Roller Follower Wear Test

| | | | |
|---|---|---|---|
| **Laboratory:** | SR | **Oil Code:** | LO-271510 |
| **Test Stand No.:** | 65 | **Test No.:** | 65-405-222-10 |
| **Laboratory Oil Code:** | 271510 | **Test Hours:** | 50 |
| **Formulation / Stand Code:** | | | |

## Roller Axle Wear

## Worst 3L

# APPENDIX – D1 (Part 1)
# TYPE C-4 GRAPHITE CLUTCH FRICTION TEST
# LO268869

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

**Report on**

**ALLISON HEAVY-DUTY TRANSMISSION FLUID**

# TYPE C-4 GRAPHITE CLUTCH FRICTION TEST

Conducted for

**ARMY LAB**

Oil Code:
**LO268869**

Test Number:
**C4-3-1341**

**October 14, 2011**

Submitted by:

Matthew Jackson
Manager
Specialty & Driveline Fluid Evaluation

The results of this report relate only to the fluid tested.
This report shall not be reproduced, except in full, without the written approval of Southwest Research Institute®.

## VIII. Graphite Clutch Friction Test

| | | | |
|---|---|---|---|
| Test Laboratory: | SwRI | Lab Fluid Code: | LO-268869 |
| Test Number: | C4-3-1341 | Sponsor Fluid Code: | LO268869 |
| Friction Plate Batch: | LOT 44 | Completion Date: | 10/14/11 |
| Steel Plate Batch: | 10/9/2008 | | |

Clutch Wear Data
(units in mm)

| | Maximum | Average |
|---|---|---|
| Steel Plates | 0.0000 | 0.0000 |
| Clutch Plate | 0.0970 | 0.0818 |

| | Before | After |
|---|---|---|
| Pack Clearance | 0.5334 | 0.5588 |

Reference Tests

| Test Number | Test Date | Test Fluid |
|---|---|---|
| C4-0-1304 | 12/09/10 | PASS REF-L-06-04 |
| C4-0-1315 | 03/30/11 | MIL-PRF-2104H |
| C4-0-1338 | 10/05/11 | MIL-PRF-2104H |

| | New | EOT |
|---|---|---|
| Viscosity at 40°C, cSt | 47.29 | 41.16 |
| Viscosity at 100°C, cSt | 8.81 | 7.80 |
| Iron Content, ppm | 2 | 61 |

| D5185 | New Fluid (ppm) |
|---|---|
| Ba | <1 |
| B | <1 |
| Ca | 3419 |
| Mg | 10 |
| P | 1272 |
| Si | 2 |
| Na | 5 |
| Zn | 1874 |

Name: Matthew Jackson

Signature: [signature]

Title: Manager

Date: 10/25/11

# ALLISON C-4 GRAPHITE FRICTION TEST SUMMARY

(Torque in Ft-Lbs)

| | |
|---|---|
| Sponsor Fluid Code: **LO268869** | Test Number: **C4-3-1341** |
| Lab Fluid Code: **LO-268869** | Fric. Plate Batch: **LOT 44** |
| Completion Date: **10/14/2011** | Steel Plate Batch: **10/9/2008** |

**PHASE A**

| CYCLE | SLIP TIME | TORQUE (MIDPOINT) | TORQUE STATIC PEAK | TORQUE (.2 Second) | STATIC PEAK - 0.2 TORQUE | LOW SPEED STATIC PEAK | LOWSPEED STATIC TORQUE |
|---|---|---|---|---|---|---|---|
| 500 | 1.17 | 54 | 56 | 42 | 14 | 60 | 53 |
| 1000 | 1.18 | 53 | 56 | 38 | 18 | 64 | 55 |

**PHASE B**

| CYCLE | SLIP TIME | TORQUE (MIDPOINT) | TORQUE STATIC PEAK | TORQUE (0.2 Second) | STATIC PEAK - 0.2 TORQUE | LOW SPEED STATIC PEAK | LOWSPEED STATIC TORQUE |
|---|---|---|---|---|---|---|---|
| 1500 | 0.75 | 106 | 141 | 96 | 45 | 147 | 134 |
| 2000 | 0.79 | 100 | 140 | 88 | 52 | 146 | 132 |
| 2500 | 0.81 | 97 | 137 | 82 | 55 | 144 | 131 |
| 3500 | 0.84 | 94 | 131 | 73 | 58 | 140 | 128 |
| 4000 | 0.86 | 92 | 129 | 72 | 57 | 139 | 126 |
| 4500 | 0.87 | 91 | 125 | 71 | 54 | 142 | 124 |
| 5000 | 0.87 | 91 | 123 | 70 | 53 | 135 | 122 |
| 5500 | 0.86 | 93 | 121 | 72 | 49 | 131 | 120 |

| | Limits | | Results | | | |
|---|---|---|---|---|---|---|
| | Max | Max Change | 1,500 N | 5,500 N | % Change | P/F |
| Slip Time Max. | 0.89 | N/A | 0.75 | 0.86 | 14.67 | P |
| 0.2 Second Dynamic Coeff. | N/A | N/A | 0.090 | 0.067 | -25.556 | |
| Mid-Point Fric. Coeff. Min. | 0.089 | N/A | 0.099 | 0.087 | -12.121 | F |
| Static Friction Coeff. | N/A | N/A | 0.132 | 0.113 | -14.394 | |
| Low Speed Peak Fric. Coeff. | N/A | N/A | 0.138 | 0.123 | -10.870 | |
| 0.25 Second Low Speed Coeff. | N/A | N/A | 0.126 | 0.112 | -11.111 | |

## SOUTHWEST RESEARCH INSTITUTE®

# ALLISON C4-GRAPHITE FRICTION TEST

**Candidate Fluid: LO268869** **Test Number : C4-3-1341** **Completion Date : 10/14/2011**

**Lab Fluid Code : LO-268869** **Steel Plate Batch: 10/09/2008** **Fric Plate Batch : LOT 44**

**(all units in mm)**

| Plates | Location of Tooth (Clockwise) | Near Inner Diameter Before | Near Inner Diameter After | Near Outer Diameter Before | Near Outer Diameter After | Inner Diameter Change | Average Overall Change | Outer Diameter Change |
|---|---|---|---|---|---|---|---|---|
| FRICTION MATERIAL | | | | | | | | |
| 2 | Top | 2.2660 | 2.1690 | 2.2480 | 2.1810 | 0.0970 | | 0.0670 |
| | 120 | 2.2470 | 2.1600 | 2.2540 | 2.1830 | 0.0870 | | 0.0710 |
| | 240 | 2.2460 | 2.1620 | 2.2640 | 2.1790 | 0.0840 | | 0.0850 |
| | Average | | | | | 0.0893 | 0.0818 | 0.0743 |
| STEEL SEPARATORS | | | | | | | | |
| 1 | Top | 1.7460 | 1.7460 | 1.7450 | 1.7450 | 0.0000 | | 0.0000 |
| | 120 | 1.7500 | 1.7500 | 1.7500 | 1.7500 | 0.0000 | | 0.0000 |
| | 240 | 1.7510 | 1.7510 | 1.7510 | 1.7510 | 0.0000 | | 0.0000 |
| | Average | | | | | 0.0000 | 0.0000 | 0.0000 |
| 3 | Top | 1.7580 | 1.7580 | 1.7580 | 1.7580 | 0.0000 | | 0.0000 |
| | 120 | 1.7540 | 1.7540 | 1.7510 | 1.7510 | 0.0000 | | 0.0000 |
| | 240 | 1.7560 | 1.7560 | 1.7560 | 1.7560 | 0.0000 | | 0.0000 |
| | Average | | | | | 0.0000 | 0.0000 | 0.0000 |

PLATE CONDITION AT E.O.T. NO UNUSUAL DISCOLORATION ON STEEL PLATES
(Anything Unusual)

Test Date: 10/14/2011

Operator's Name: JOE M

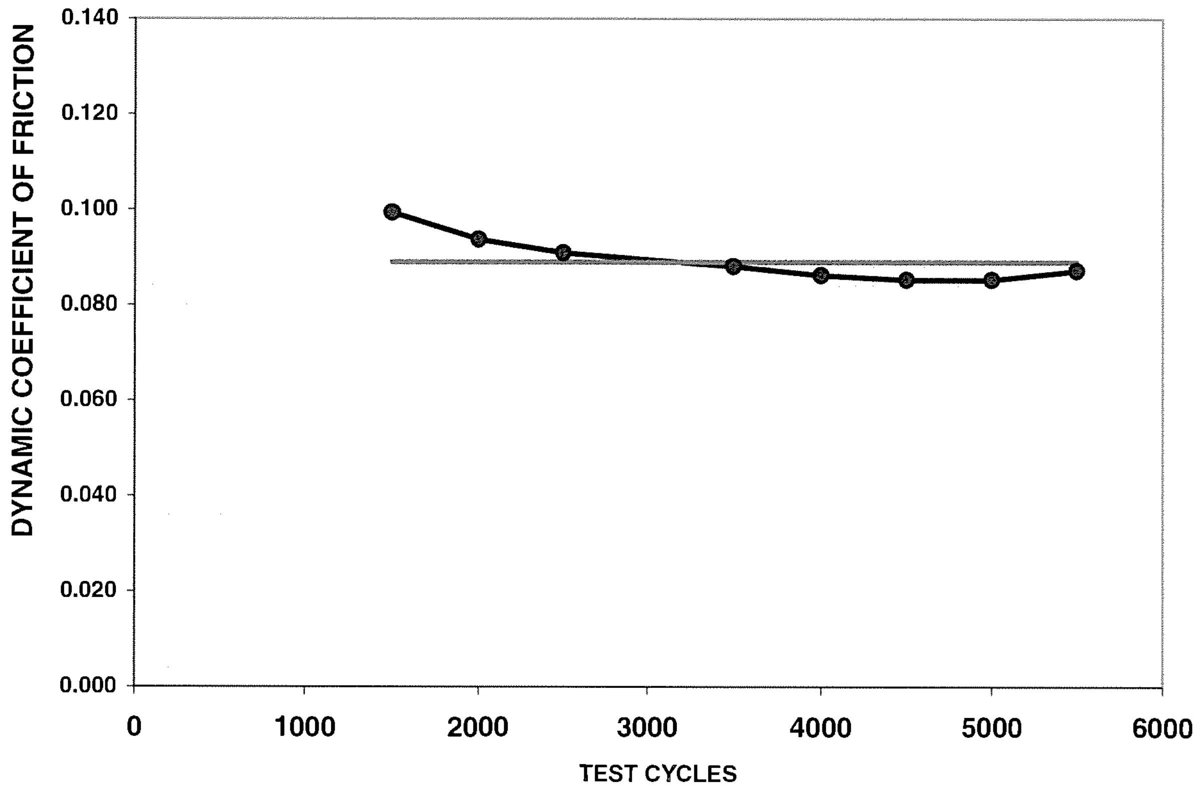
Reviewed By (Signature and Date)
10/24/11

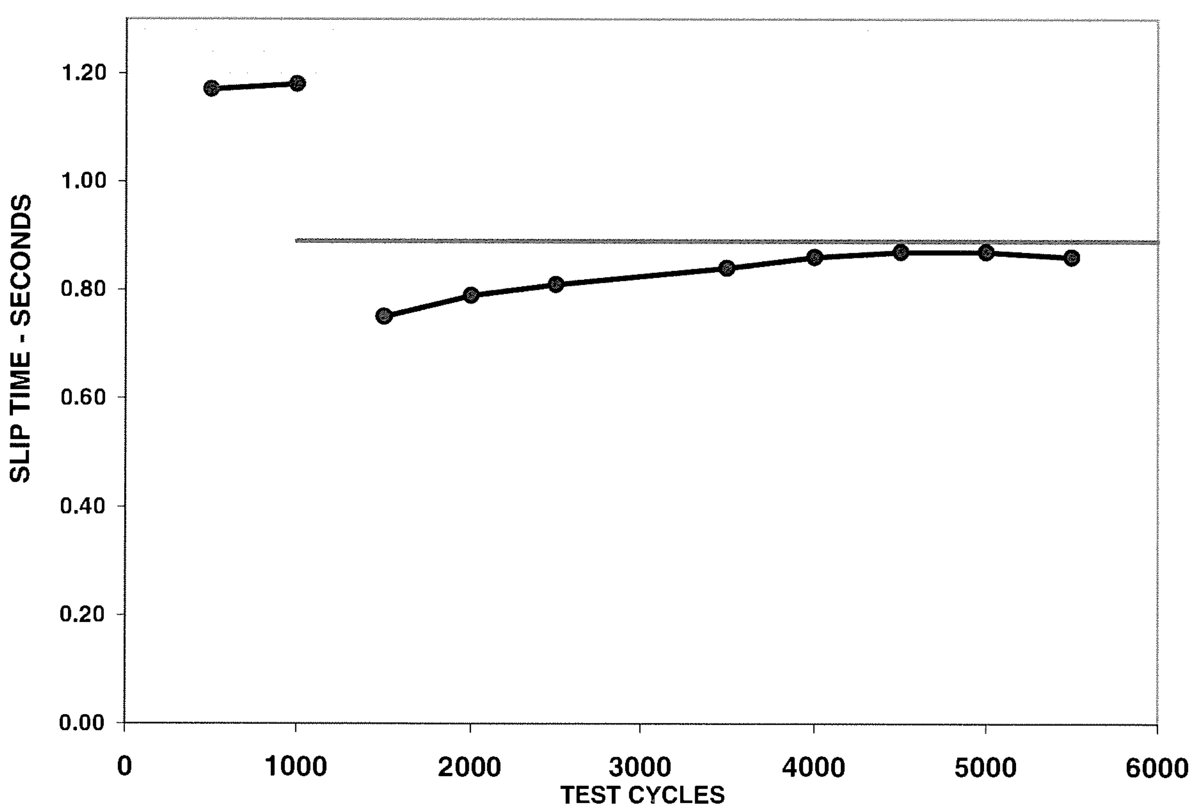
Pack ID#: 4667

ALLISON HEAVY-DUTY TRANSMISSION FLUID
TYPE C-4 GRAPHITE FRICTION TEST

EOT Date: 10/14/2011
Test Number: C4-3-1341

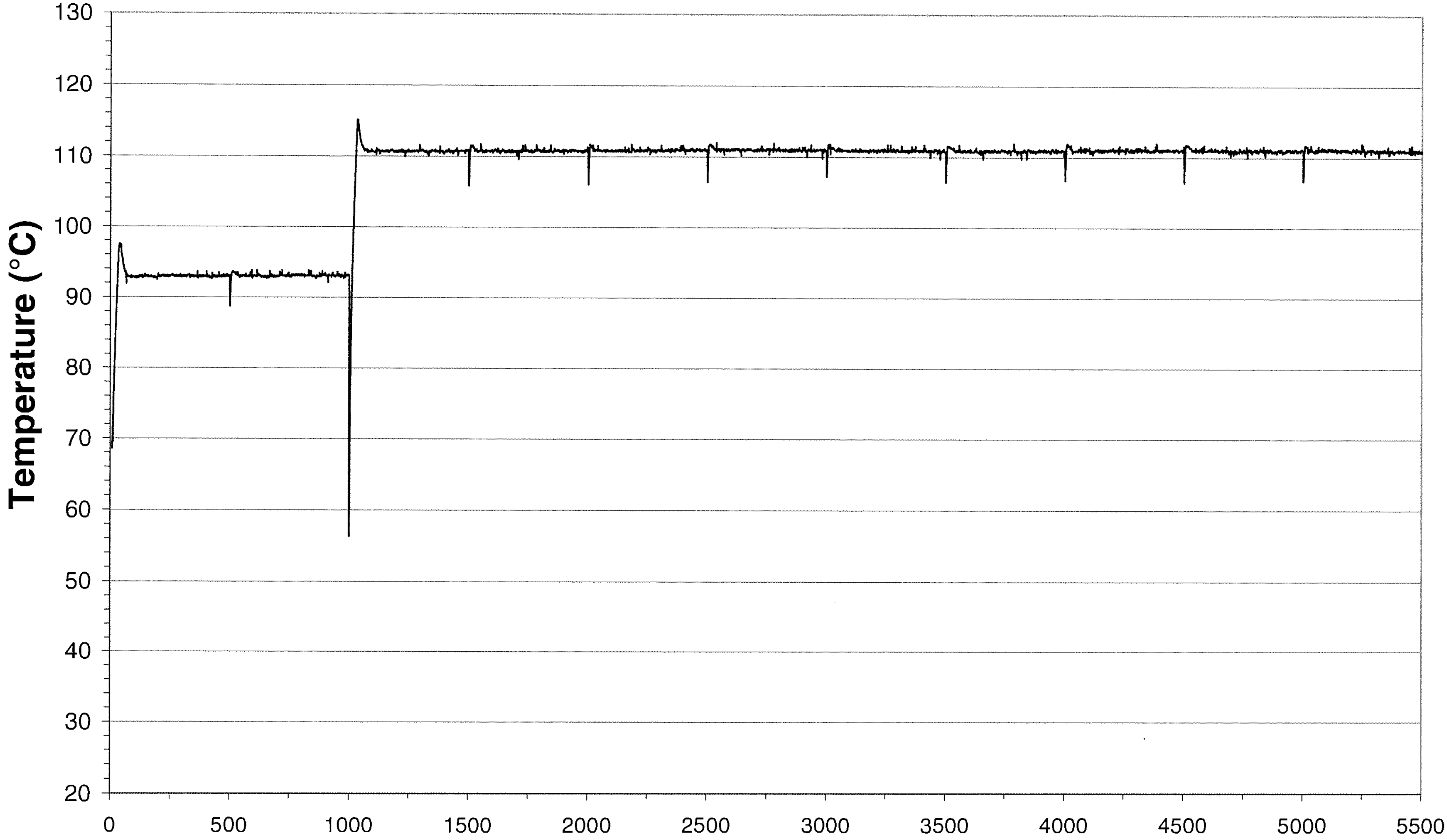
Fluid Code: LO268869
Plate Batch: LOT 44
Steel Batch: 10/9/2008



# C4-3-1341 LO268869

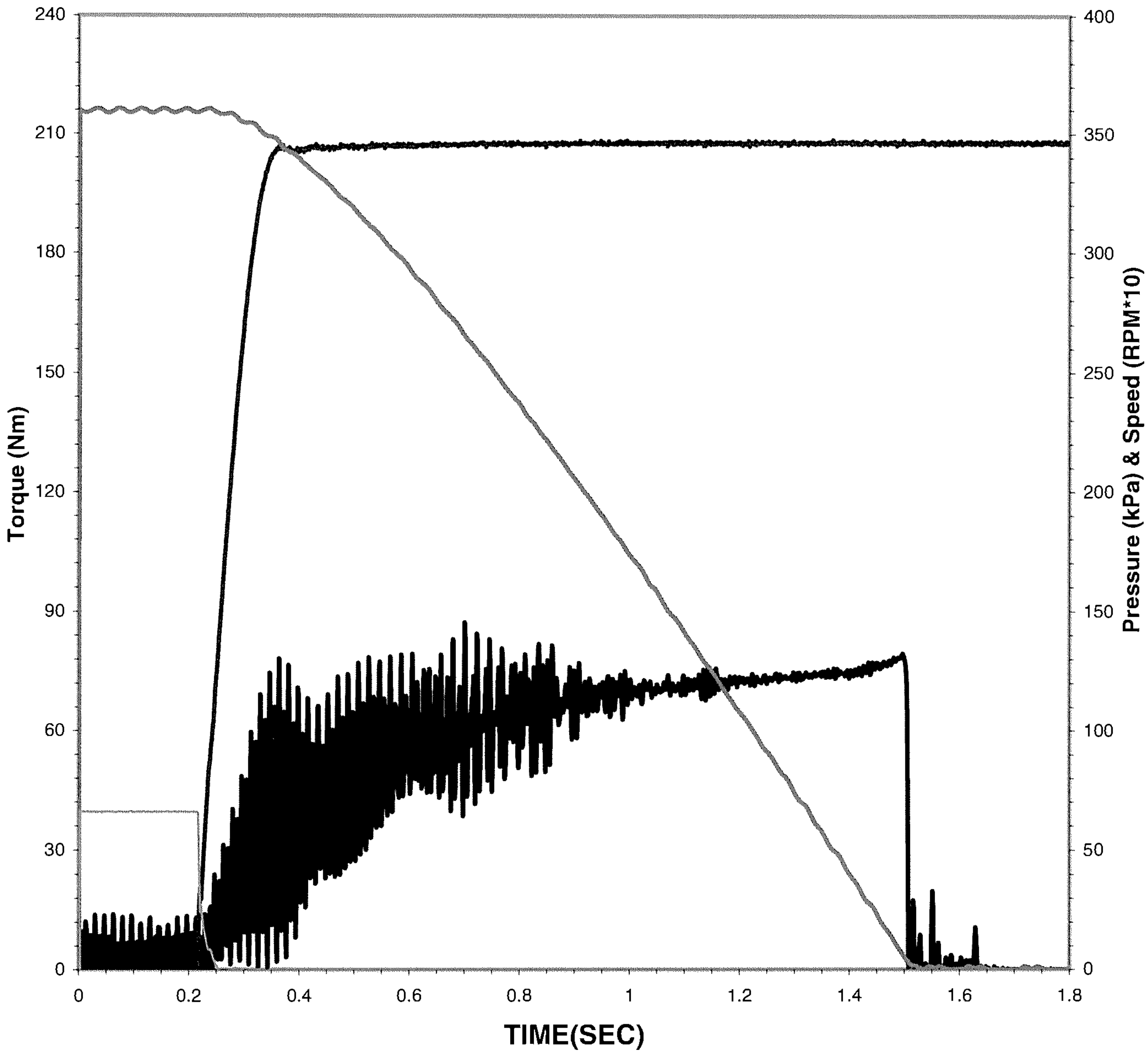
AVG: Phase A = 92.7 °C, Phase B = 110.8 °C



## DYNAMIC TRACES

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE A




| | |
|---|---|
| Date of Test: | 10/13/2011 |
| Time of Test: | 15:15:40 |
| Test Number: | C4-3-1341 |
| Fluid Code: | LO268869 |
| Cycle Number: | 10 |
| Temperature: | 71.6 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 347 kPa (345 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 14.2 KJ (14.50 ± 0.40 KJ) |
| Engage Time: | 1.289 Sec |

**Torque**

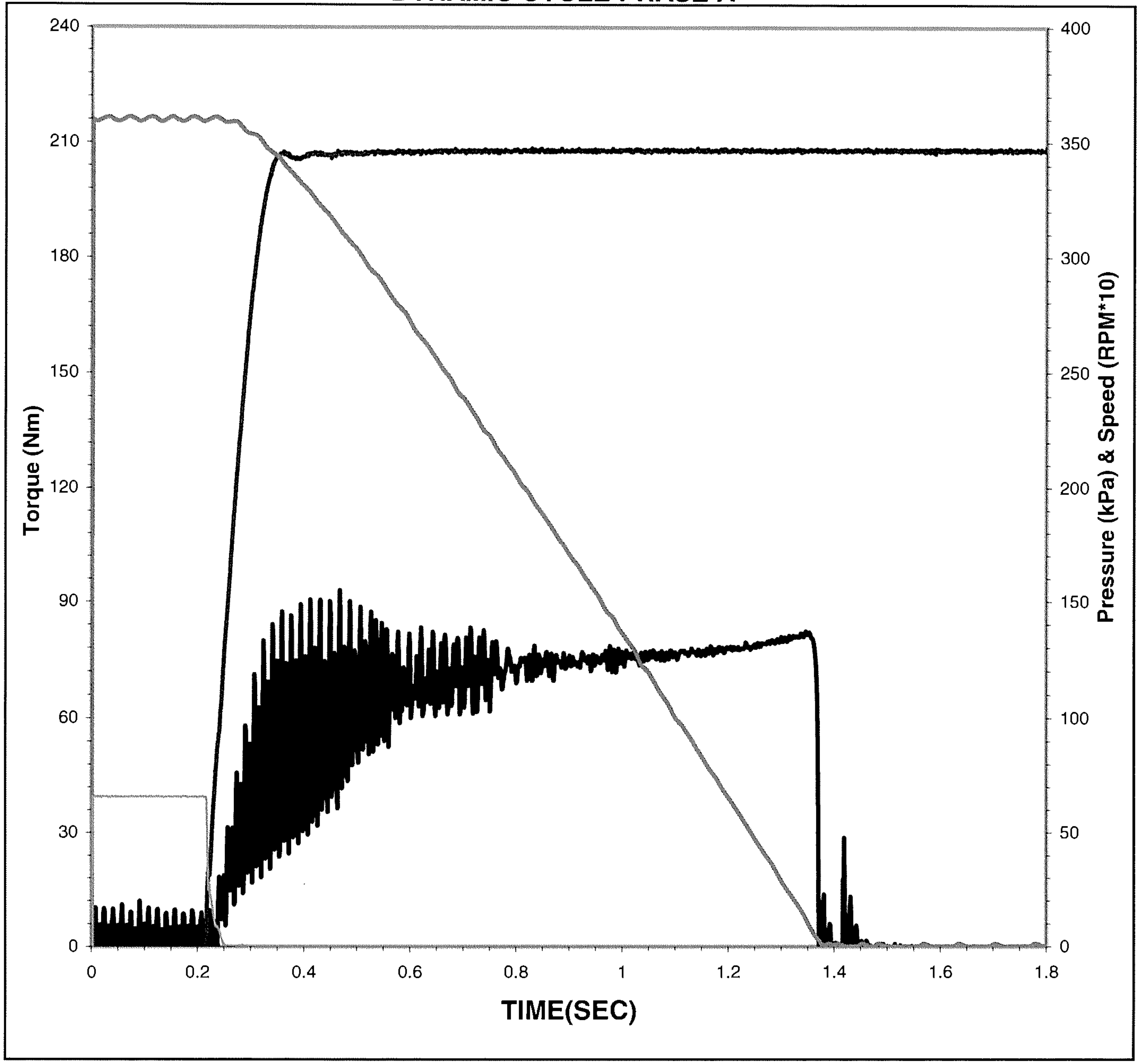
| | |
|---|---|
| 0.2 Sec Dyn: | 44 N*m |
| Midpoint Dyn: | 67 N*m |
| LwSpd Dynamic: | 75 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.073 |
| Midpoint Dyn: | 0.111 |
| LwSpd Dynamic: | 0.125 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE A




**Date of Test:** 10/13/2011

**Time of Test:** 17:18:06

**Test Number:** C4-3-1341

**Fluid Code:** LO268869

**Cycle Number:** 499

**Temperature:** 92.8 °C
(93.3 ± 3.0 °C)

**Apply Pressure:** 347 kPa
(345 ± 7 KPa)

**Apply Rate:** 0.13 Sec
(0.15 ± 0.02 Sec)

**Energy:** 14.3 KJ
(14.50 ± 0.40 KJ)

**Engage Time:** 1.152 Sec

**Torque**

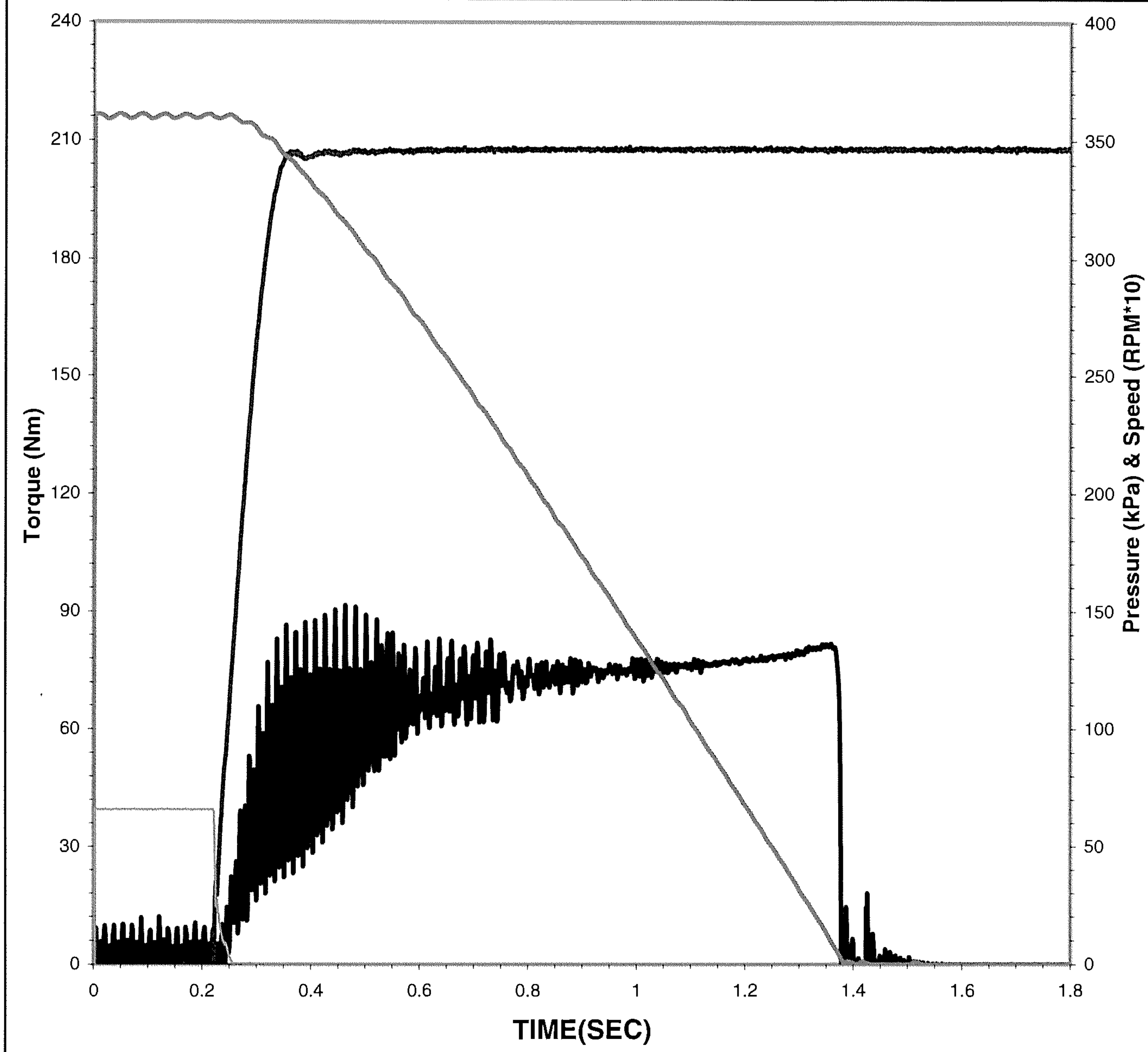
| | |
|---|---|
| 0.2 Sec Dyn: | 57 N*m |
| Midpoint Dyn: | 74 N*m |
| LwSpd Dynamic: | 75 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.095 |
| Midpoint Dyn: | 0.122 |
| LwSpd Dynamic: | 0.125 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE A




| | |
|---|---|
| Date of Test: | 10/13/2011 |
| Time of Test: | 17:18:21 |
| Test Number: | C4-3-1341 |
| Fluid Code: | LO268869 |
| Cycle Number: | 500 |
| Temperature: | 93.0 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 347 kPa (345 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 14.3 KJ (14.50 ± 0.40 KJ) |
| Engage Time: | 1.154 Sec |

**Torque**

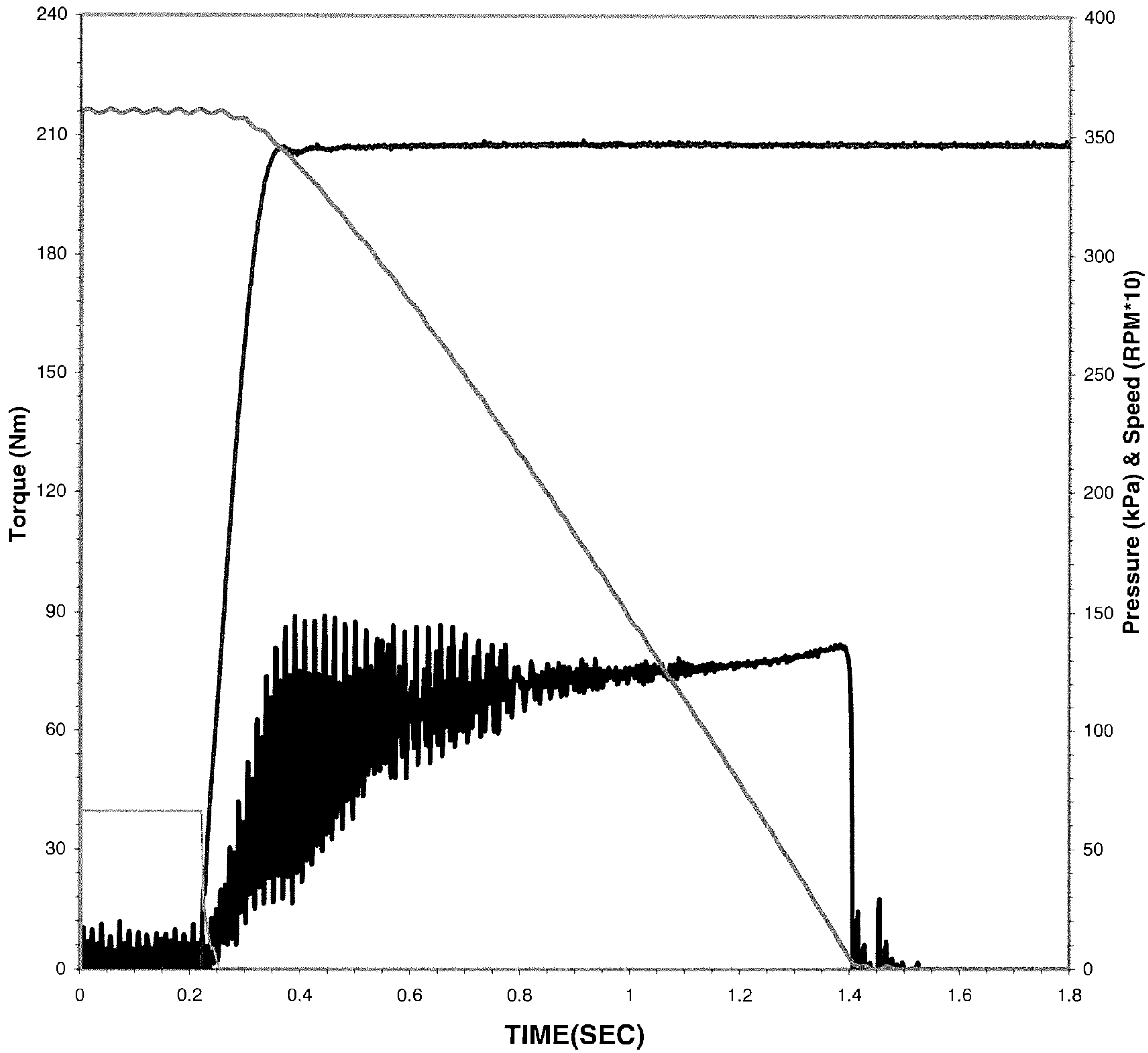
| | |
|---|---|
| 0.2 Sec Dyn: | 57 N*m |
| Midpoint Dyn: | 74 N*m |
| LwSpd Dynamic: | 75 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.095 |
| Midpoint Dyn: | 0.122 |
| LwSpd Dynamic: | 0.124 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE A




| | |
|---|---|
| Date of Test: | 10/13/2011 |
| Time of Test: | 17:18:48 |
| Test Number: | C4-3-1341 |
| Fluid Code: | LO268869 |
| Cycle Number: | 501 |
| Temperature: | 88.7 °C<br>(93.3 ± 3.0 °C) |
| Apply Pressure: | 347 kPa<br>(345 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 14.3 KJ<br>(14.50 ± 0.40 KJ) |
| Engage Time: | 1.183 Sec |

**Torque**

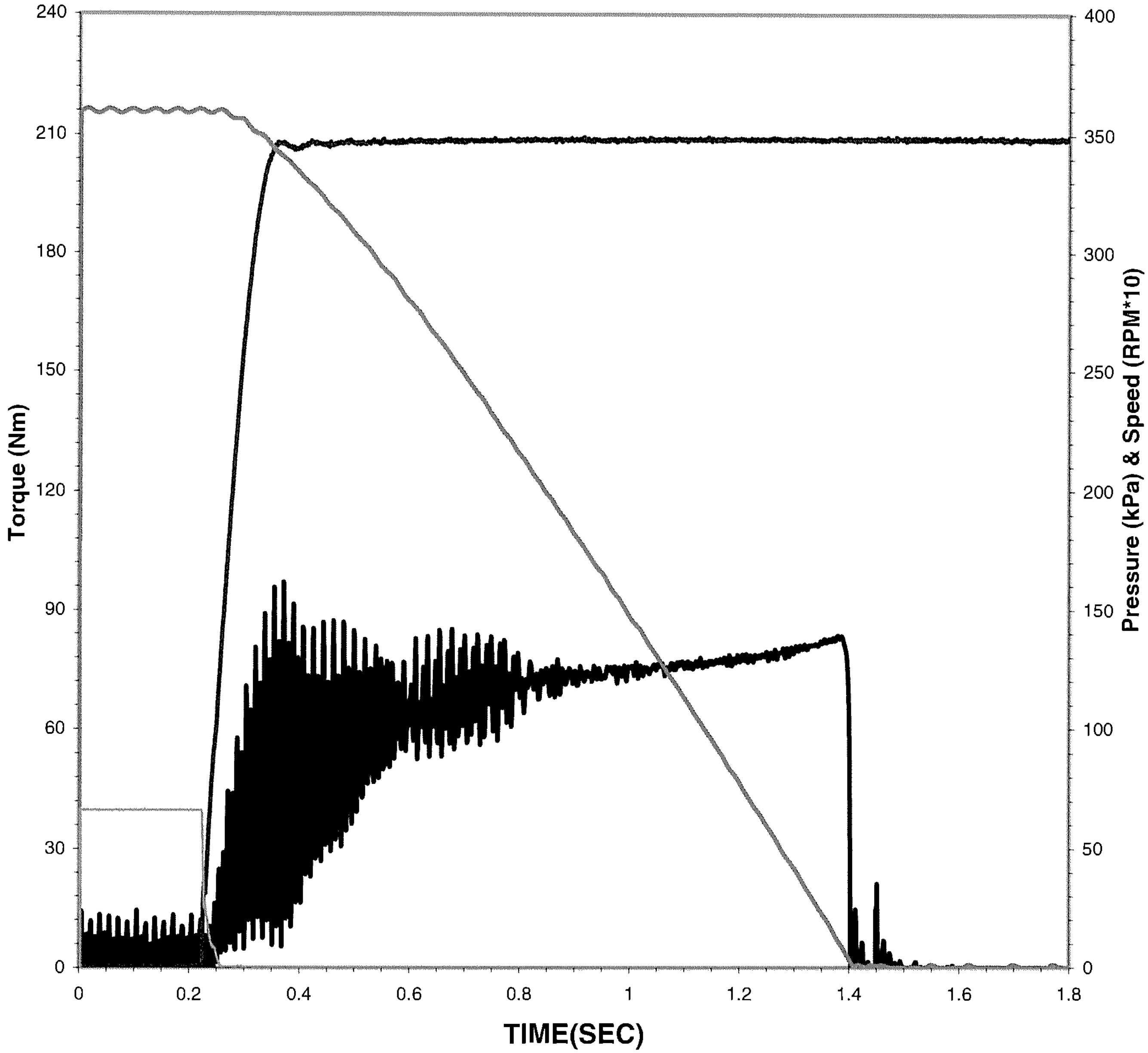
| | |
|---|---|
| 0.2 Sec Dyn: | 56 N*m |
| Midpoint Dyn: | 73 N*m |
| LwSpd Dynamic: | 76 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.092 |
| Midpoint Dyn: | 0.121 |
| LwSpd Dynamic: | 0.126 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE A




| | |
|---|---|
| Date of Test: | 10/13/2011 |
| Time of Test: | 19:23:03 |
| Test Number: | C4-3-1341 |
| Fluid Code: | LO268869 |
| Cycle Number: | 998 |
| Temperature: | 93.0 °C<br>(93.3 ± 3.0 °C) |
| Apply Pressure: | 348 kPa<br>(345 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 14.3 KJ<br>(14.50 ± 0.40 KJ) |
| Engage Time: | 1.177 Sec |

**Torque**

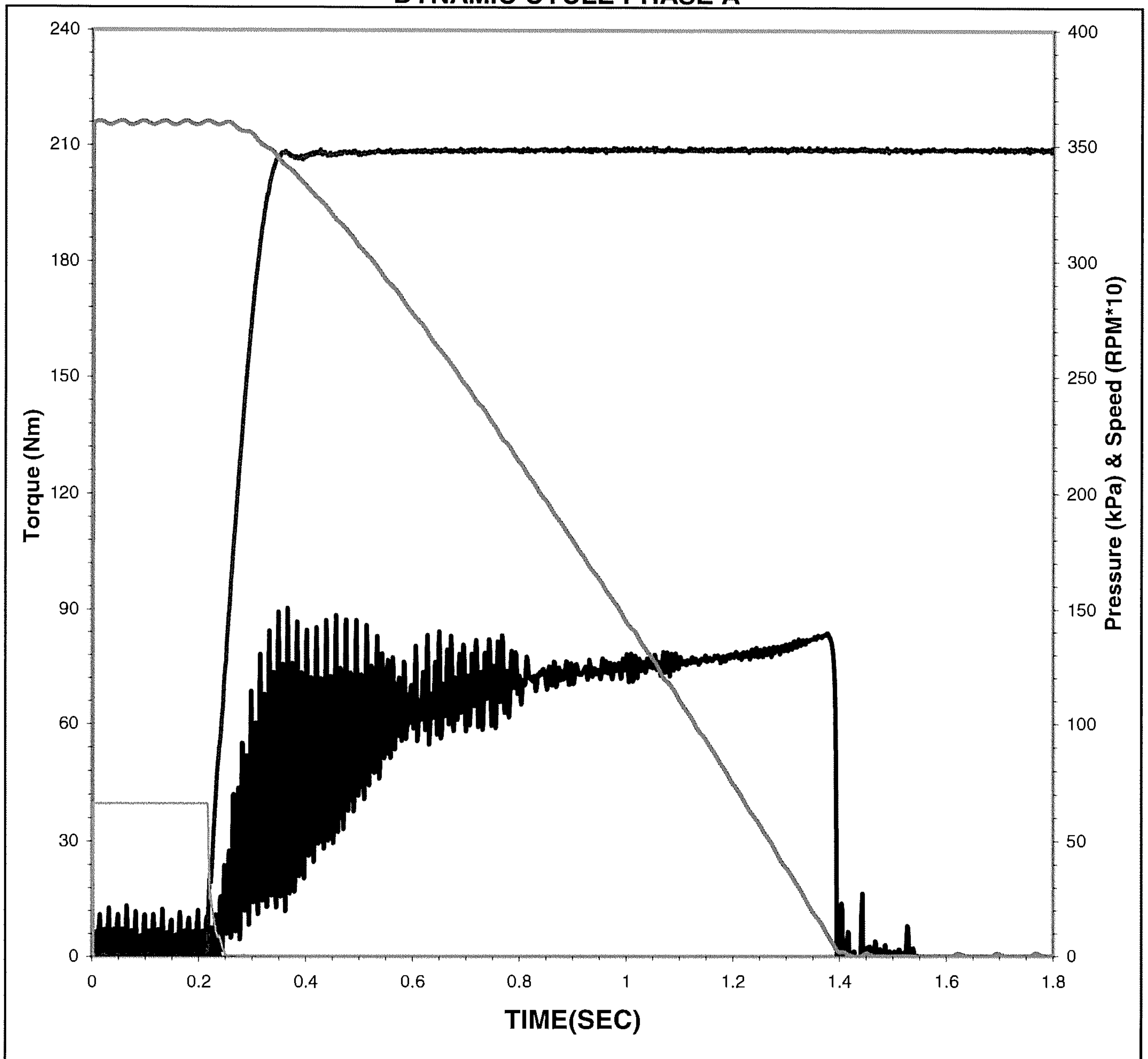
| | |
|---|---|
| 0.2 Sec Dyn: | 52 N*m |
| Midpoint Dyn: | 73 N*m |
| LwSpd Dynamic: | 76 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.086 |
| Midpoint Dyn: | 0.121 |
| LwSpd Dynamic: | 0.127 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE A




| | |
|---|---|
| Date of Test: | 10/13/2011 |
| Time of Test: | 19:23:18 |
| Test Number: | C4-3-1341 |
| Fluid Code: | LO268869 |
| Cycle Number: | 999 |
| Temperature: | 93.0 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 348 kPa (345 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 14.3 KJ (14.50 ± 0.40 KJ) |
| Engage Time: | 1.176 Sec |

**Torque**

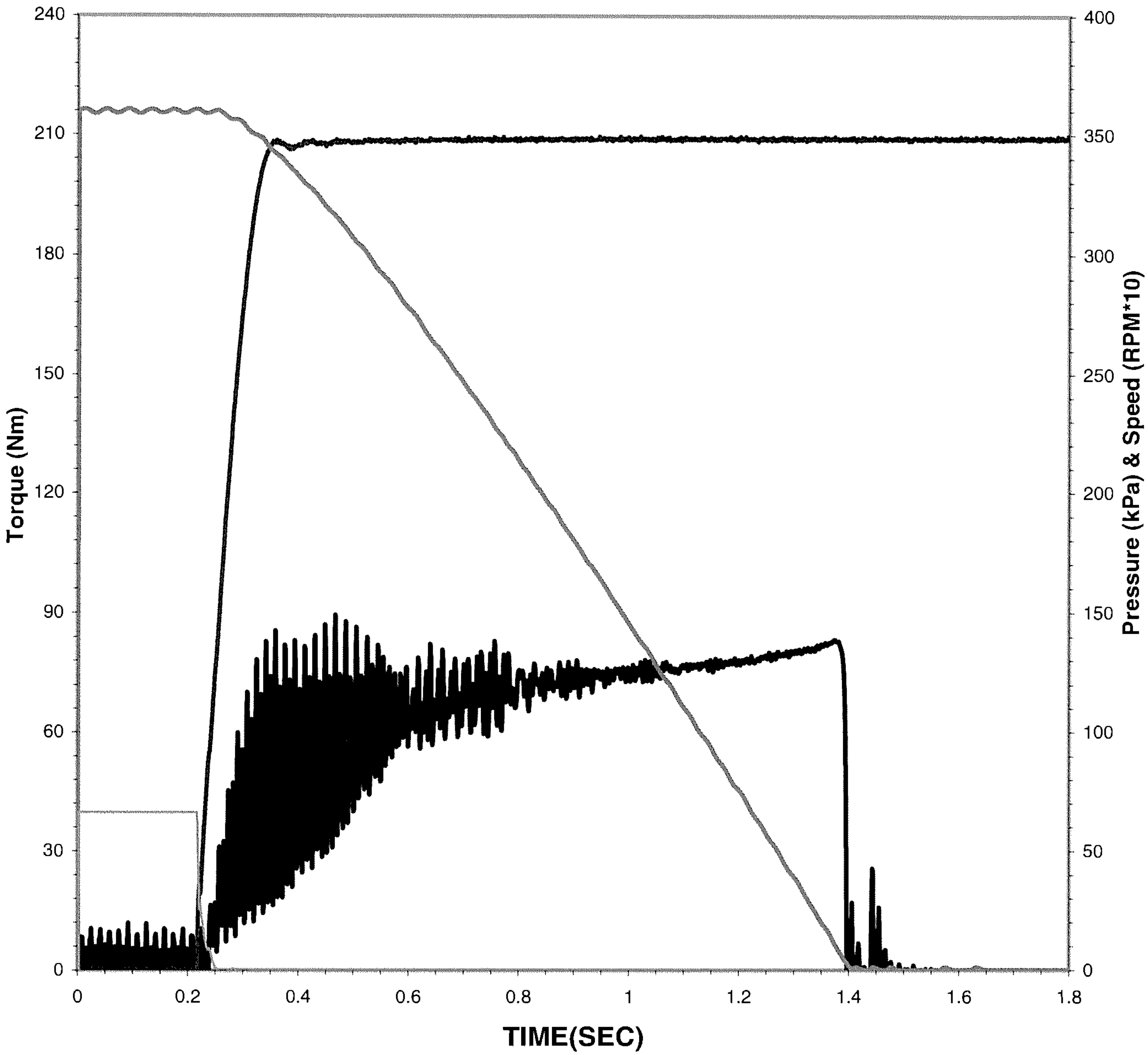
| | |
|---|---|
| 0.2 Sec Dyn: | 52 N*m |
| Midpoint Dyn: | 73 N*m |
| LwSpd Dynamic: | 77 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.086 |
| Midpoint Dyn: | 0.120 |
| LwSpd Dynamic: | 0.127 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE A




| | |
|---|---|
| Date of Test: | 10/13/2011 |
| Time of Test: | 19:23:33 |
| Test Number: | C4-3-1341 |
| Fluid Code: | LO268869 |
| Cycle Number: | 1000 |
| Temperature: | 93.1 °C<br>(93.3 ± 3.0 °C) |
| Apply Pressure: | 348 kPa<br>(345 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 14.3 KJ<br>(14.50 ± 0.40 KJ) |
| Engage Time: | 1.178 Sec |

**Torque**

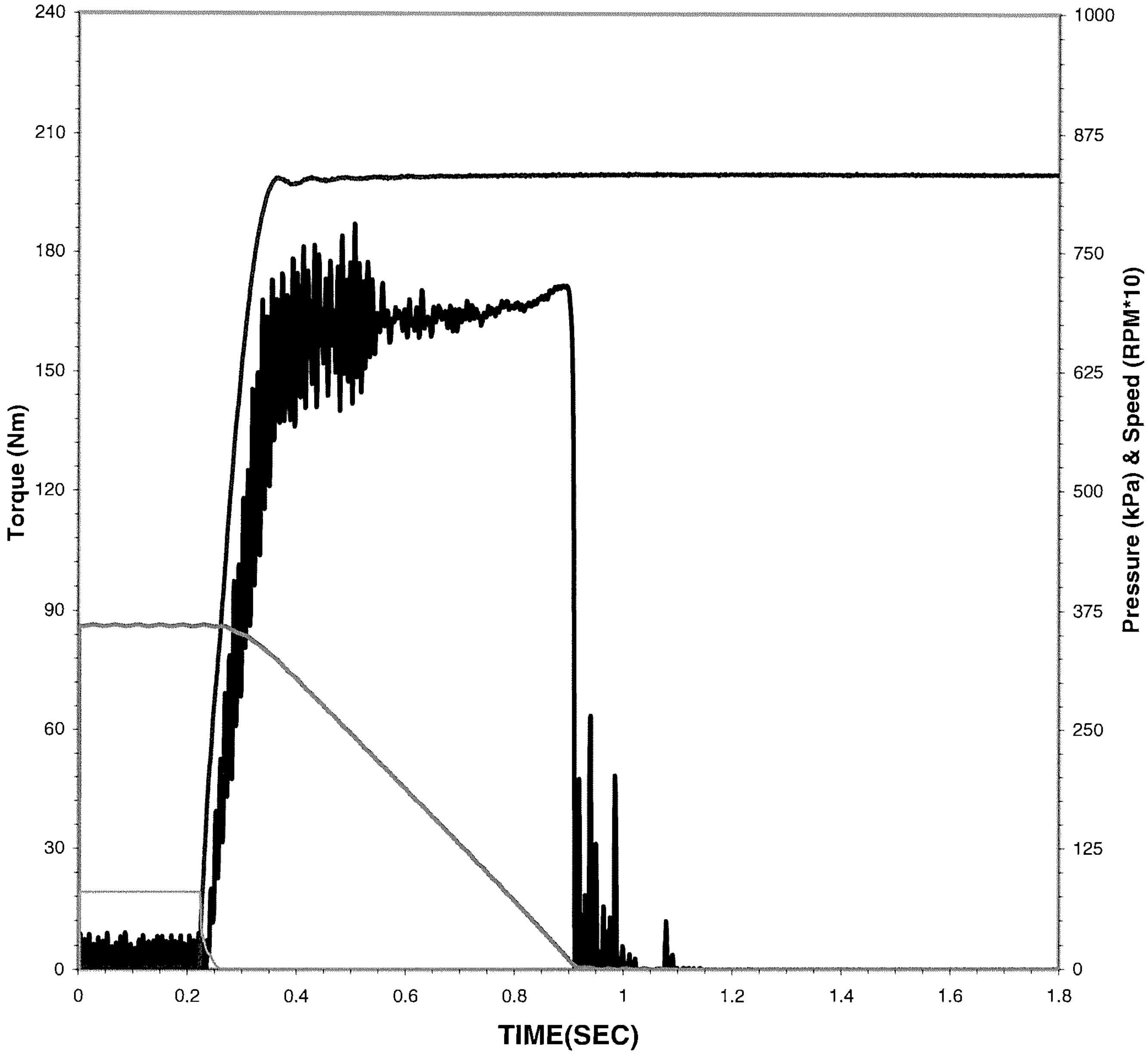
| | |
|---|---|
| 0.2 Sec Dyn: | 52 N*m |
| Midpoint Dyn: | 72 N*m |
| LwSpd Dynamic: | 76 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.086 |
| Midpoint Dyn: | 0.120 |
| LwSpd Dynamic: | 0.126 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/13/2011 |
| Time of Test: | 20:17:13 |
| Test Number: | C4-3-1341 |
| Fluid Code: | LO268869 |
| Cycle Number: | 1010 |
| Temperature: | 89.2 °C<br>(112.7 ± 3.0 °C) |
| Apply Pressure: | 827 kPa<br>827 ± 7 KPa) |
| Apply Rate: | 0.14 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ<br>(18.71 ± 0.40 KJ) |
| Engage Time: | 0.688 Sec |

**Torque**

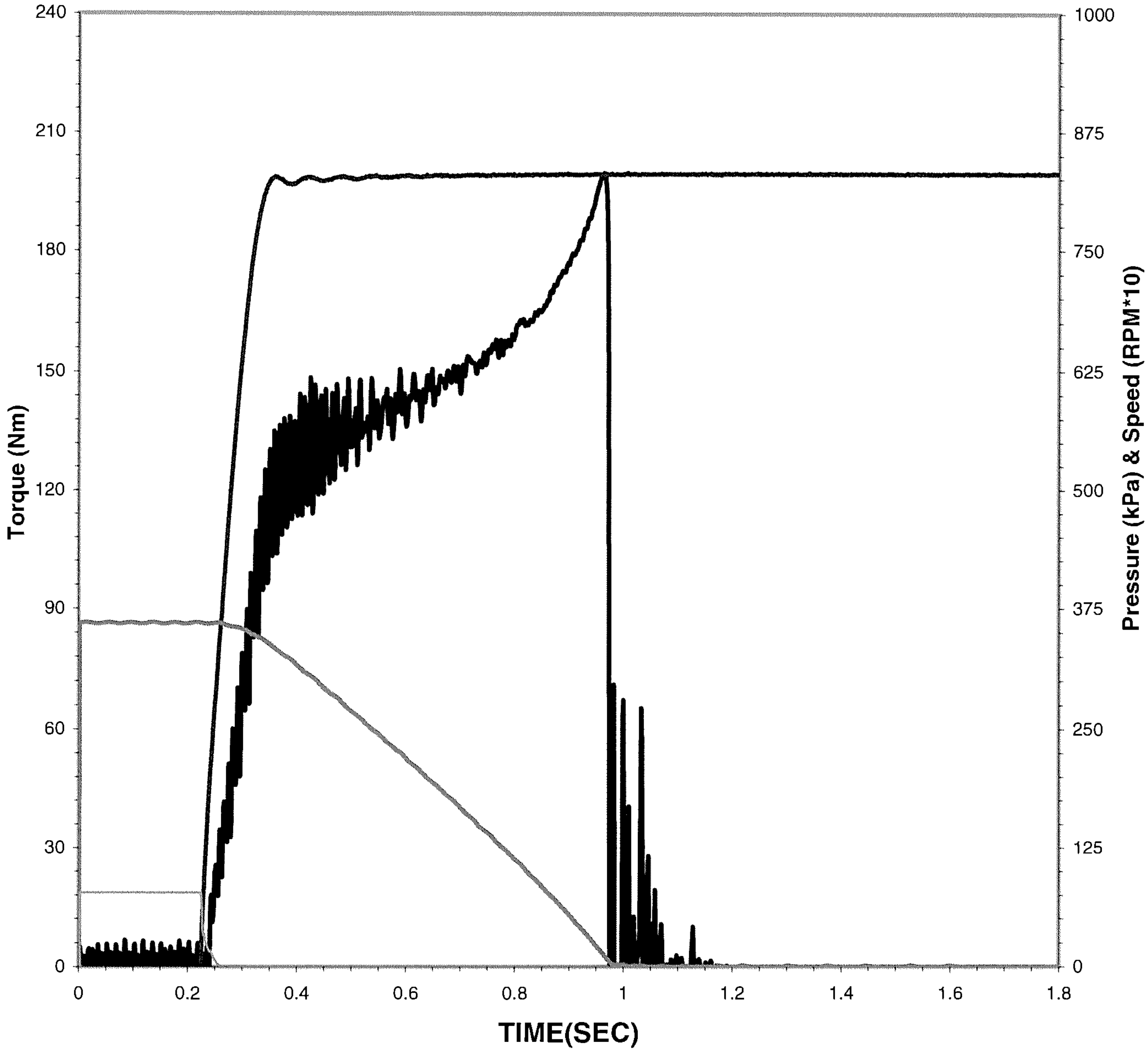
| | |
|---|---|
| 0.2 Sec Dyn: | 161 N*m |
| Midpoint Dyn: | 163 N*m |
| LwSpd Dynamic: | 159 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.112 |
| Midpoint Dyn: | 0.113 |
| LwSpd Dynamic: | 0.110 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/13/2011 |
| Time of Test: | 22:19:29 |
| Test Number: | C4-3-1341 |
| Fluid Code: | LO268869 |
| Cycle Number: | 1499 |
| Temperature: | 110.9 °C<br>(112.7 ± 3.0 °C) |
| Apply Pressure: | 829 kPa<br>827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ<br>(18.71 ± 0.40 KJ) |
| Engage Time: | 0.75 Sec |

**Torque**

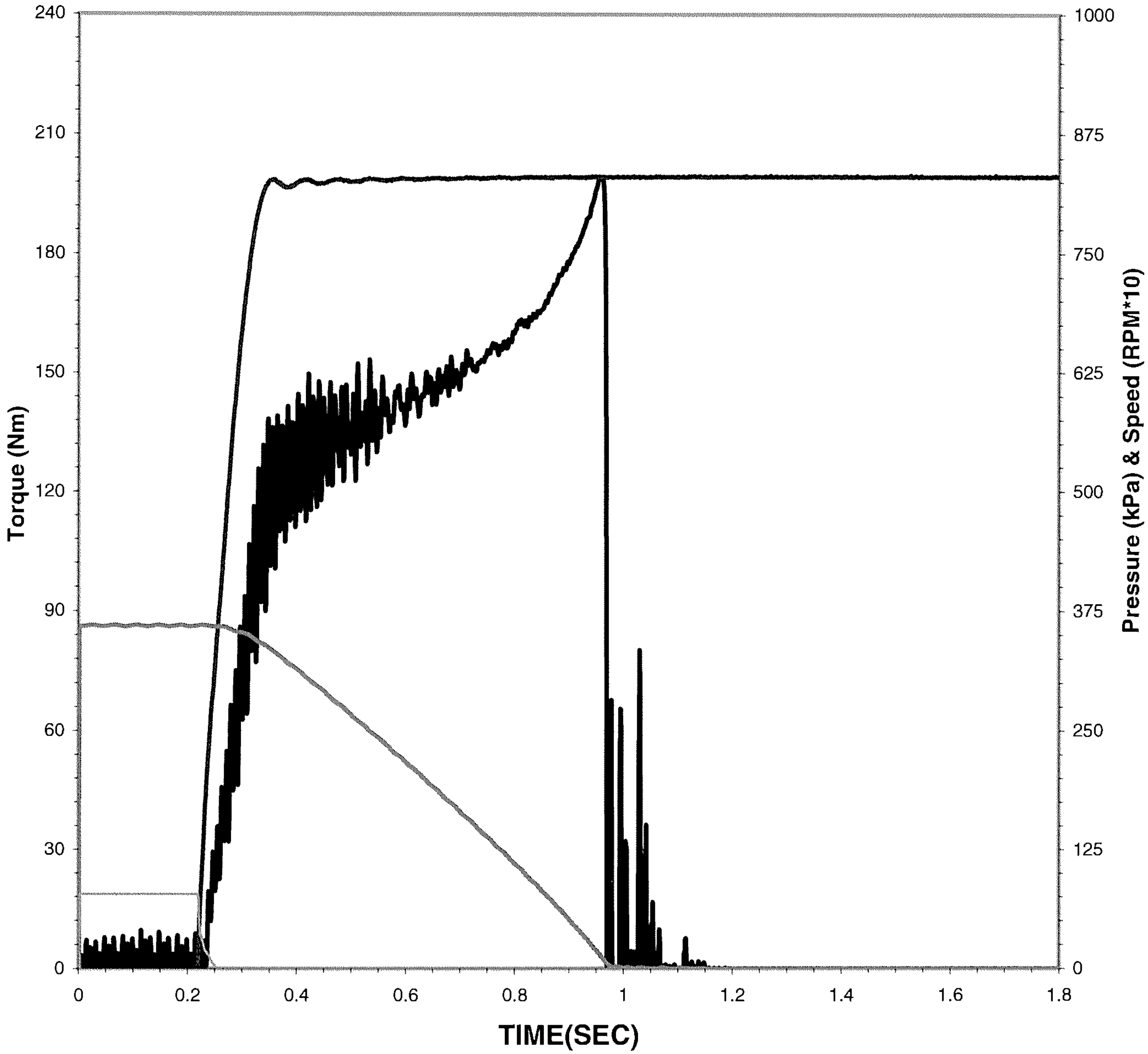
| | |
|---|---|
| 0.2 Sec Dyn: | 131 N*m |
| Midpoint Dyn: | 143 N*m |
| LwSpd Dynamic: | 194 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.090 |
| Midpoint Dyn: | 0.099 |
| LwSpd Dynamic: | 0.134 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/13/2011 |
| Time of Test: | 22:19:44 |
| Test Number: | C4-3-1341 |
| Fluid Code: | LO268869 |
| Cycle Number: | 1500 |
| Temperature: | 110.8 °C<br>(112.7 ± 3.0 °C) |
| Apply Pressure: | 829 kPa<br>827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ<br>(18.71 ± 0.40 KJ) |
| Engage Time: | 0.75 Sec |

**Torque**

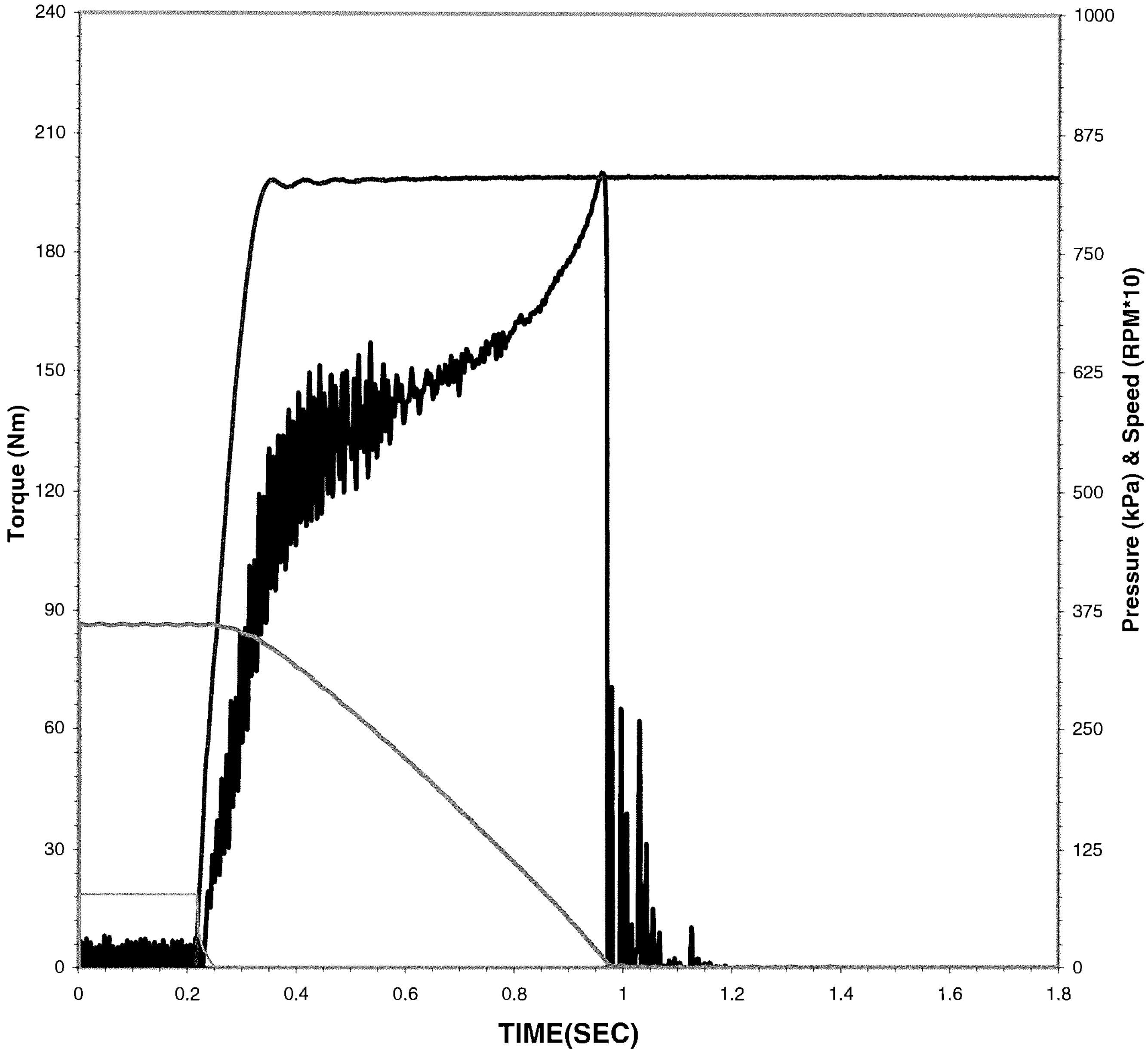
| | |
|---|---|
| 0.2 Sec Dyn: | 130 N*m |
| Midpoint Dyn: | 143 N*m |
| LwSpd Dynamic: | 192 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.090 |
| Midpoint Dyn: | 0.099 |
| LwSpd Dynamic: | 0.132 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/13/2011 |
| Time of Test: | 22:20:10 |
| Test Number: | C4-3-1341 |
| Fluid Code: | LO268869 |
| Cycle Number: | 1501 |
| Temperature: | 105.8 °C (112.7 ± 3.0 °C) |
| Apply Pressure: | 829 kPa 827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ (18.71 ± 0.40 KJ) |
| Engage Time: | 0.755 Sec |

**Torque**

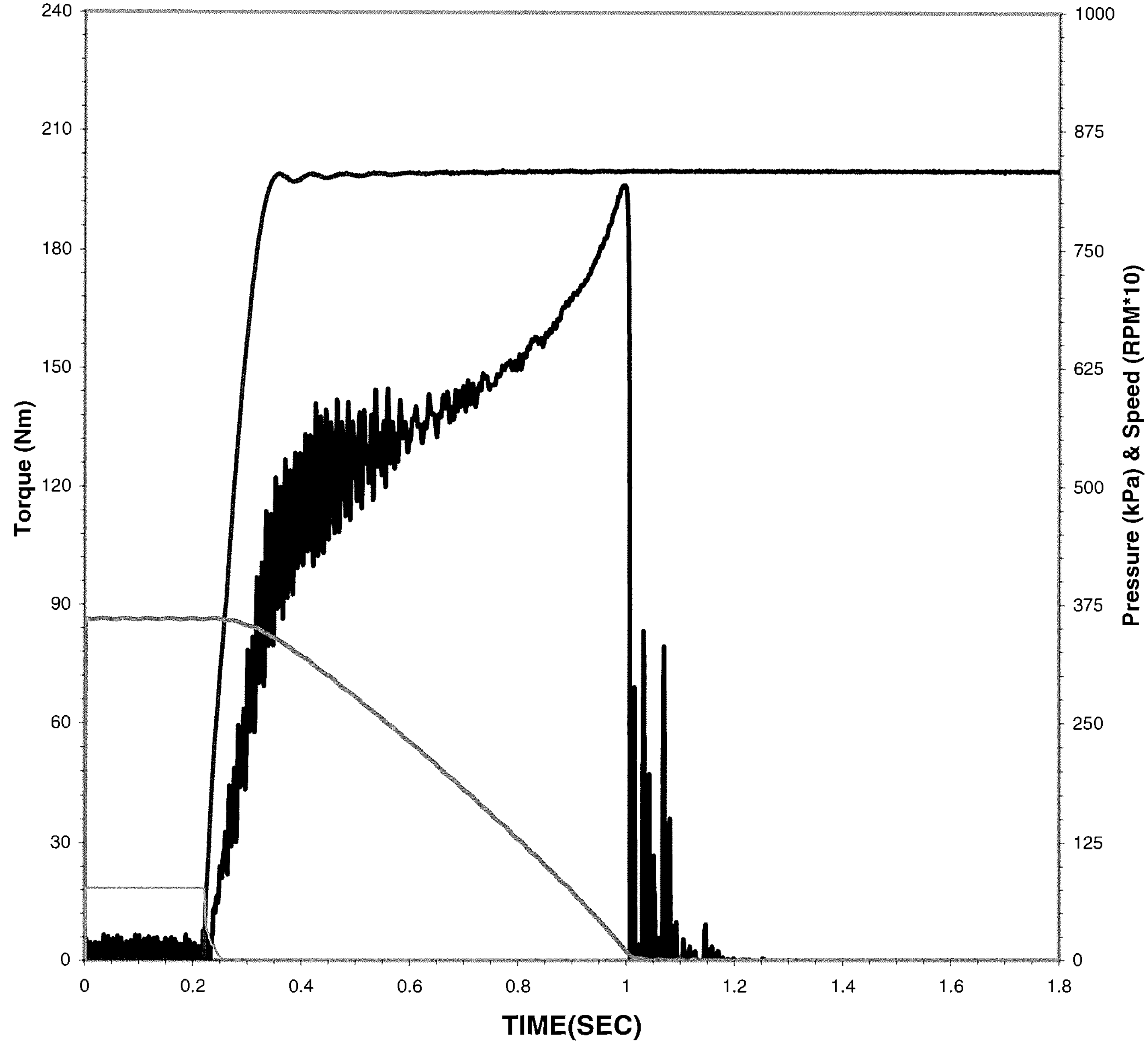
| | |
|---|---|
| 0.2 Sec Dyn: | 131 N*m |
| Midpoint Dyn: | 143 N*m |
| LwSpd Dynamic: | 190 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.091 |
| Midpoint Dyn: | 0.099 |
| LwSpd Dynamic: | 0.131 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 0:24:40 |
| Test Number: | C4-3-1341 |
| Fluid Code: | LO268869 |
| Cycle Number: | 1999 |
| Temperature: | 110.7 °C<br>(112.7 ± 3.0 °C) |
| Apply Pressure: | 830 kPa<br>827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ<br>(18.71 ± 0.40 KJ) |
| Engage Time: | 0.786 Sec |

**Torque**

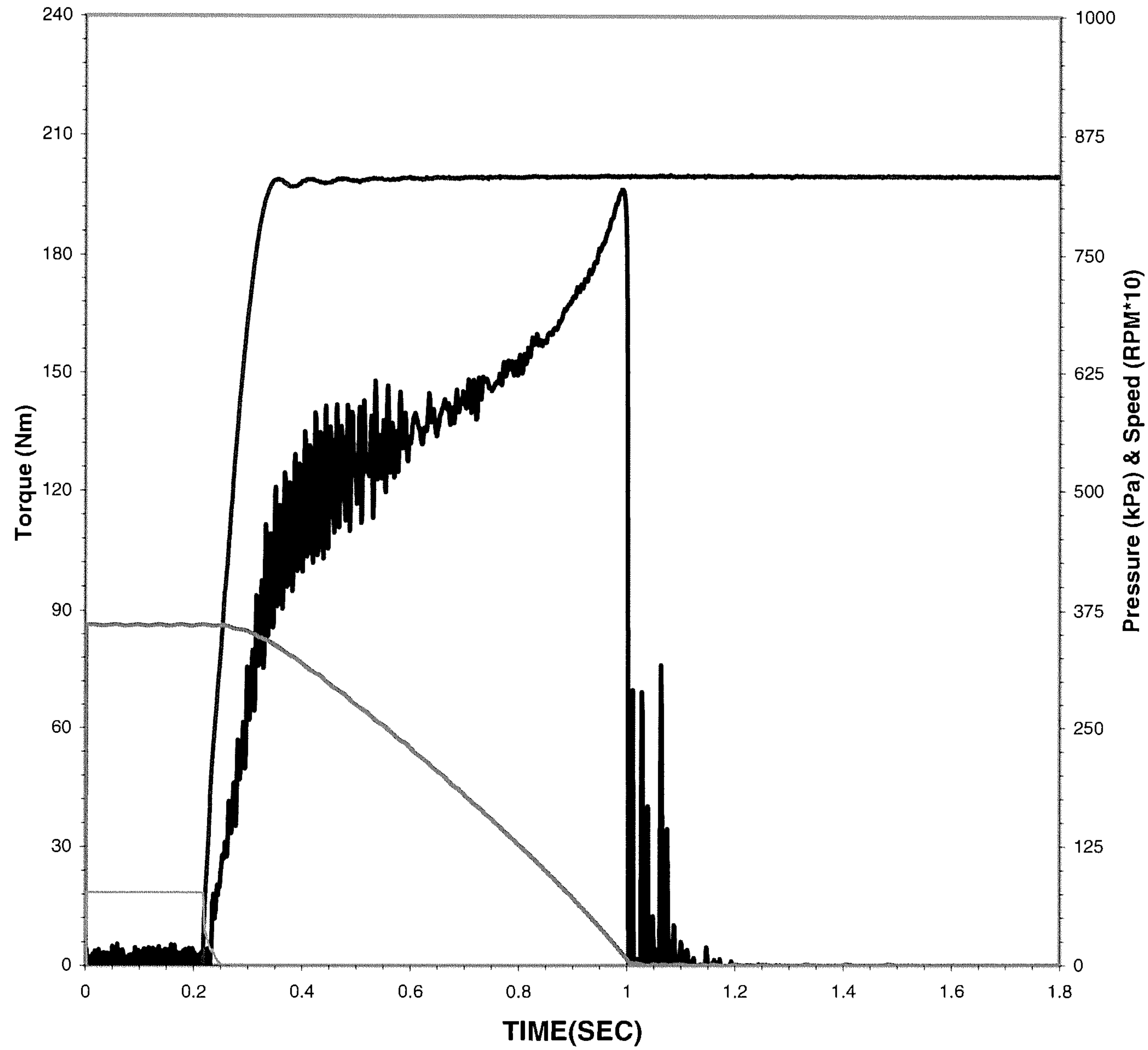
| | |
|---|---|
| 0.2 Sec Dyn: | 121 N*m |
| Midpoint Dyn: | 136 N*m |
| LwSpd Dynamic: | 189 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.084 |
| Midpoint Dyn: | 0.094 |
| LwSpd Dynamic: | 0.131 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 0:24:55 |
| Test Number: | C4-3-1341 |
| Fluid Code: | LO268869 |
| Cycle Number: | 2000 |
| Temperature: | 110.6 °C<br>(112.7 ± 3.0 °C) |
| Apply Pressure: | 830 kPa<br>827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ<br>(18.71 ± 0.40 KJ) |
| Engage Time: | 0.786 Sec |

**Torque**

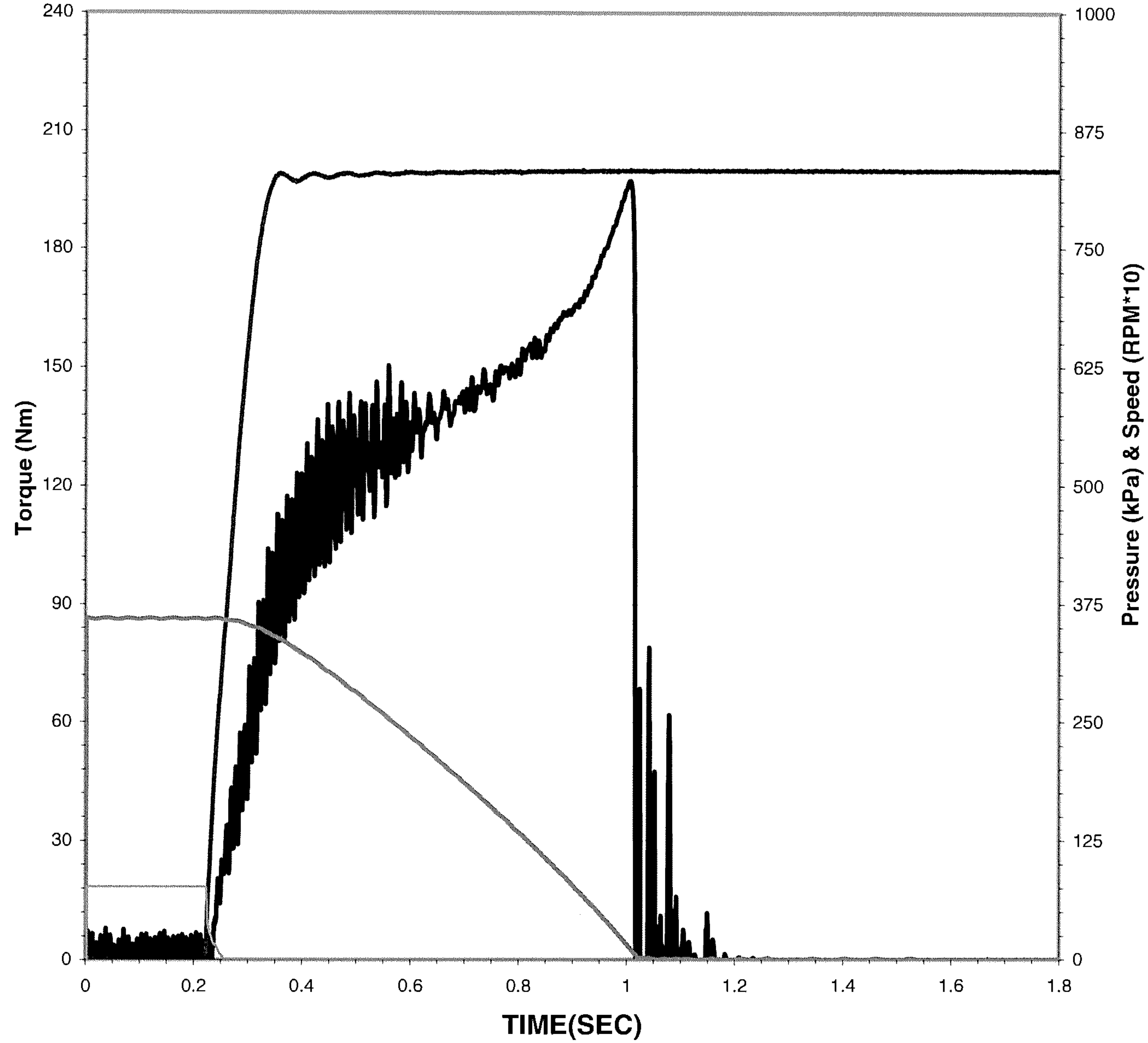
| | |
|---|---|
| 0.2 Sec Dyn: | 121 N*m |
| Midpoint Dyn: | 136 N*m |
| LwSpd Dynamic: | 189 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.084 |
| Midpoint Dyn: | 0.094 |
| LwSpd Dynamic: | 0.131 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 0:25:22 |
| Test Number: | C4-3-1341 |
| Fluid Code: | LO268869 |
| Cycle Number: | 2001 |
| Temperature: | 106.0 °C<br>(112.7 ± 3.0 °C) |
| Apply Pressure: | 830 kPa<br>827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ<br>(18.71 ± 0.40 KJ) |
| Engage Time: | 0.794 Sec |

**Torque**

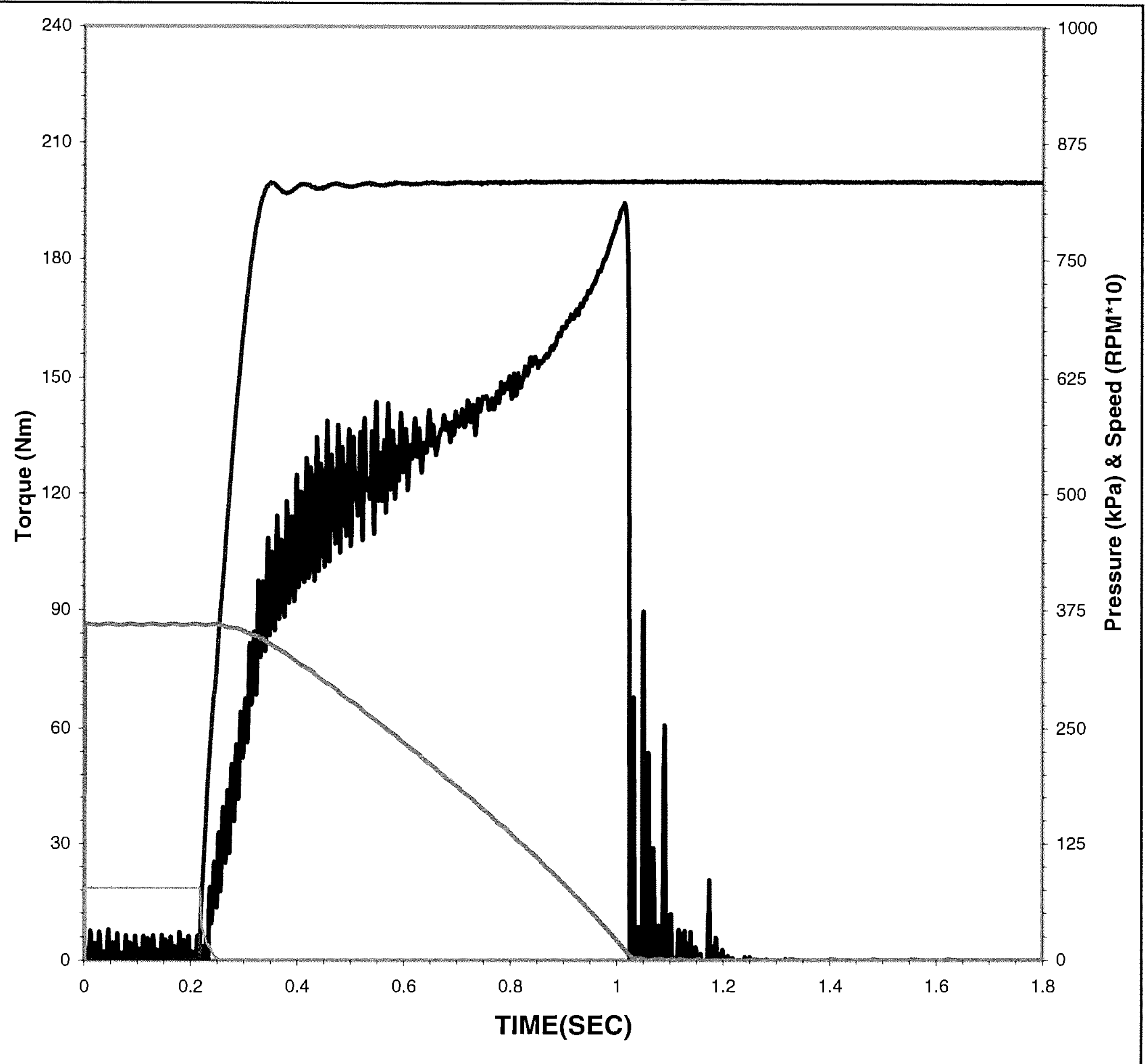
| | |
|---|---|
| 0.2 Sec Dyn: | 117 N*m |
| Midpoint Dyn: | 136 N*m |
| LwSpd Dynamic: | 191 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.081 |
| Midpoint Dyn: | 0.094 |
| LwSpd Dynamic: | 0.132 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




**Date of Test:** 10/14/2011

**Time of Test:** 2:29:52

**Test Number:** C4-3-1341

**Fluid Code:** LO268869

**Cycle Number:** 2499

**Temperature:** 111.0 °C
(112.7 ± 3.0 °C)

**Apply Pressure:** 830 kPa
827 ± 7 KPa)

**Apply Rate:** 0.13 Sec
(0.15 ± 0.02 Sec)

**Energy:** 18.4 KJ
(18.71 ± 0.40 KJ)

**Engage Time:** 0.807 Sec

**Torque**

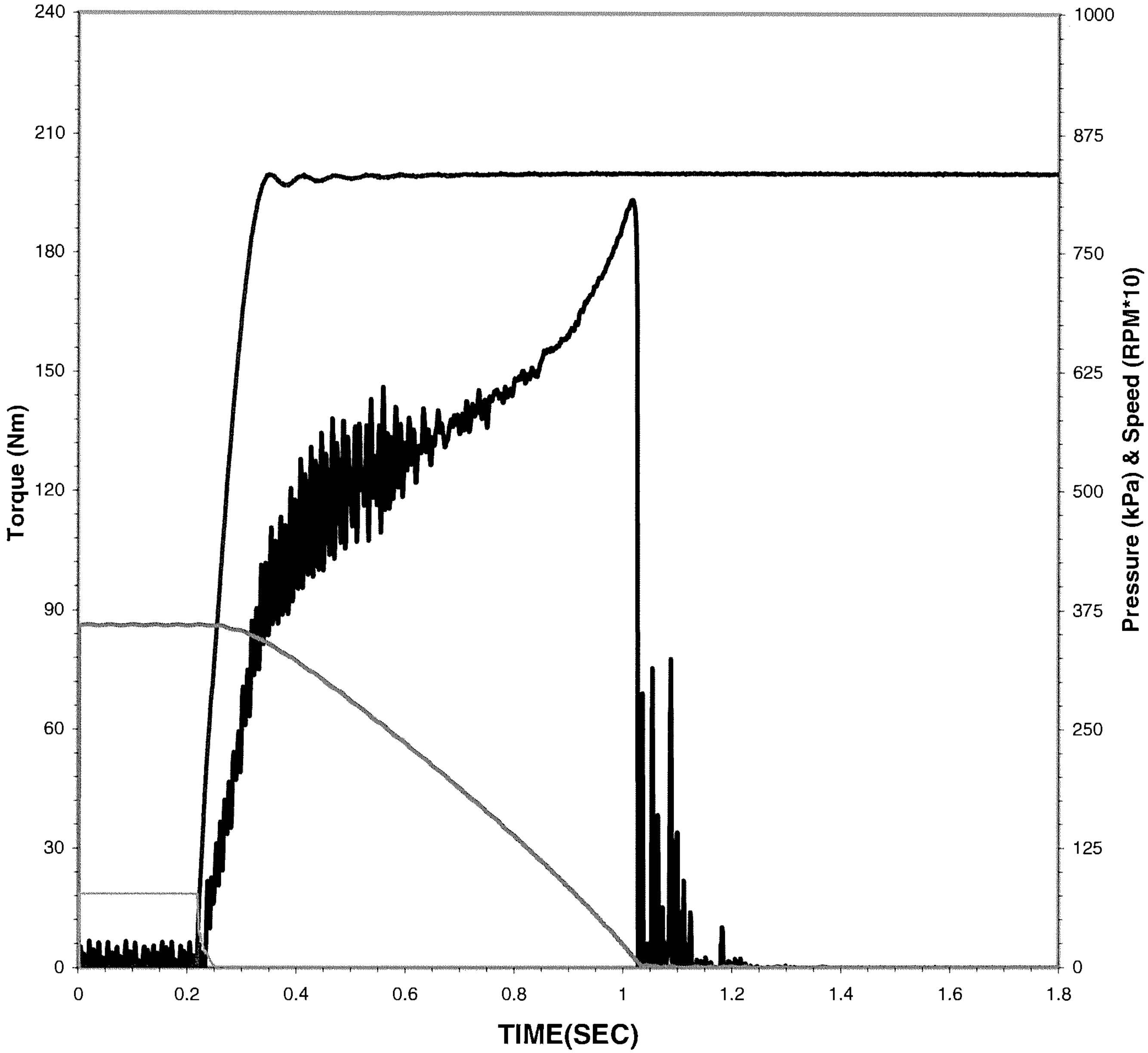
| | |
|---|---|
| 0.2 Sec Dyn: | 113 N*m |
| Midpoint Dyn: | 132 N*m |
| LwSpd Dynamic: | 186 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.078 |
| Midpoint Dyn: | 0.091 |
| LwSpd Dynamic: | 0.128 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 2:30:07 |
| Test Number: | C4-3-1341 |
| Fluid Code: | LO268869 |
| Cycle Number: | 2500 |
| Temperature: | 110.9 °C<br>(112.7 ± 3.0 °C) |
| Apply Pressure: | 830 kPa<br>827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ<br>(18.71 ± 0.40 KJ) |
| Engage Time: | 0.809 Sec |

**Torque**

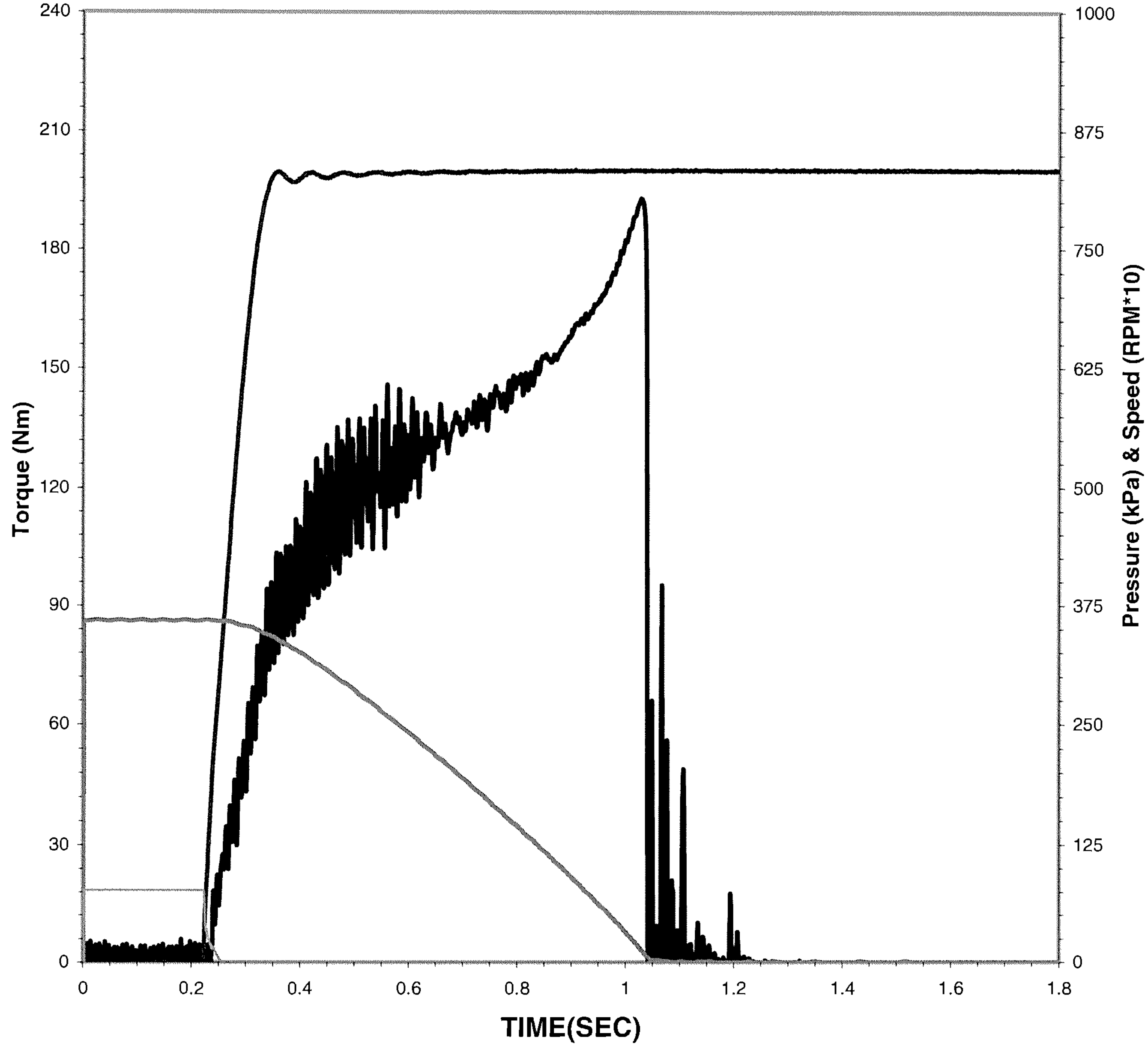
| | |
|---|---|
| 0.2 Sec Dyn: | 113 N*m |
| Midpoint Dyn: | 132 N*m |
| LwSpd Dynamic: | 186 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.078 |
| Midpoint Dyn: | 0.091 |
| LwSpd Dynamic: | 0.128 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 2:30:34 |
| Test Number: | C4-3-1341 |
| Fluid Code: | LO268869 |
| Cycle Number: | 2501 |
| Temperature: | 106.4 °C<br>(112.7 ± 3.0 °C) |
| Apply Pressure: | 830 kPa<br>827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ<br>(18.71 ± 0.40 KJ) |
| Engage Time: | 0.819 Sec |

**Torque**

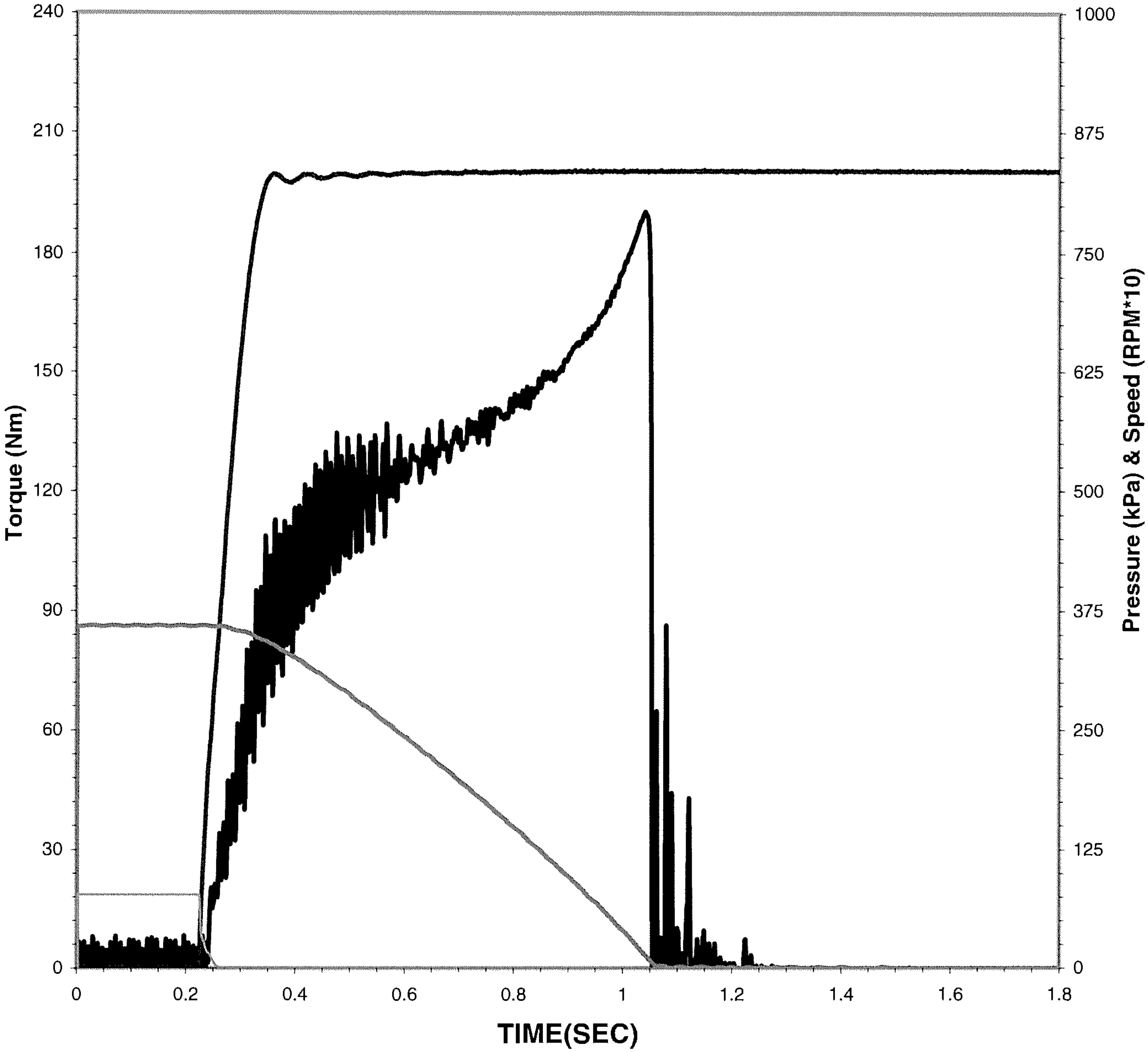
| | |
|---|---|
| 0.2 Sec Dyn: | 109 N*m |
| Midpoint Dyn: | 131 N*m |
| LwSpd Dynamic: | 186 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.076 |
| Midpoint Dyn: | 0.091 |
| LwSpd Dynamic: | 0.128 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 4:35:04 |
| Test Number: | C4-3-1341 |
| Fluid Code: | LO268869 |
| Cycle Number: | 2999 |
| Temperature: | 110.9 °C<br>(112.7 ± 3.0 °C) |
| Apply Pressure: | 831 kPa<br>827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ<br>(18.71 ± 0.40 KJ) |
| Engage Time: | 0.829 Sec |

**Torque**

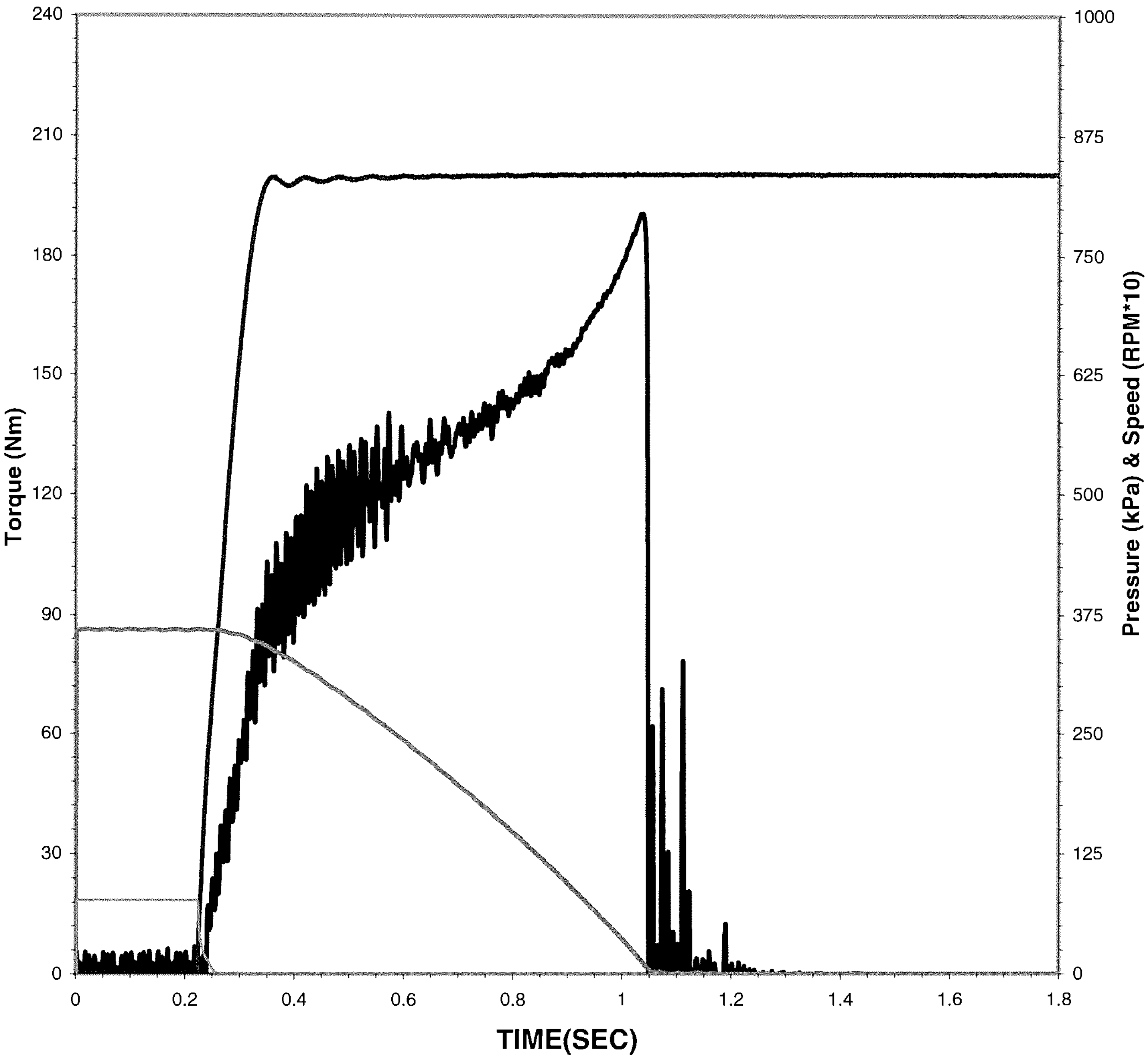
| | |
|---|---|
| 0.2 Sec Dyn: | 106 N*m |
| Midpoint Dyn: | 129 N*m |
| LwSpd Dynamic: | 182 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.073 |
| Midpoint Dyn: | 0.089 |
| LwSpd Dynamic: | 0.126 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 4:35:19 |
| Test Number: | C4-3-1341 |
| Fluid Code: | LO268869 |
| Cycle Number: | 3000 |
| Temperature: | 110.8 °C (112.7 ± 3.0 °C) |
| Apply Pressure: | 831 kPa 827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ (18.71 ± 0.40 KJ) |
| Engage Time: | 0.825 Sec |

**Torque**

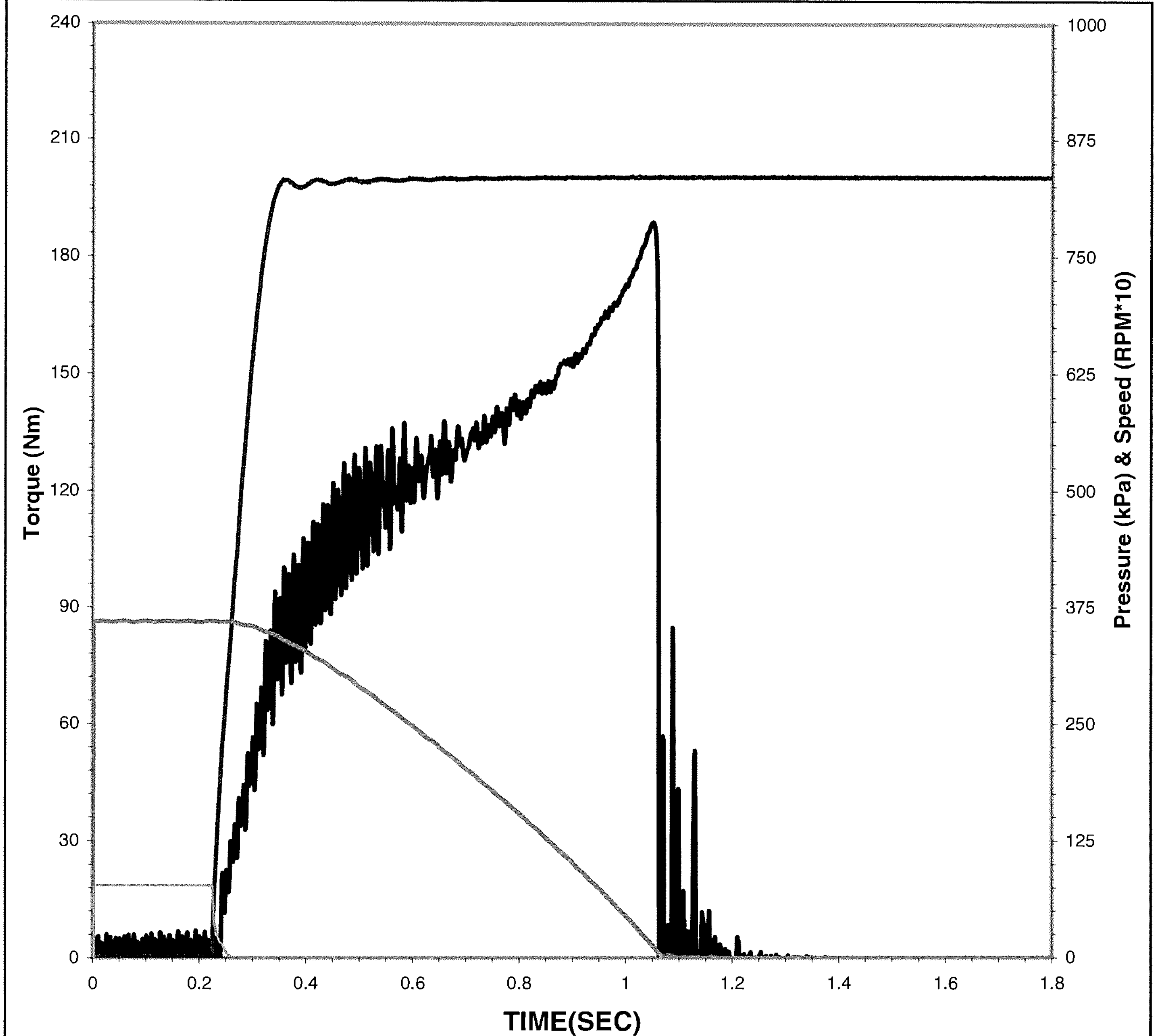
| | |
|---|---|
| 0.2 Sec Dyn: | 107 N*m |
| Midpoint Dyn: | 130 N*m |
| LwSpd Dynamic: | 179 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.074 |
| Midpoint Dyn: | 0.090 |
| LwSpd Dynamic: | 0.124 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 4:35:46 |
| Test Number: | C4-3-1341 |
| Fluid Code: | LO268869 |
| Cycle Number: | 3001 |
| Temperature: | 107.2 °C<br>(112.7 ± 3.0 °C) |
| Apply Pressure: | 831 kPa<br>827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ<br>(18.71 ± 0.40 KJ) |
| Engage Time: | 0.838 Sec |

**Torque**

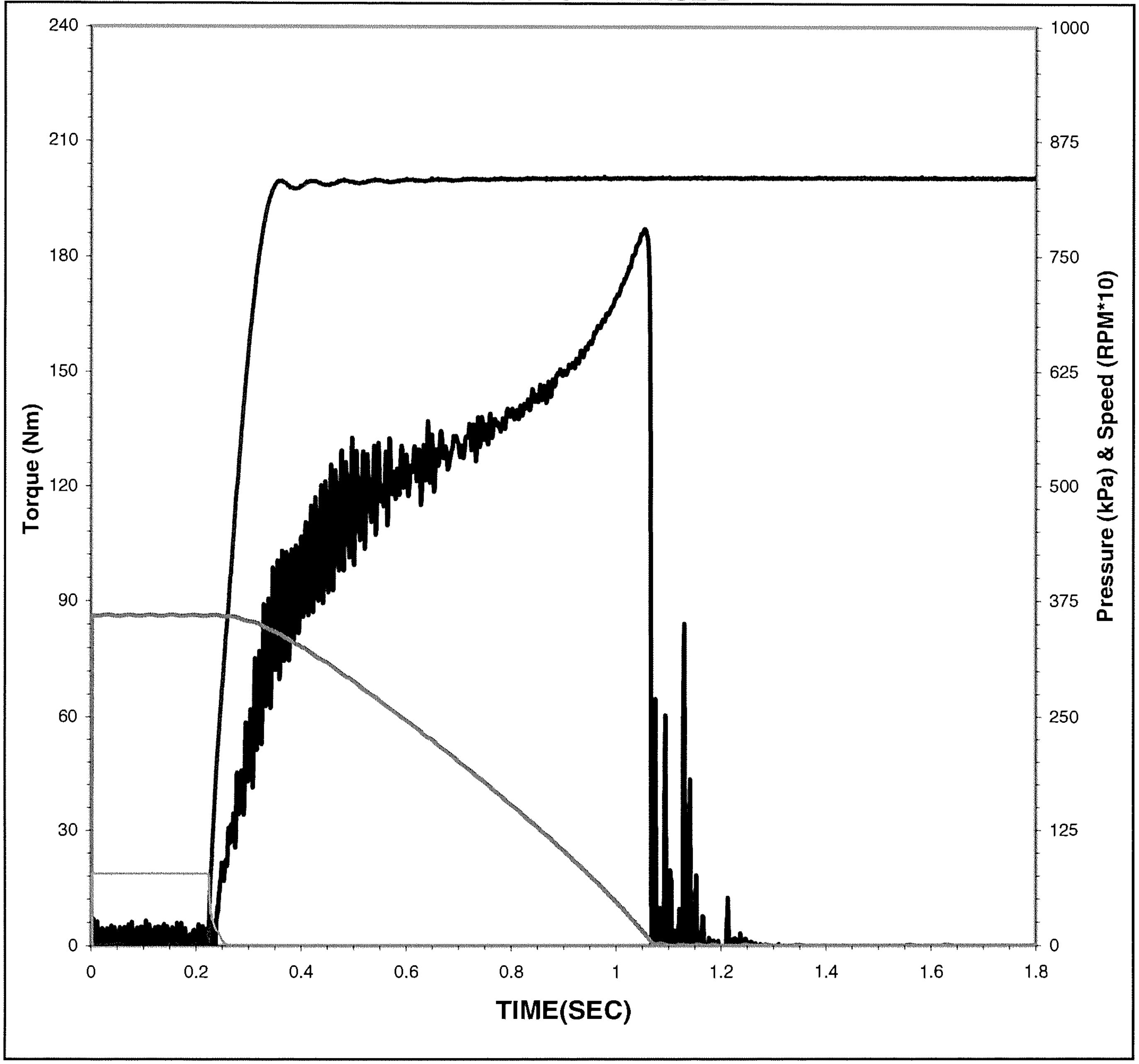
| | |
|---|---|
| 0.2 Sec Dyn: | 102 N*m |
| Midpoint Dyn: | 128 N*m |
| LwSpd Dynamic: | 177 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.070 |
| Midpoint Dyn: | 0.088 |
| LwSpd Dynamic: | 0.123 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 6:40:16 |
| Test Number: | C4-3-1341 |
| Fluid Code: | LO268869 |
| Cycle Number: | 3499 |
| Temperature: | 110.7 °C (112.7 ± 3.0 °C) |
| Apply Pressure: | 832 kPa 827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ (18.71 ± 0.40 KJ) |
| Engage Time: | 0.843 Sec |

**Torque**

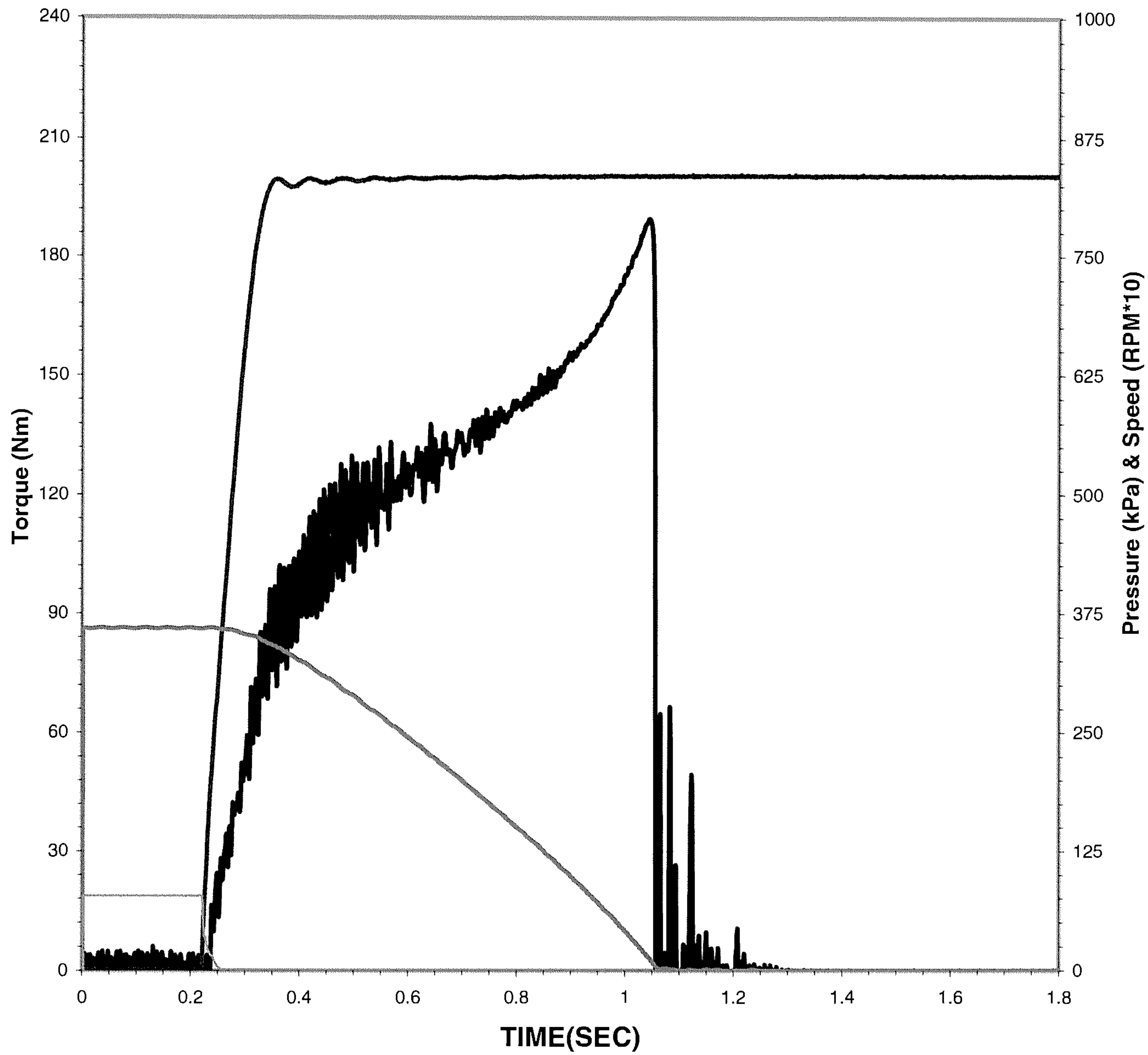
| | |
|---|---|
| 0.2 Sec Dyn: | 103 N*m |
| Midpoint Dyn: | 127 N*m |
| LwSpd Dynamic: | 179 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.071 |
| Midpoint Dyn: | 0.088 |
| LwSpd Dynamic: | 0.123 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 6:40:31 |
| Test Number: | C4-3-1341 |
| Fluid Code: | LO268869 |
| Cycle Number: | 3500 |
| Temperature: | 110.8 °C<br>(112.7 ± 3.0 °C) |
| Apply Pressure: | 832 kPa<br>827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ<br>(18.71 ± 0.40 KJ) |
| Engage Time: | 0.836 Sec |

**Torque**

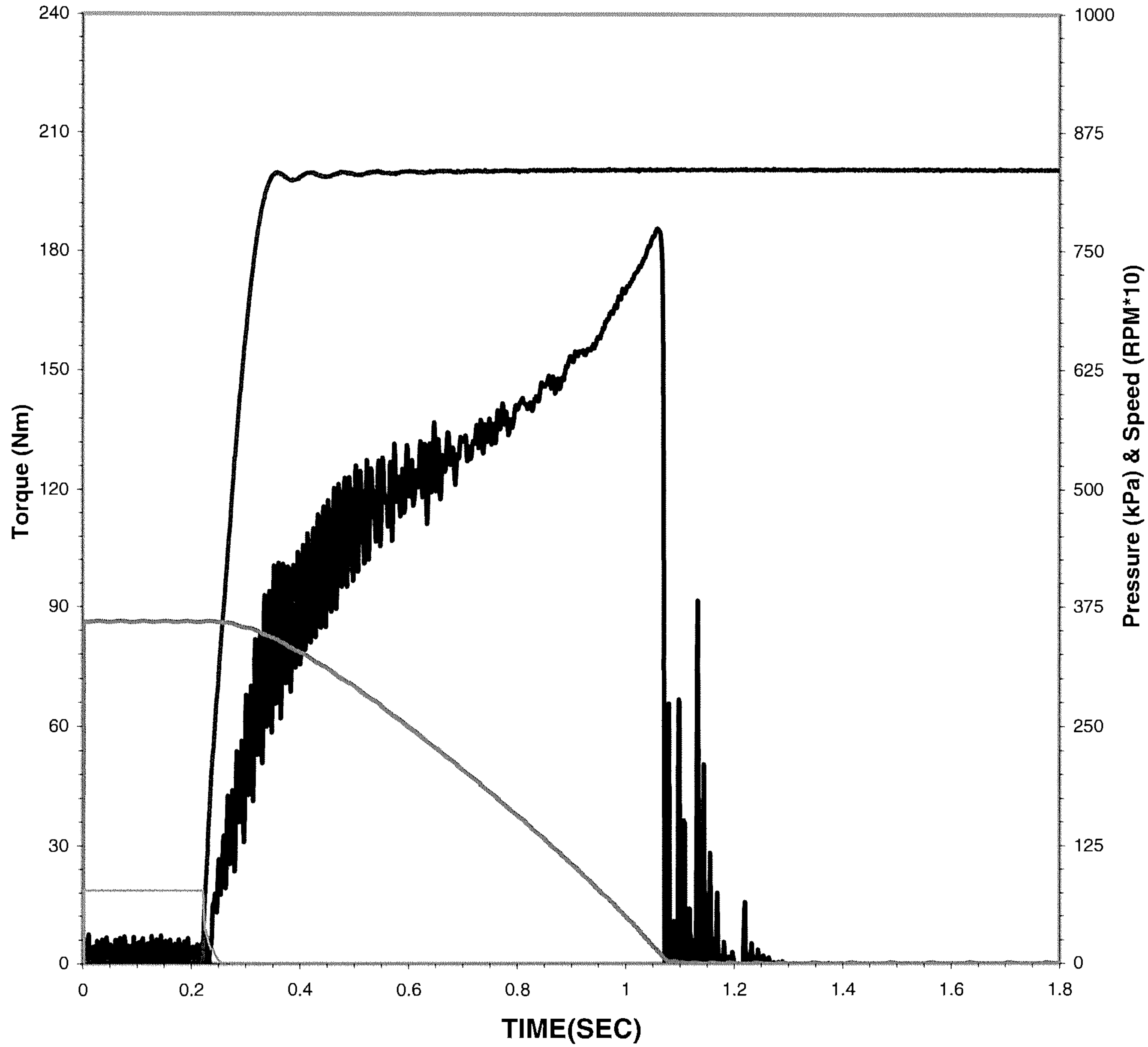
| | |
|---|---|
| 0.2 Sec Dyn: | 103 N*m |
| Midpoint Dyn: | 128 N*m |
| LwSpd Dynamic: | 180 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.071 |
| Midpoint Dyn: | 0.089 |
| LwSpd Dynamic: | 0.124 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 6:40:57 |
| Test Number: | C4-3-1341 |
| Fluid Code: | LO268869 |
| Cycle Number: | 3501 |
| Temperature: | 106.4 °C<br>(112.7 ± 3.0 °C) |
| Apply Pressure: | 832 kPa<br>827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ<br>(18.71 ± 0.40 KJ) |
| Engage Time: | 0.851 Sec |

**Torque**

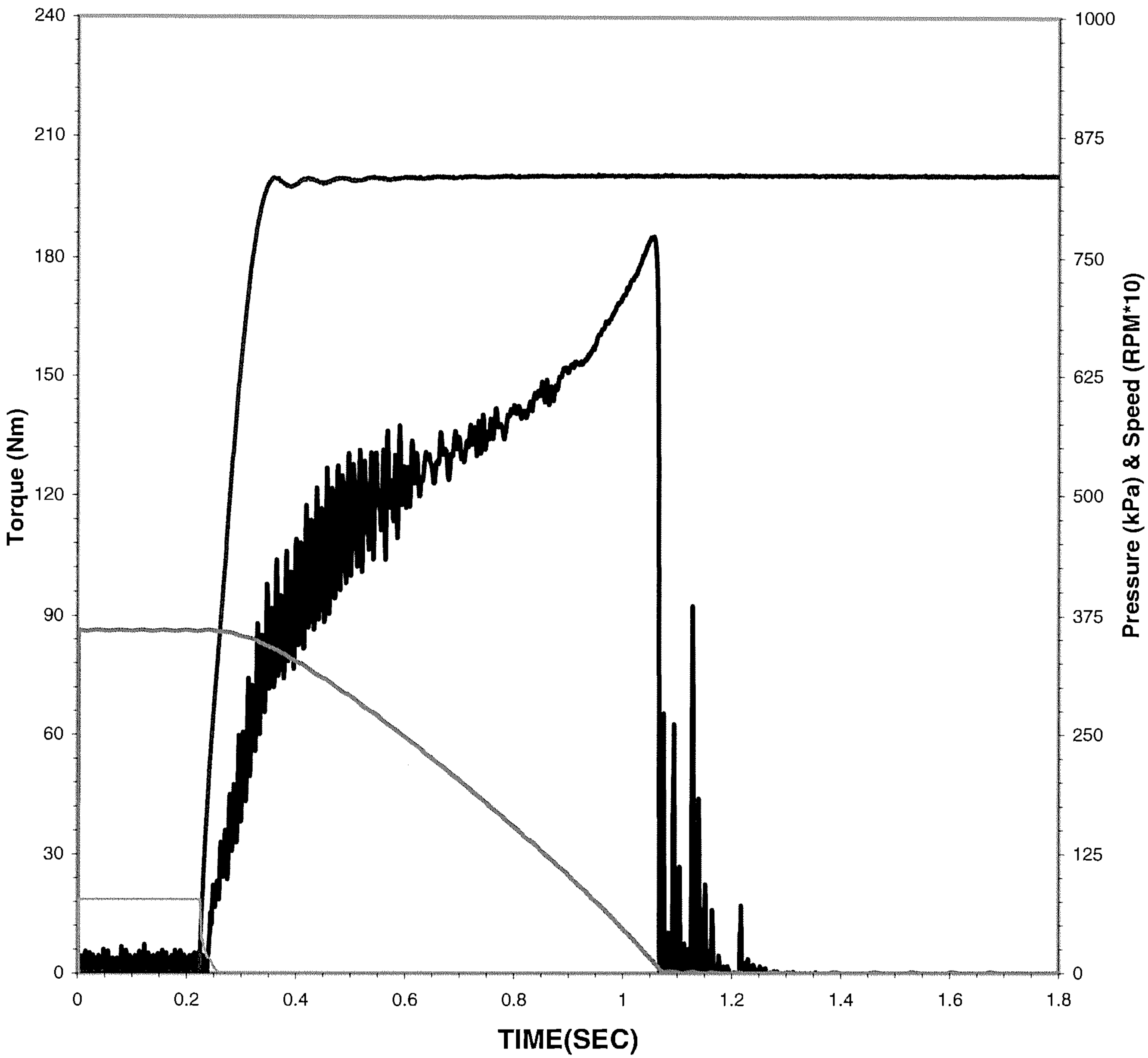
| | |
|---|---|
| 0.2 Sec Dyn: | 96 N*m |
| Midpoint Dyn: | 126 N*m |
| LwSpd Dynamic: | 176 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.066 |
| Midpoint Dyn: | 0.087 |
| LwSpd Dynamic: | 0.122 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 8:45:28 |
| Test Number: | C4-3-1341 |
| Fluid Code: | LO268869 |
| Cycle Number: | 3999 |
| Temperature: | 110.9 °C<br>(112.7 ± 3.0 °C) |
| Apply Pressure: | 831 kPa<br>827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ<br>(18.71 ± 0.40 KJ) |
| Engage Time: | 0.843 Sec |

**Torque**

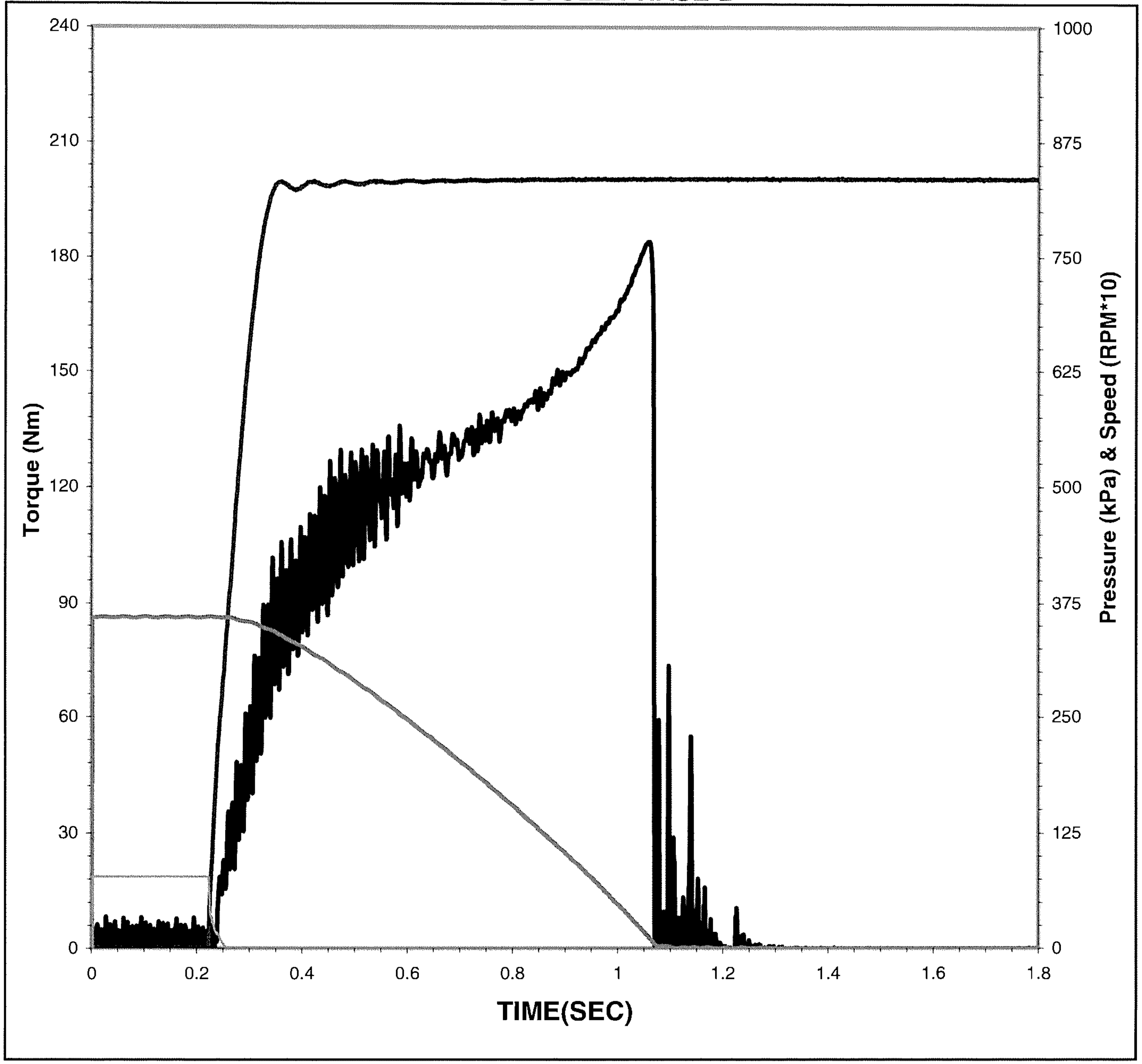
| | |
|---|---|
| 0.2 Sec Dyn: | 102 N*m |
| Midpoint Dyn: | 128 N*m |
| LwSpd Dynamic: | 176 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.071 |
| Midpoint Dyn: | 0.089 |
| LwSpd Dynamic: | 0.122 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 8:45:43 |
| Test Number: | C4-3-1341 |
| Fluid Code: | LO268869 |
| Cycle Number: | 4000 |
| Temperature: | 110.9 °C (112.7 ± 3.0 °C) |
| Apply Pressure: | 831 kPa 827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ (18.71 ± 0.40 KJ) |
| Engage Time: | 0.848 Sec |

**Torque**

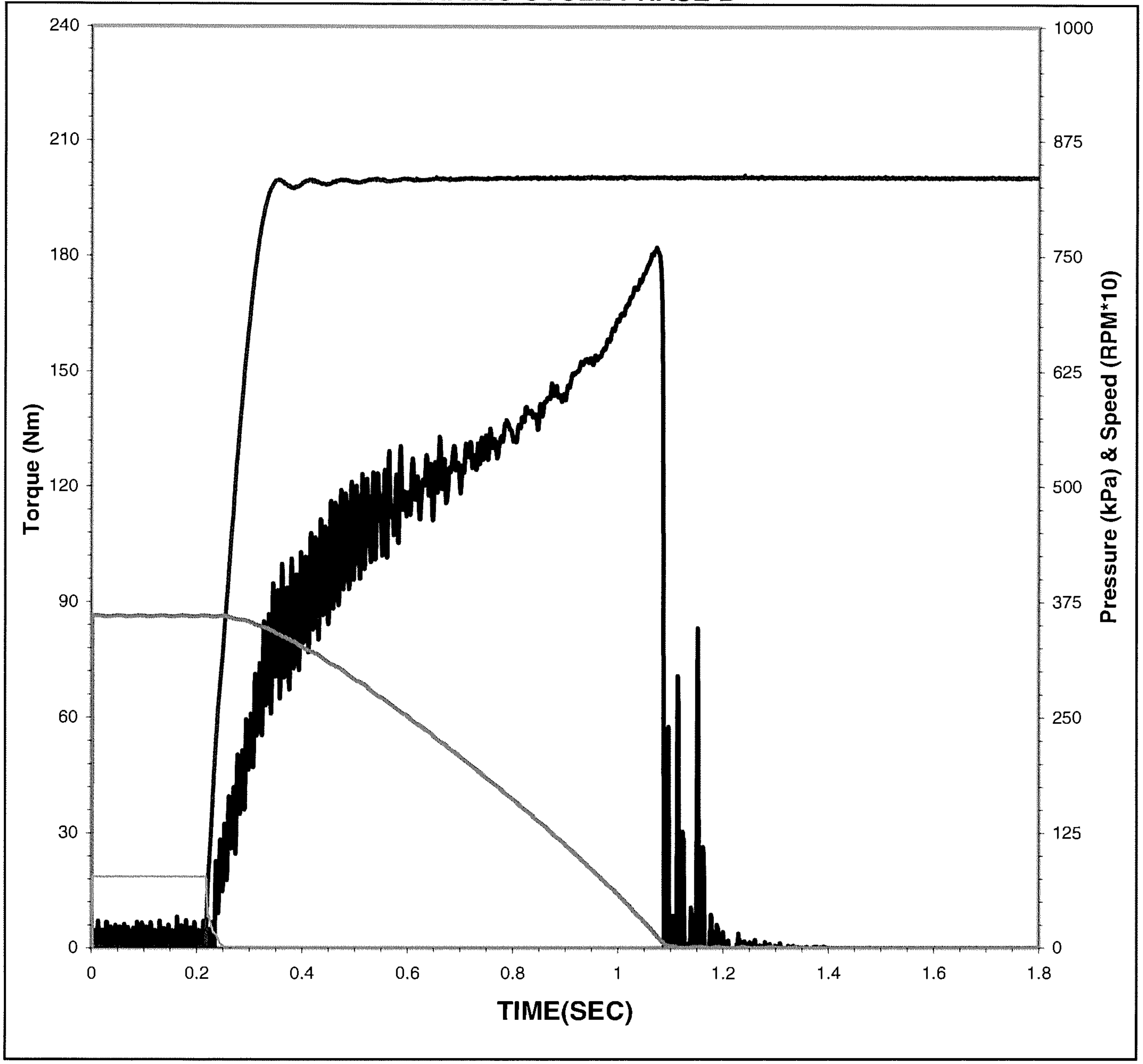
| | |
|---|---|
| 0.2 Sec Dyn: | 100 N*m |
| Midpoint Dyn: | 127 N*m |
| LwSpd Dynamic: | 176 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.069 |
| Midpoint Dyn: | 0.088 |
| LwSpd Dynamic: | 0.122 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 8:46:09 |
| Test Number: | C4-3-1341 |
| Fluid Code: | LO268869 |
| Cycle Number: | 4001 |
| Temperature: | 106.7 °C (112.7 ± 3.0 °C) |
| Apply Pressure: | 832 kPa 827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ (18.71 ± 0.40 KJ) |
| Engage Time: | 0.87 Sec |

**Torque**

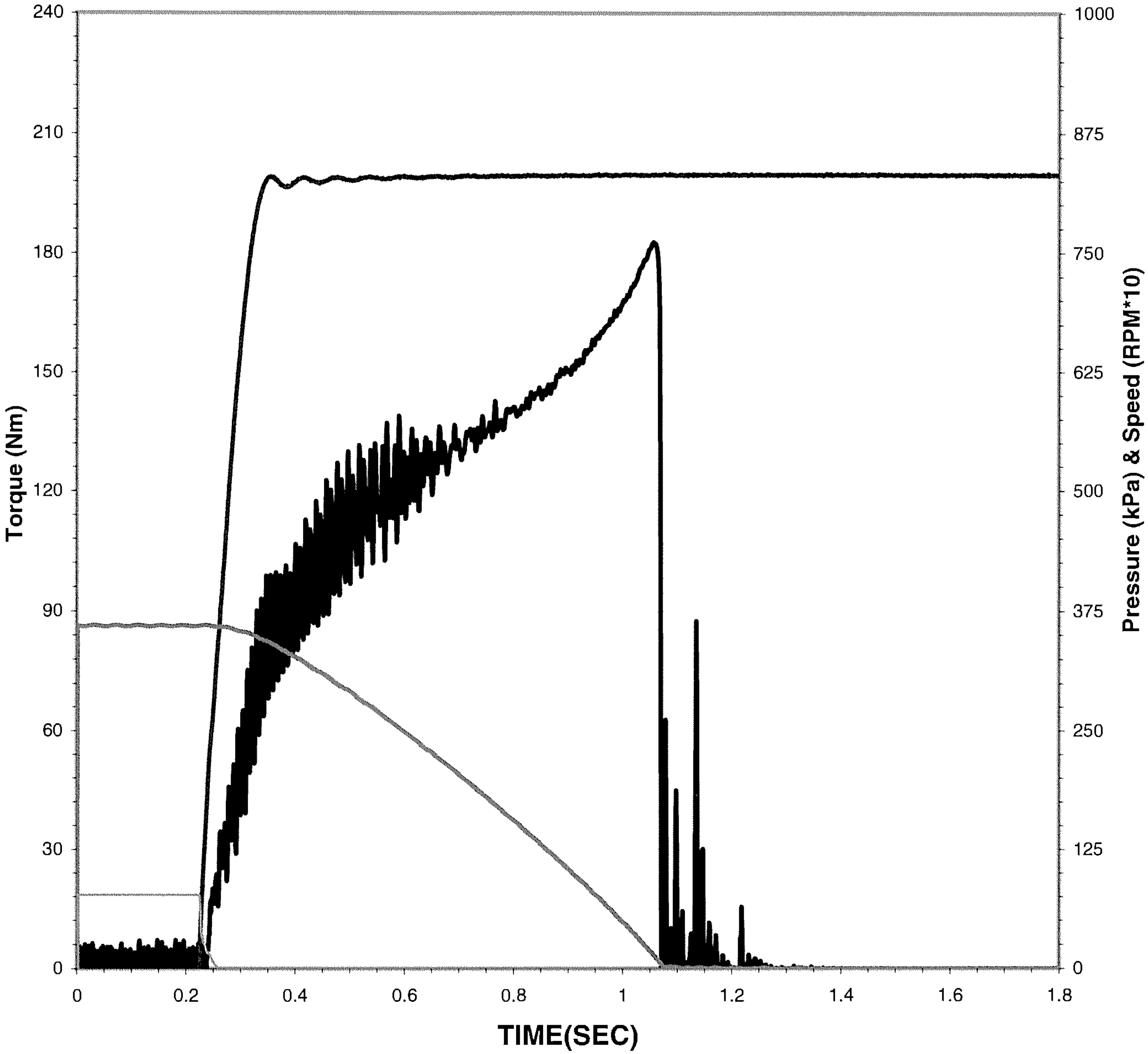
| | |
|---|---|
| 0.2 Sec Dyn: | 95 N*m |
| Midpoint Dyn: | 123 N*m |
| LwSpd Dynamic: | 175 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.065 |
| Midpoint Dyn: | 0.085 |
| LwSpd Dynamic: | 0.121 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 10:50:39 |
| Test Number: | C4-3-1341 |
| Fluid Code: | LO268869 |
| Cycle Number: | 4499 |
| Temperature: | 111.6 °C<br>(112.7 ± 3.0 °C) |
| Apply Pressure: | 830 kPa<br>827 ± 7 KPa) |
| Apply Rate: | 0.12 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ<br>(18.71 ± 0.40 KJ) |
| Engage Time: | 0.846 Sec |

**Torque**

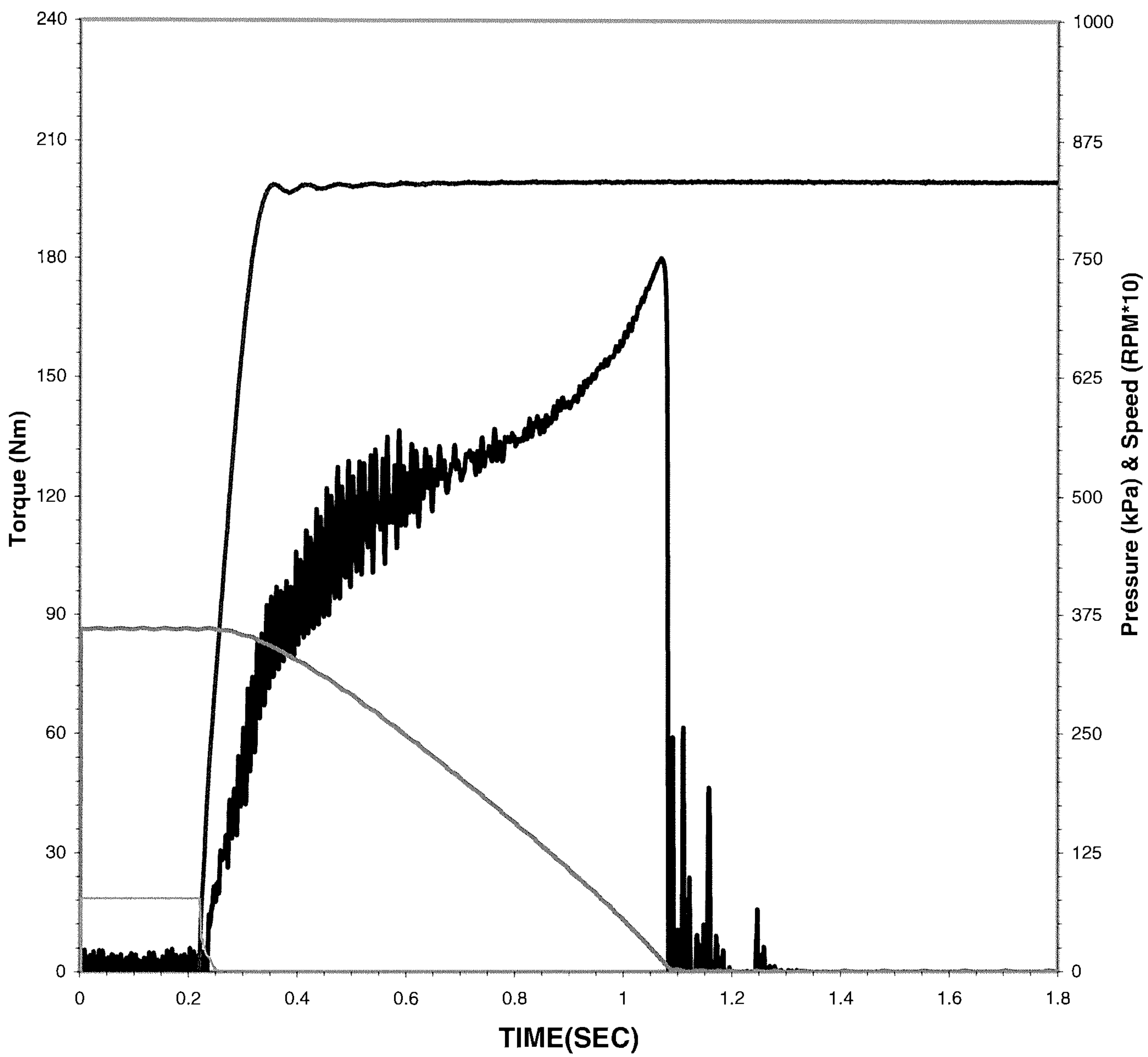
| | |
|---|---|
| 0.2 Sec Dyn: | 99 N*m |
| Midpoint Dyn: | 128 N*m |
| LwSpd Dynamic: | 173 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.069 |
| Midpoint Dyn: | 0.088 |
| LwSpd Dynamic: | 0.120 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 10:50:54 |
| Test Number: | C4-3-1341 |
| Fluid Code: | LO268869 |
| Cycle Number: | 4500 |
| Temperature: | 110.8 °C (112.7 ± 3.0 °C) |
| Apply Pressure: | 830 kPa 827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ (18.71 ± 0.40 KJ) |
| Engage Time: | 0.863 Sec |

**Torque**

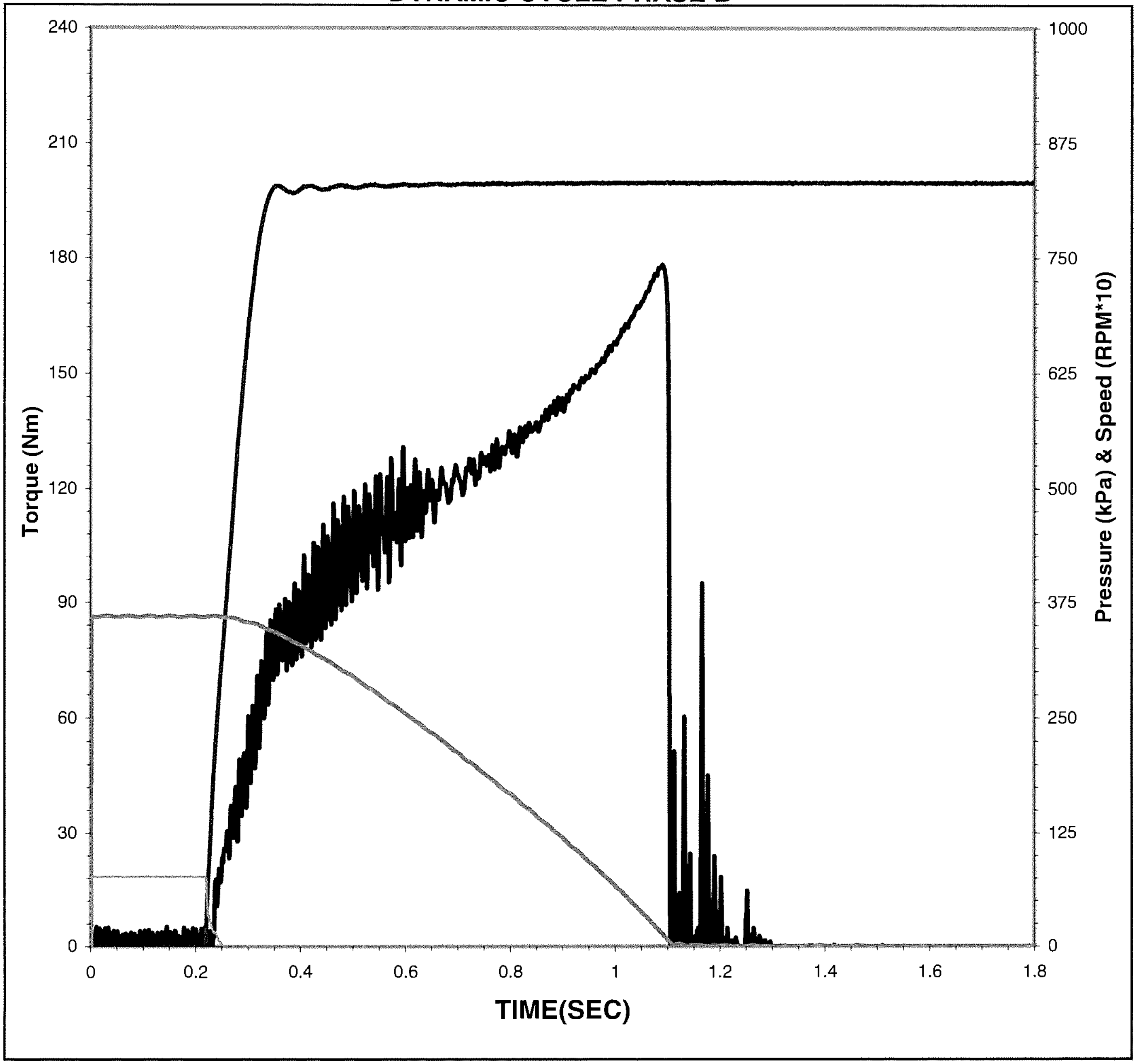
| | |
|---|---|
| 0.2 Sec Dyn: | 99 N*m |
| Midpoint Dyn: | 126 N*m |
| LwSpd Dynamic: | 171 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.069 |
| Midpoint Dyn: | 0.087 |
| LwSpd Dynamic: | 0.118 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 10:51:21 |
| Test Number: | C4-3-1341 |
| Fluid Code: | LO268869 |
| Cycle Number: | 4501 |
| Temperature: | 106.4 °C (112.7 ± 3.0 °C) |
| Apply Pressure: | 830 kPa 827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ (18.71 ± 0.40 KJ) |
| Engage Time: | 0.885 Sec |

**Torque**

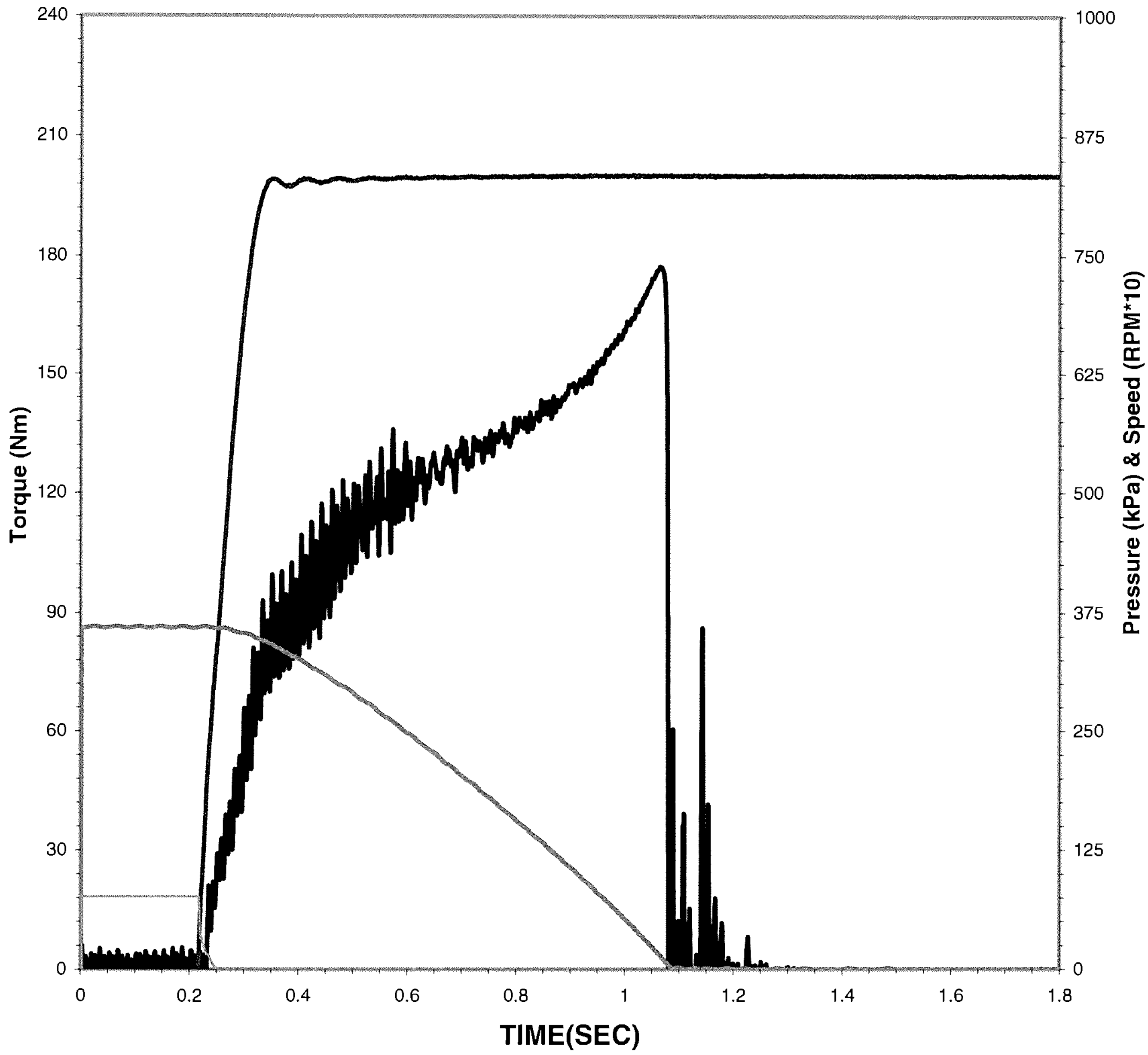
| | |
|---|---|
| 0.2 Sec Dyn: | 92 N*m |
| Midpoint Dyn: | 120 N*m |
| LwSpd Dynamic: | 169 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.064 |
| Midpoint Dyn: | 0.083 |
| LwSpd Dynamic: | 0.117 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 12:55:51 |
| Test Number: | C4-3-1341 |
| Fluid Code: | LO268869 |
| Cycle Number: | 4999 |
| Temperature: | 111.0 °C |
| | (112.7 ± 3.0 °C) |
| Apply Pressure: | 832 kPa |
| | 827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec |
| | (0.15 ± 0.02 Sec) |
| Energy: | 18.5 KJ |
| | (18.71 ± 0.40 KJ) |
| Engage Time: | 0.864 Sec |

**Torque**

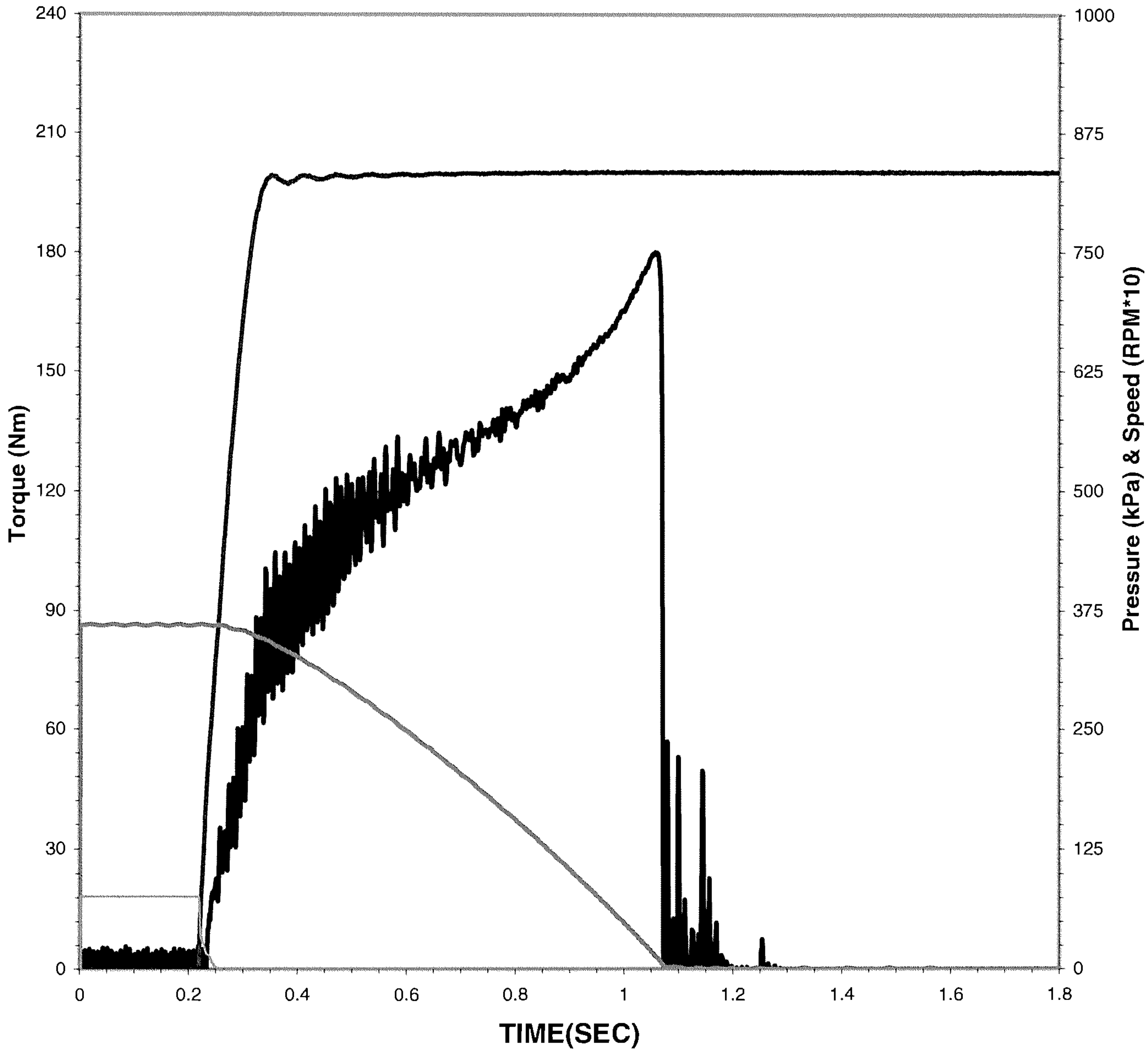
| | |
|---|---|
| 0.2 Sec Dyn: | 97 N*m |
| Midpoint Dyn: | 126 N*m |
| LwSpd Dynamic: | 166 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.067 |
| Midpoint Dyn: | 0.087 |
| LwSpd Dynamic: | 0.115 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 12:56:06 |
| Test Number: | C4-3-1341 |
| Fluid Code: | LO268869 |
| Cycle Number: | 5000 |
| Temperature: | 110.9 °C (112.7 ± 3.0 °C) |
| Apply Pressure: | 832 kPa 827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.5 KJ (18.71 ± 0.40 KJ) |
| Engage Time: | 0.854 Sec |

**Torque**

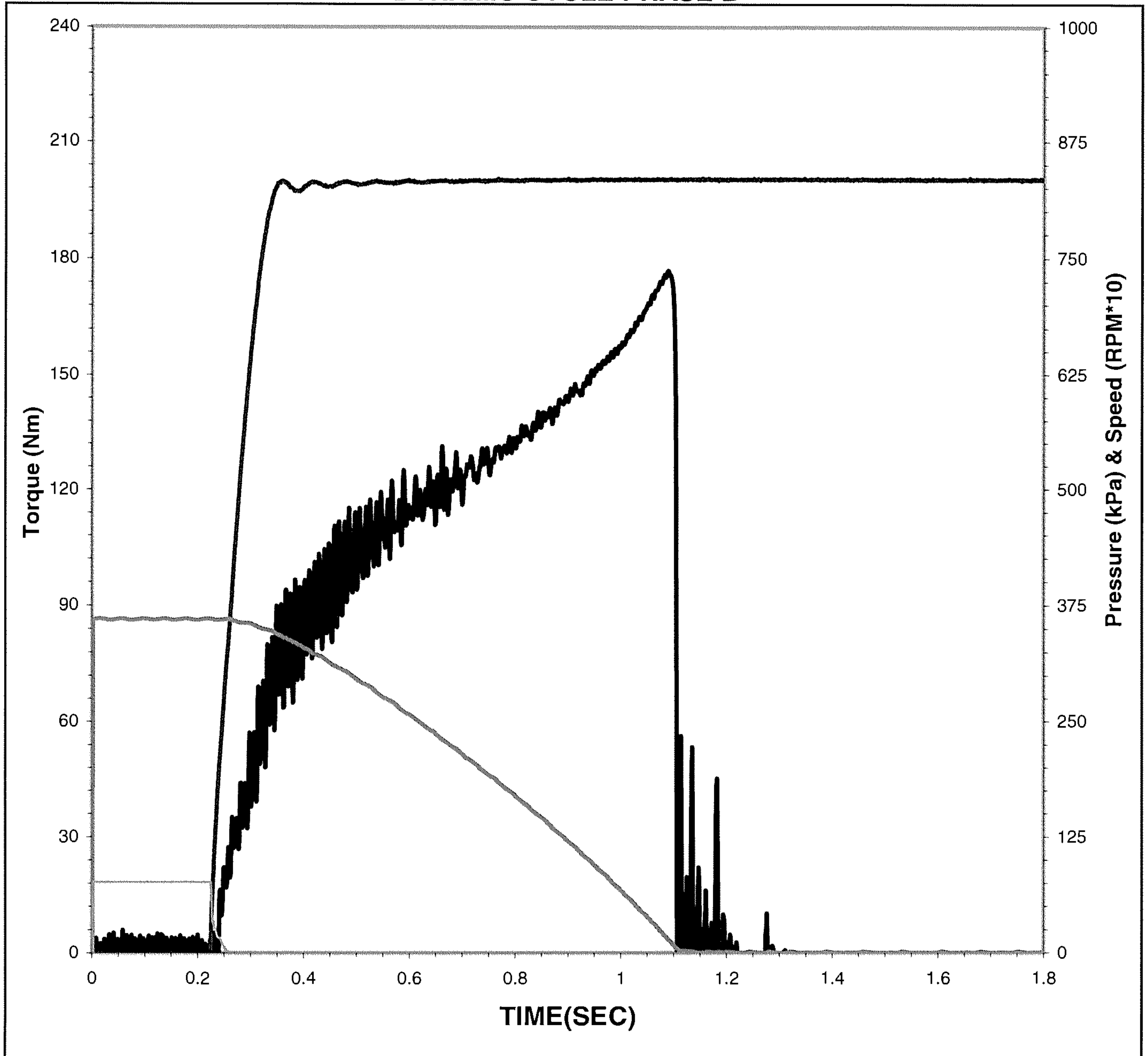
| | |
|---|---|
| 0.2 Sec Dyn: | 99 N*m |
| Midpoint Dyn: | 127 N*m |
| LwSpd Dynamic: | 171 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.068 |
| Midpoint Dyn: | 0.088 |
| LwSpd Dynamic: | 0.118 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 12:56:33 |
| Test Number: | C4-3-1341 |
| Fluid Code: | LO268869 |
| Cycle Number: | 5001 |
| Temperature: | 106.6 °C<br>(112.7 ± 3.0 °C) |
| Apply Pressure: | 833 kPa<br>827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.5 KJ<br>(18.71 ± 0.40 KJ) |
| Engage Time: | 0.882 Sec |

**Torque**

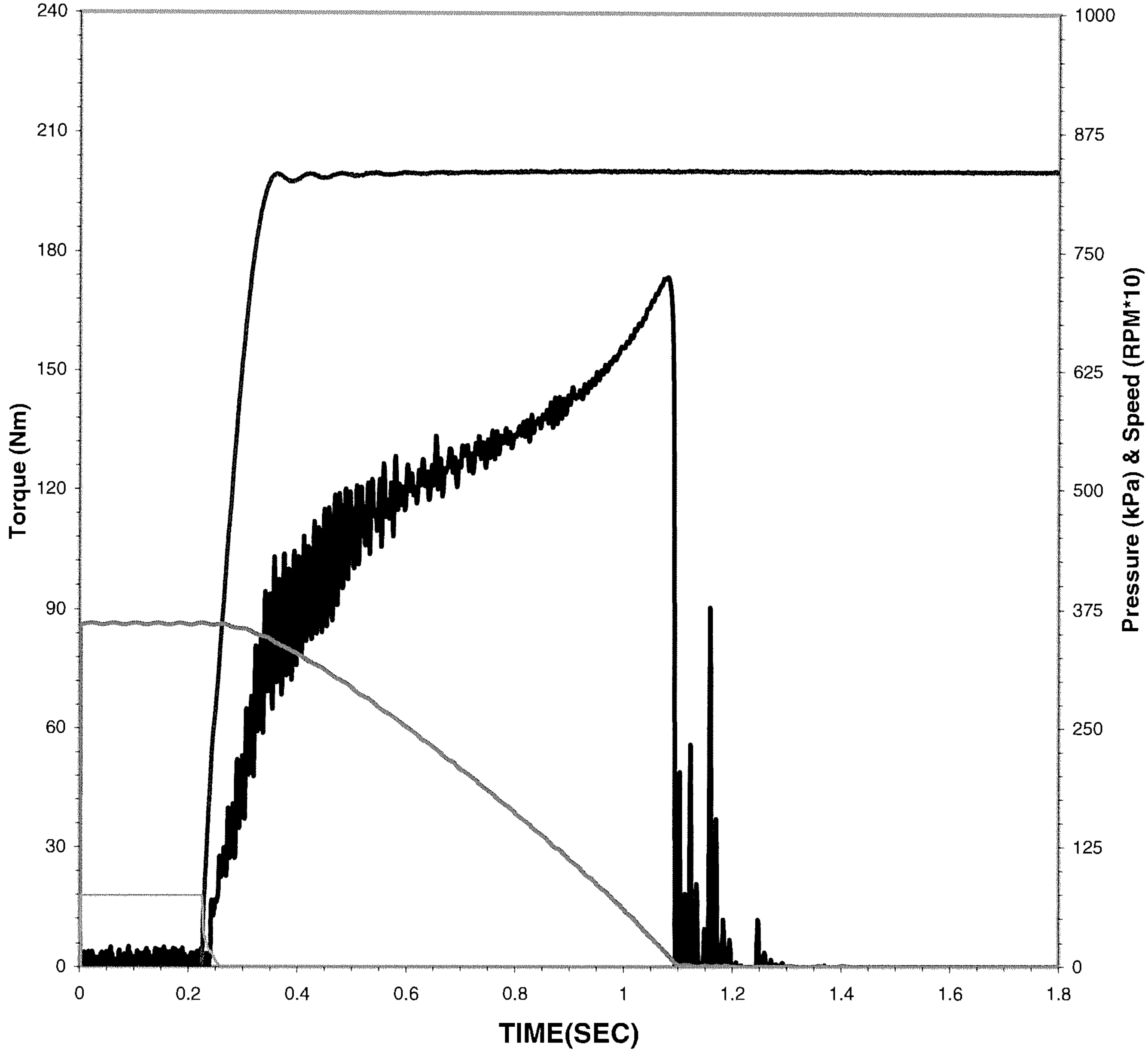
| | |
|---|---|
| 0.2 Sec Dyn: | 92 N*m |
| Midpoint Dyn: | 121 N*m |
| LwSpd Dynamic: | 163 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.064 |
| Midpoint Dyn: | 0.083 |
| LwSpd Dynamic: | 0.113 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 15:00:48 |
| Test Number: | C4-3-1341 |
| Fluid Code: | LO268869 |
| Cycle Number: | 5498 |
| Temperature: | 110.8 °C (112.7 ± 3.0 °C) |
| Apply Pressure: | 833 kPa 827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ (18.71 ± 0.40 KJ) |
| Engage Time: | 0.87 Sec |

**Torque**

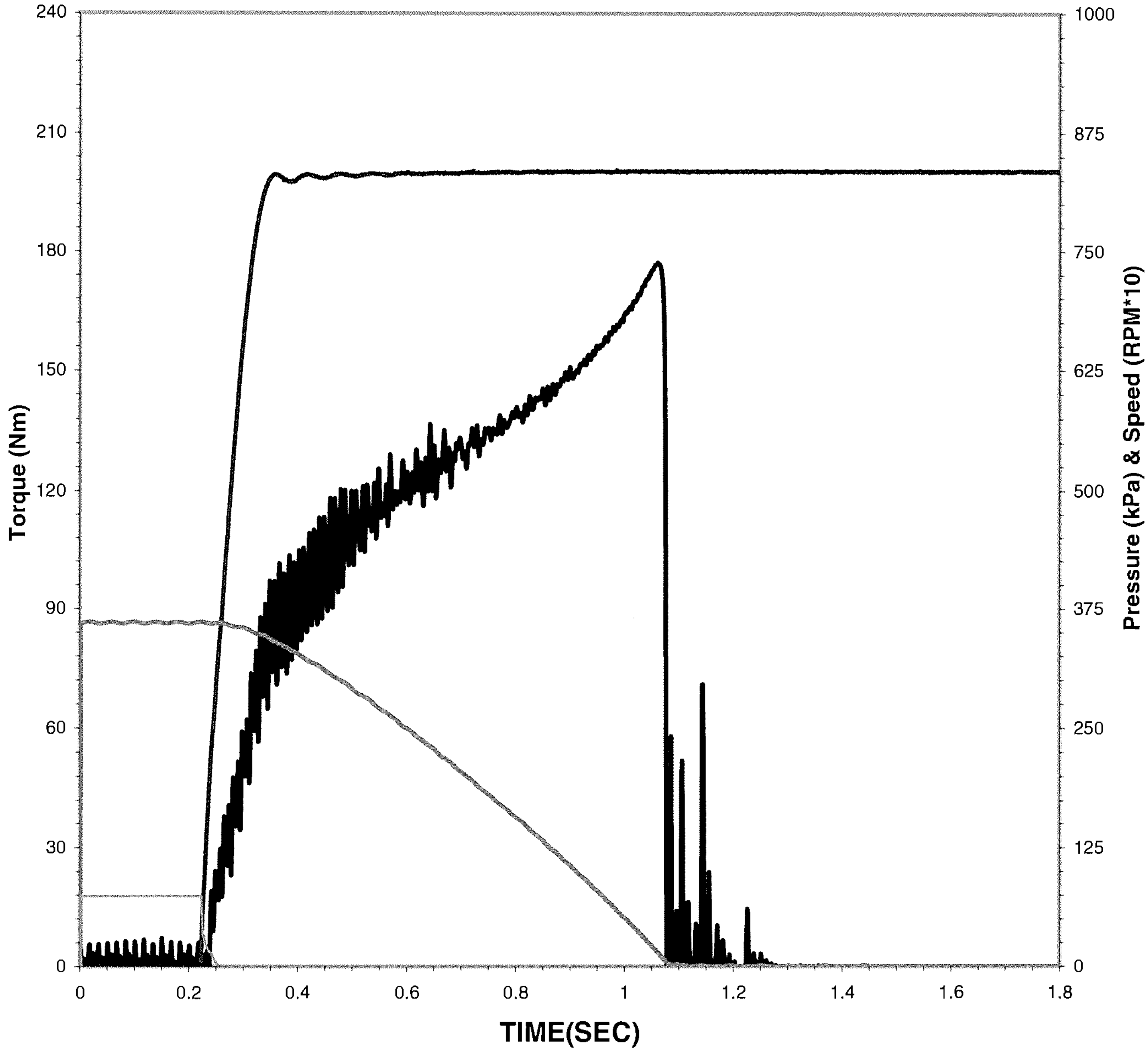
| | |
|---|---|
| 0.2 Sec Dyn: | 98 N*m |
| Midpoint Dyn: | 125 N*m |
| LwSpd Dynamic: | 163 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.067 |
| Midpoint Dyn: | 0.086 |
| LwSpd Dynamic: | 0.113 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 15:01:03 |
| Test Number: | C4-3-1341 |
| Fluid Code: | LO268869 |
| Cycle Number: | 5499 |
| Temperature: | 110.8 °C<br>(112.7 ± 3.0 °C) |
| Apply Pressure: | 833 kPa<br>827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ<br>(18.71 ± 0.40 KJ) |
| Engage Time: | 0.855 Sec |

**Torque**

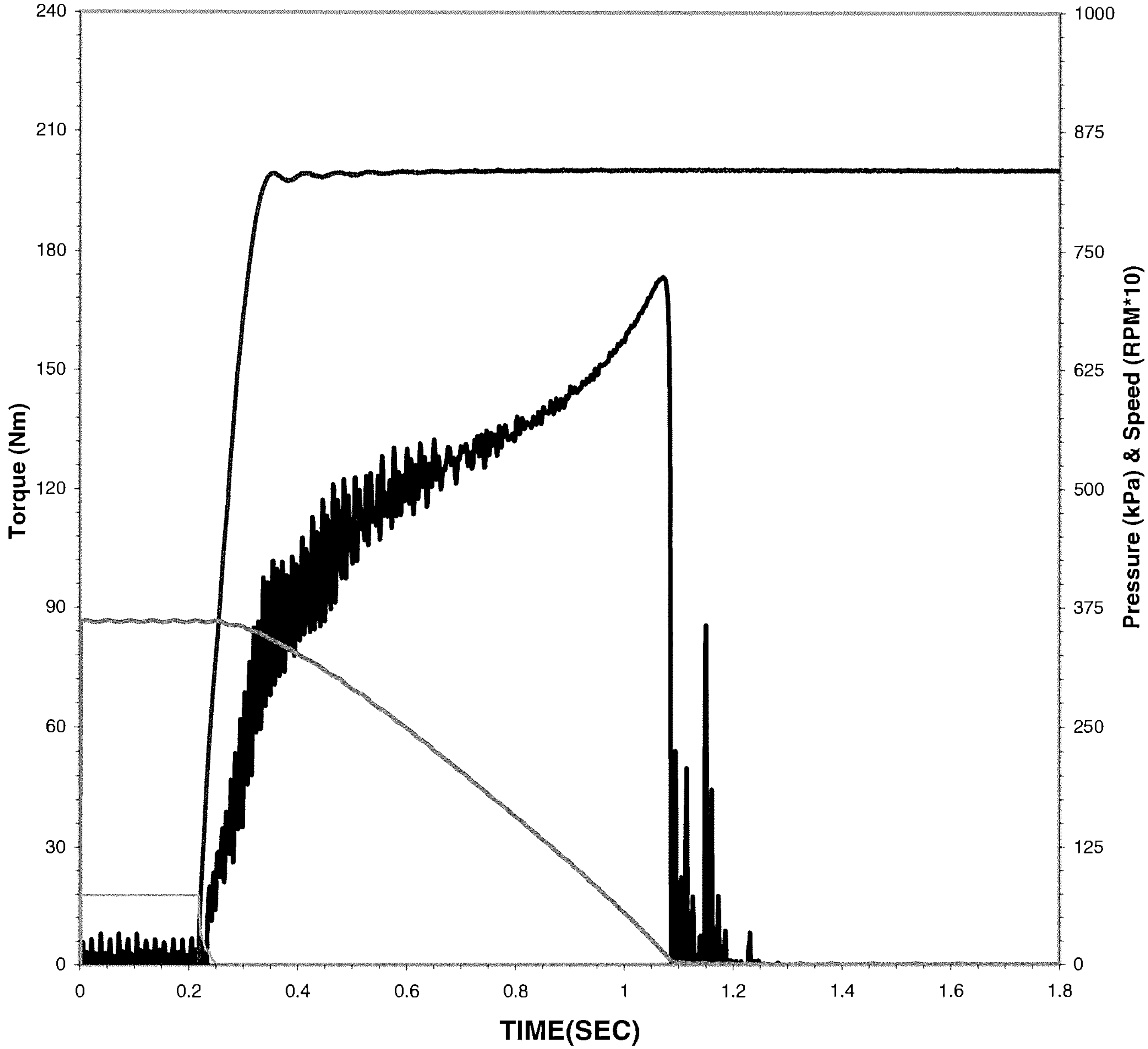
| | |
|---|---|
| 0.2 Sec Dyn: | 98 N*m |
| Midpoint Dyn: | 126 N*m |
| LwSpd Dynamic: | 167 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.068 |
| Midpoint Dyn: | 0.087 |
| LwSpd Dynamic: | 0.116 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




Date of Test: 10/14/2011

Time of Test: 15:01:18

Test Number: C4-3-1341

Fluid Code: LO268869

Cycle Number: 5500

Temperature: 110.9 °C
(112.7 ± 3.0 °C)

Apply Pressure: 833 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.5 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.869 Sec

**Torque**

0.2 Sec Dyn: 96 N*m
Midpoint Dyn: 125 N*m
LwSpd Dynamic: 163 N*m

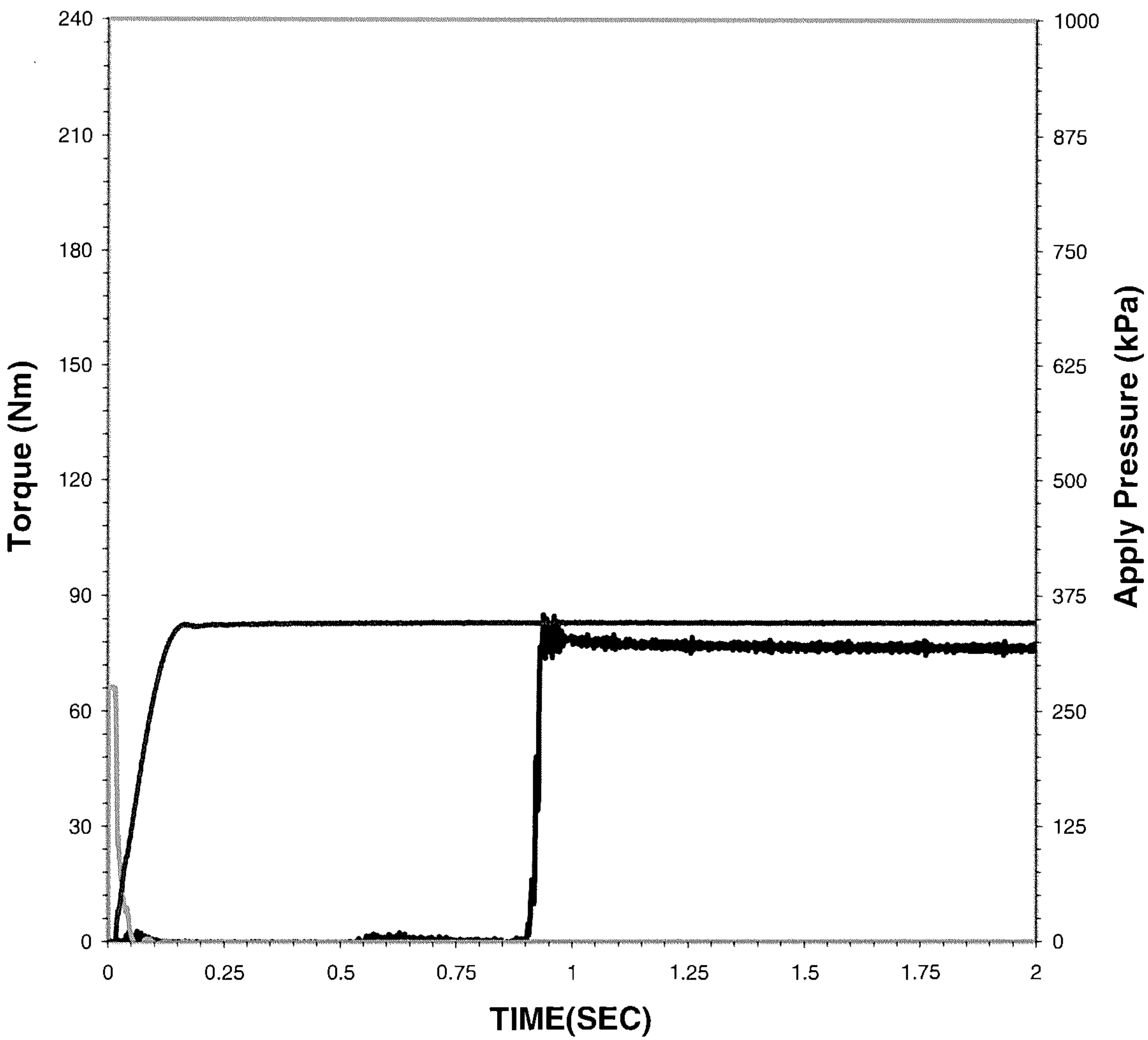
**Coefficient of Friction**

.2 Sec Dyn: 0.066
Midpoint Dyn: 0.086
LwSpd Dynamic: 0.112

**STATIC TRACES**

# ALLISON C-4 GRAPHITE DATA

## STATIC CYCLE




Date of Test: 10/13/2011

Time of Test: 15:15:51

Test Number: C4-3-1341

Fluid Code: LO268869

Cycle Number: 10

**PHASE A**

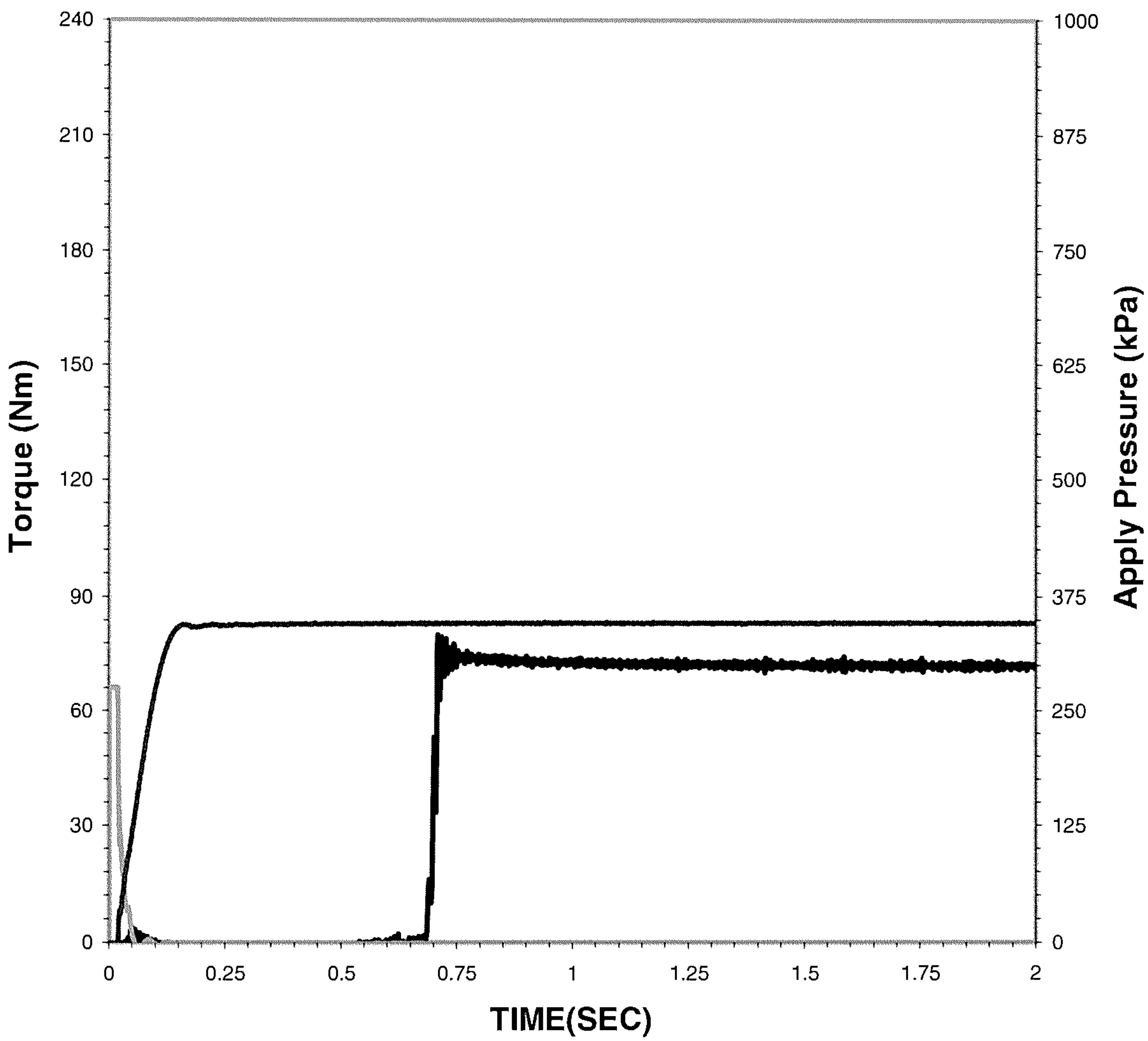
Apply Pressure:
At .25 Second: 347 kPa

**Torque**
Static Peak: 85 Nm
.25 Second: 78 Nm

**Coefficient of Friction**
Static Peak: 0.141
.25 Second: 0.129

# ALLISON C-4 GRAPHITE DATA

## STATIC CYCLE




Date of Test: 10/13/2011

Time of Test: 17:18:33

Test Number: C4-3-1341

Fluid Code: LO268869

Cycle Number: 500

**PHASE A**

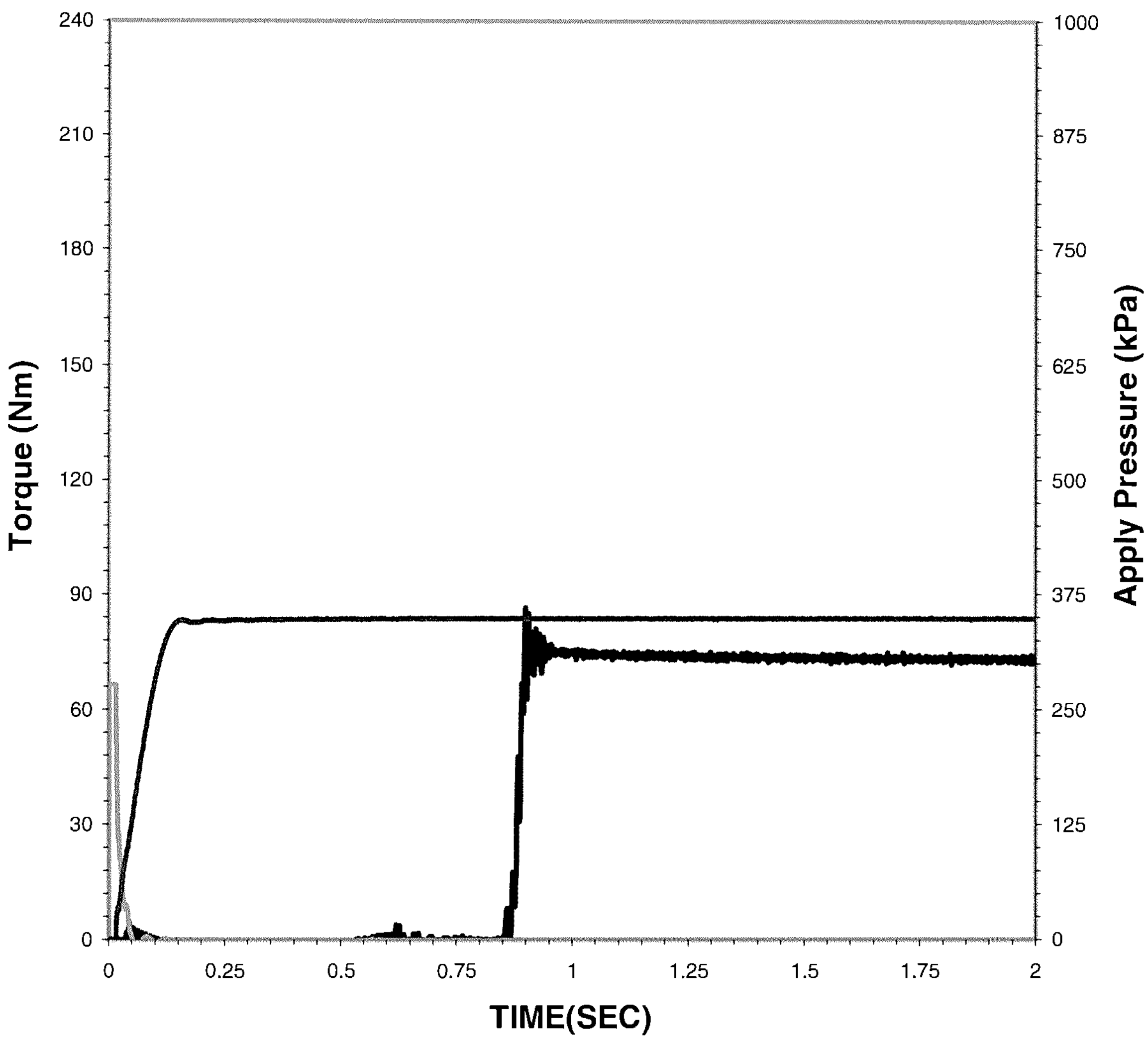
Apply Pressure:
At .25 Second: 347 kPa

**Torque**
Static Peak: 81 Nm
.25 Second: 73 Nm

**Coefficient of Friction**
Static Peak: 0.134
.25 Second: 0.120

# ALLISON C-4 GRAPHITE DATA

## STATIC CYCLE




Date of Test: 10/13/2011

Time of Test: 19:23:45

Test Number: C4-3-1341

Fluid Code: LO268869

Cycle Number: 1000

**PHASE A**

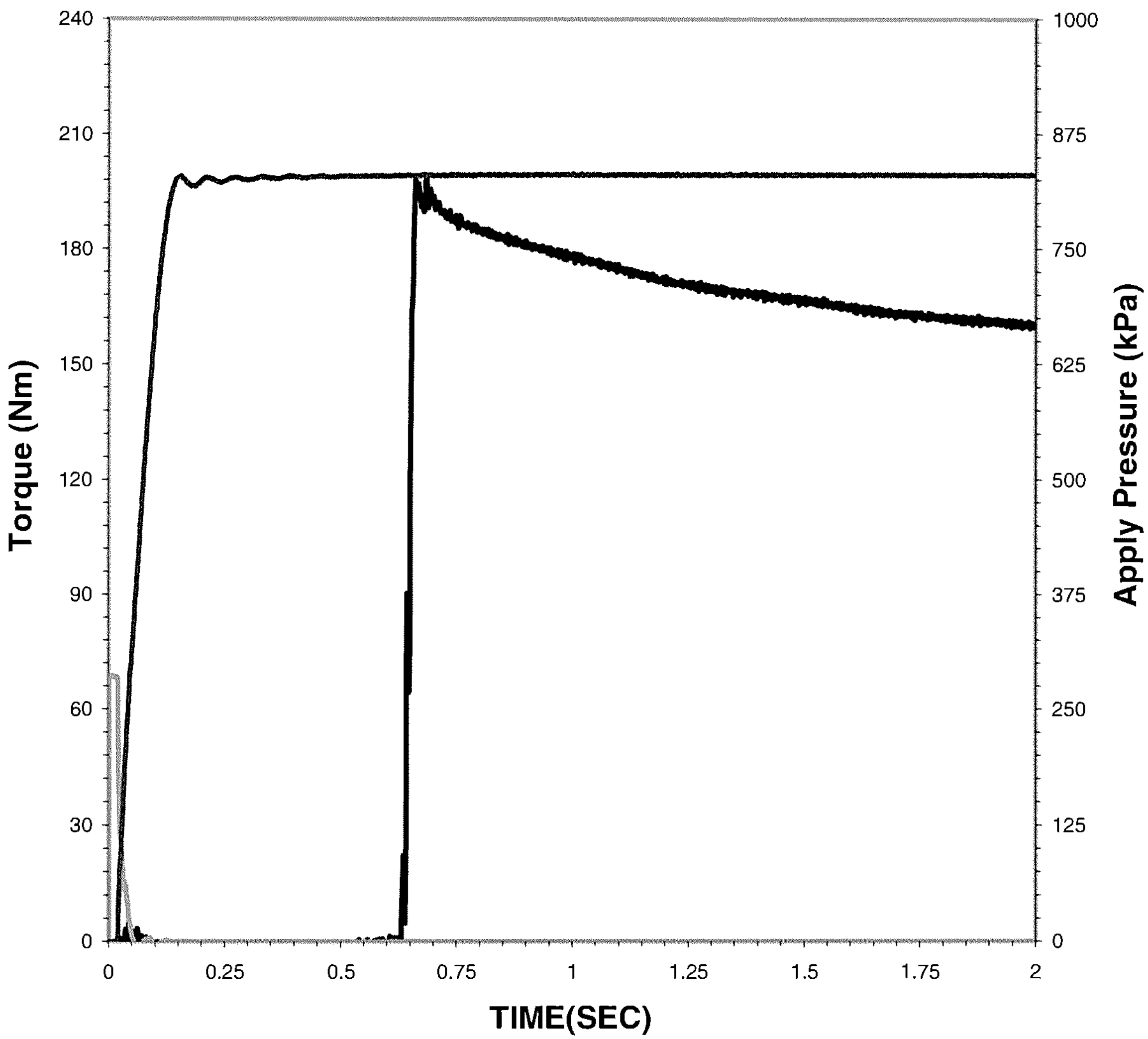
Apply Pressure:
At .25 Second: 348 kPa

**Torque**
Static Peak: 87 Nm
.25 Second: 75 Nm

**Coefficient of Friction**
Static Peak: 0.144
.25 Second: 0.125

# ALLISON C-4 GRAPHITE DATA

## STATIC CYCLE




Date of Test: 10/13/2011

Time of Test: 22:19:55

Test Number: C4-3-1341

Fluid Code: LO268869

Cycle Number: 1500

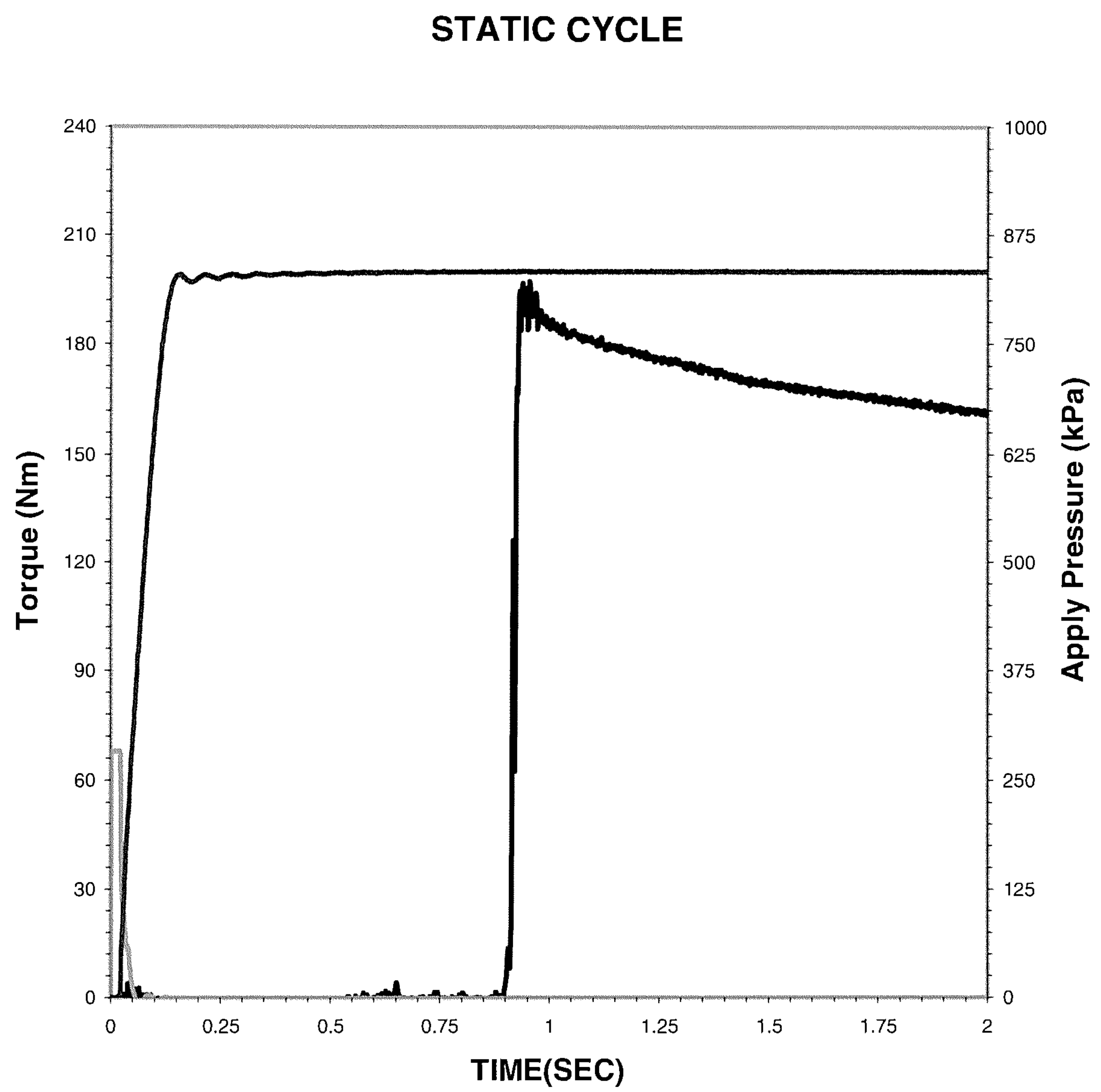
**PHASE B**

Apply Pressure:
At .25 Second: 829 kPa

**Torque**
Static Peak: 199 Nm
.25 Second: 182 Nm

**Coefficient of Friction**
Static Peak: 0.137
.25 Second: 0.126

# ALLISON C-4 GRAPHITE DATA




Date of Test: 10/14/2011

Time of Test: 0:25:07

Test Number: C4-3-1341

Fluid Code: LO268869

Cycle Number: 2000

**PHASE B**

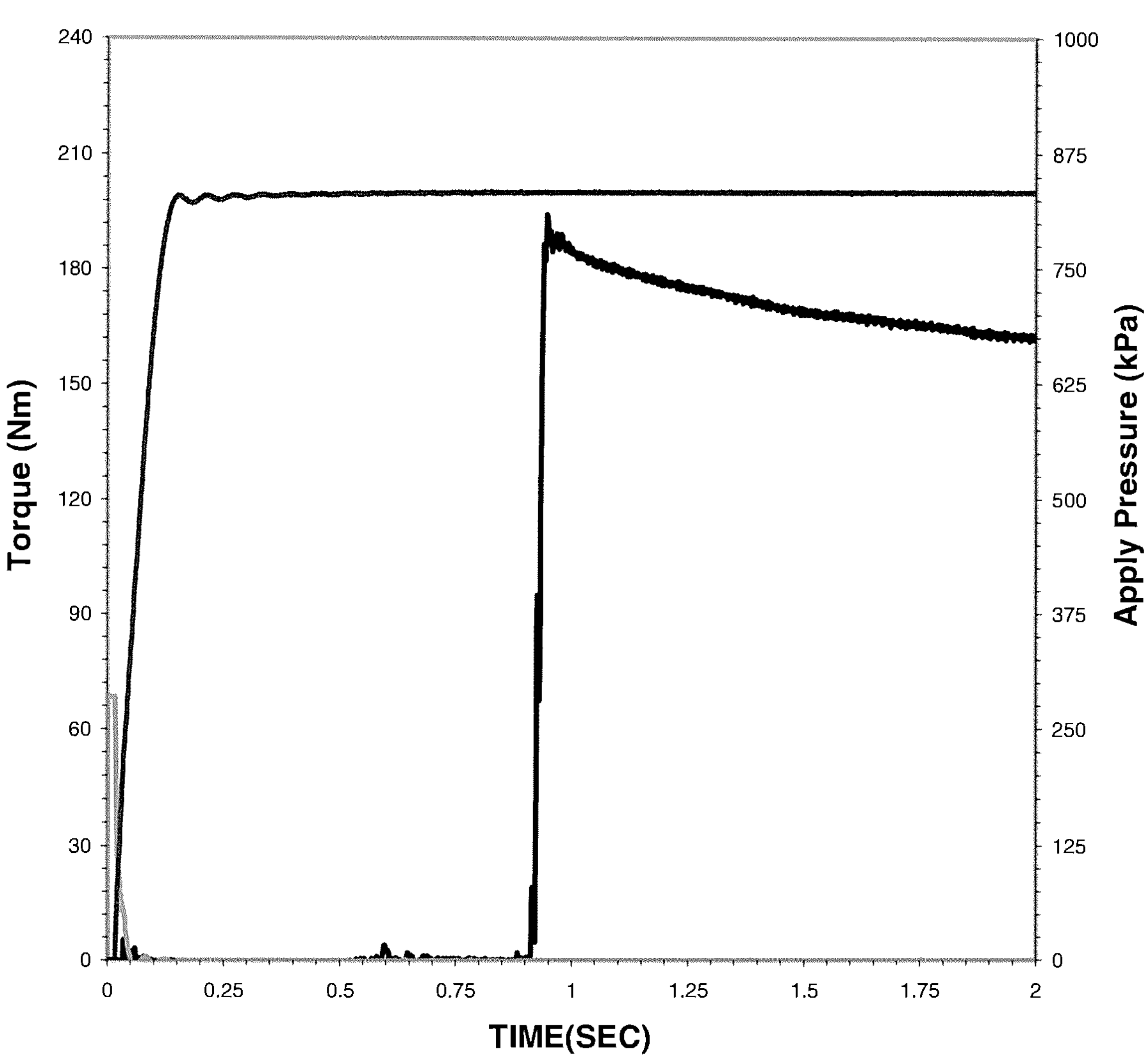
Apply Pressure:
At .25 Second: 830 kPa

**Torque**
Static Peak: 198 Nm
.25 Second: 179 Nm

**Coefficient of Friction**
Static Peak: 0.137
.25 Second: 0.124

# ALLISON C-4 GRAPHITE DATA

## STATIC CYCLE




Date of Test: 10/14/2011

Time of Test: 2:30:19

Test Number: C4-3-1341

Fluid Code: LO268869

Cycle Number: 2500

**PHASE B**

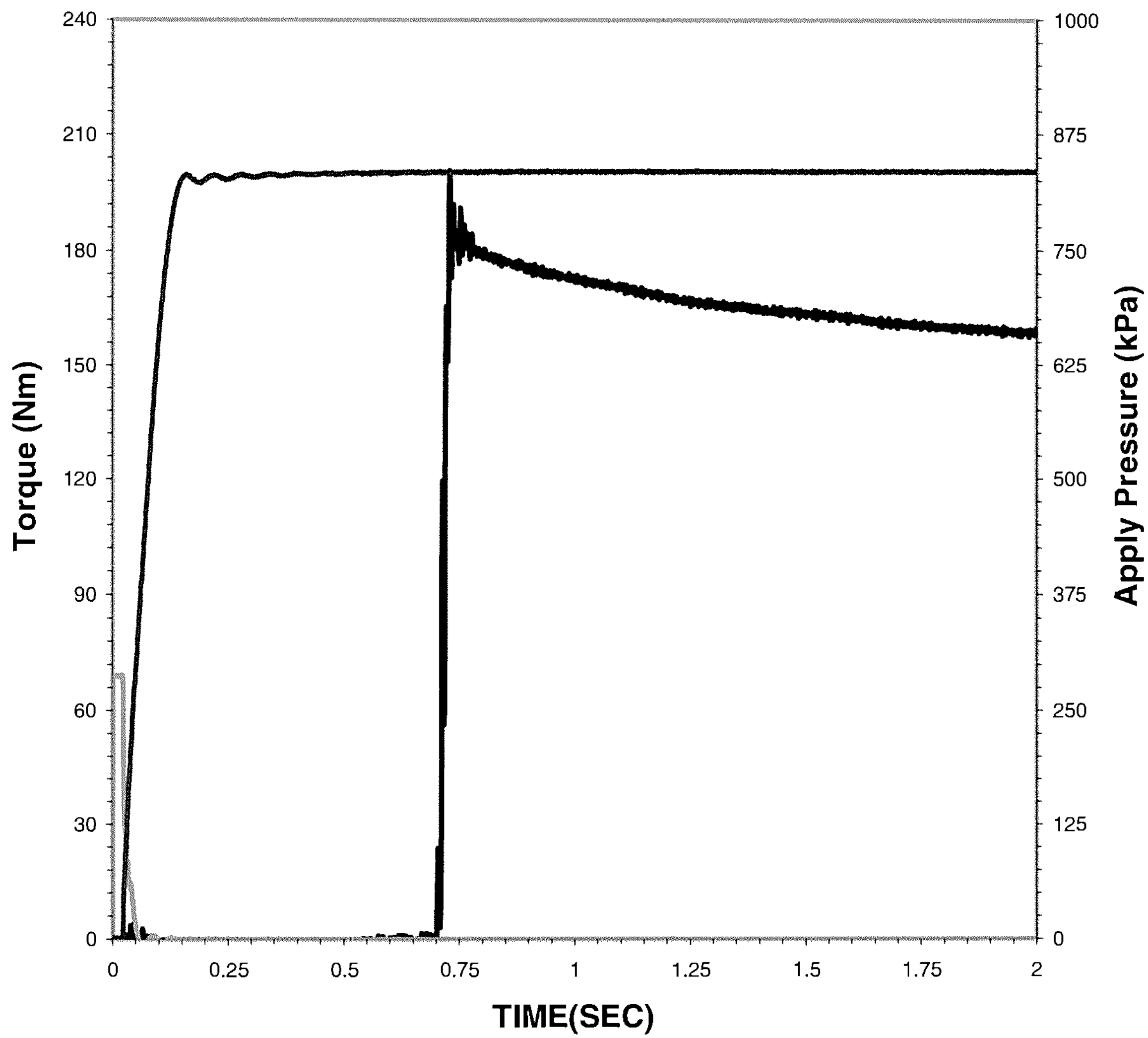
Apply Pressure:
At .25 Second: 830 kPa

**Torque**
Static Peak: 195 Nm
.25 Second: 178 Nm

**Coefficient of Friction**
Static Peak: 0.135
.25 Second: 0.123

# ALLISON C-4 GRAPHITE DATA

## STATIC CYCLE




Date of Test: 10/14/2011

Time of Test: 4:35:31

Test Number: C4-3-1341

Fluid Code: LO268869

Cycle Number: 3000

**PHASE B**

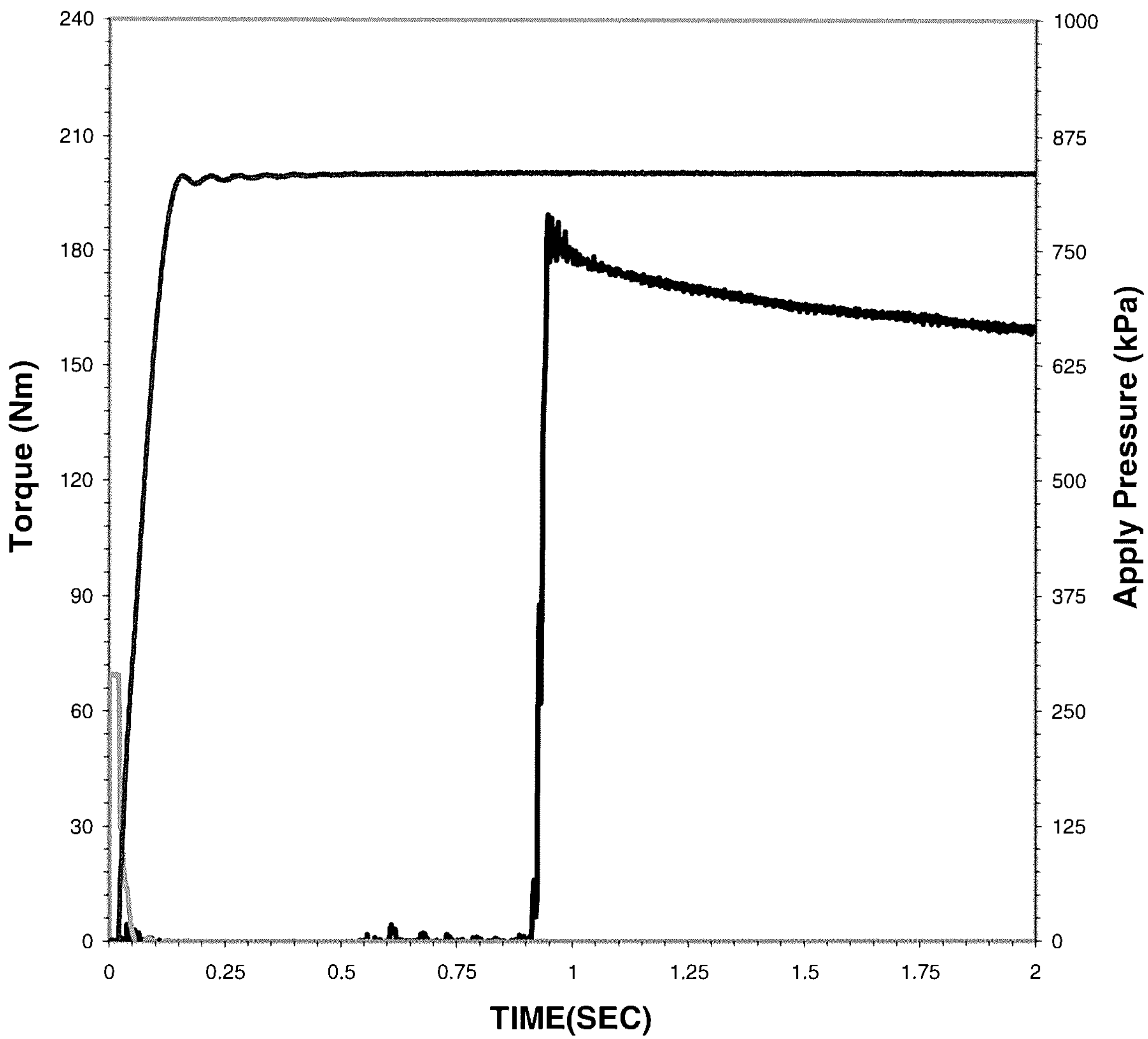
Apply Pressure:
At .25 Second: 831 kPa

**Torque**
Static Peak: 201 Nm
.25 Second: 174 Nm

**Coefficient of Friction**
Static Peak: 0.139
.25 Second: 0.120

# ALLISON C-4 GRAPHITE DATA

## STATIC CYCLE




Date of Test: 10/14/2011

Time of Test: 6:40:42

Test Number: C4-3-1341

Fluid Code: LO268869

Cycle Number: 3500

**PHASE B**

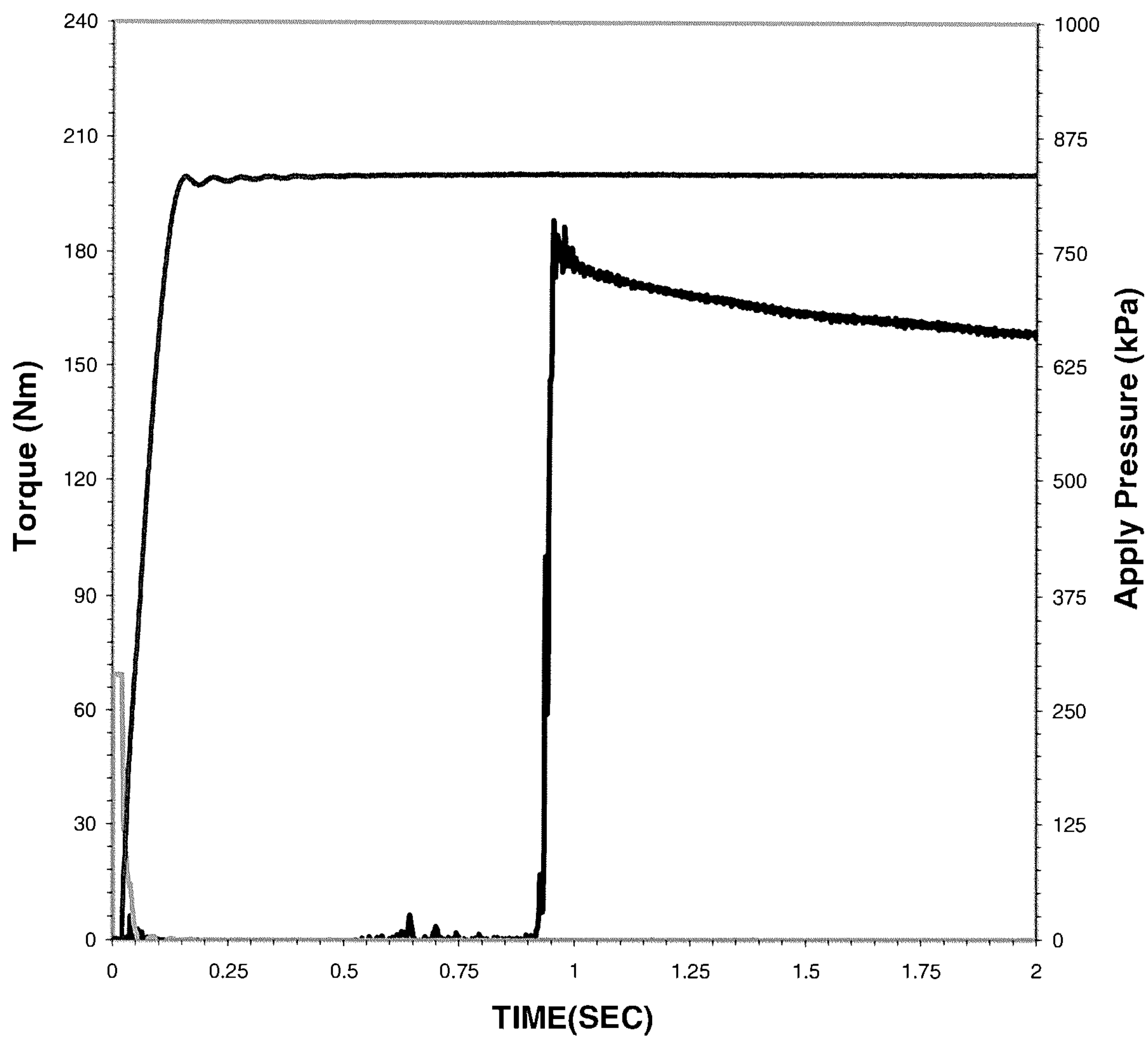
Apply Pressure:
At .25 Second: 832 kPa

**Torque**
Static Peak: 190 Nm
.25 Second: 174 Nm

**Coefficient of Friction**
Static Peak: 0.131
.25 Second: 0.120

# ALLISON C-4 GRAPHITE DATA

## STATIC CYCLE




Date of Test: 10/14/2011

Time of Test: 8:45:54

Test Number: C4-3-1341

Fluid Code: LO268869

Cycle Number: 4000

**PHASE B**

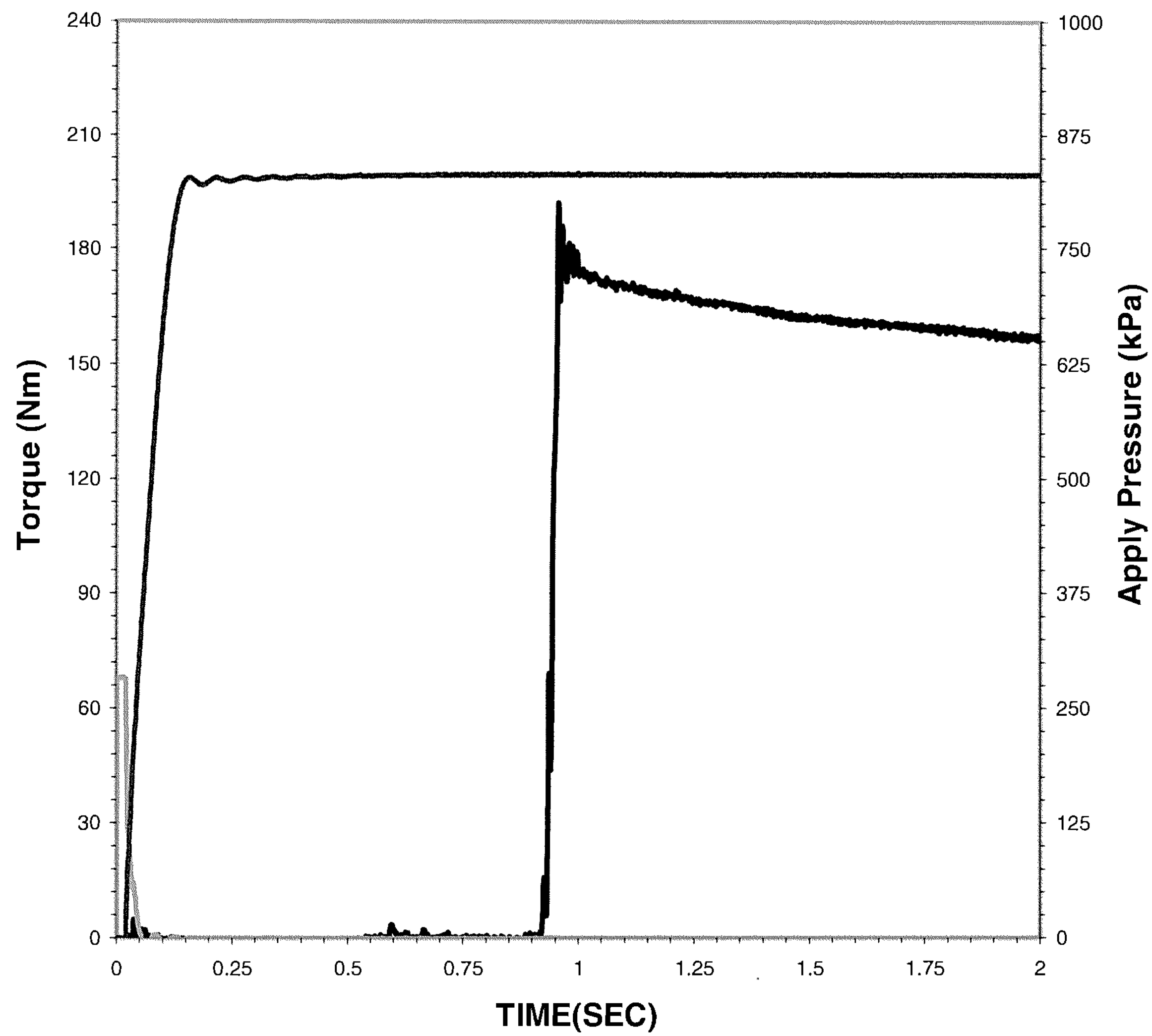
Apply Pressure:
At .25 Second: 831 kPa

**Torque**
Static Peak: 189 Nm
.25 Second: 171 Nm

**Coefficient of Friction**
Static Peak: 0.130
.25 Second: 0.118

# ALLISON C-4 GRAPHITE DATA

## STATIC CYCLE




Date of Test: 10/14/2011

Time of Test: 10:51:06

Test Number: C4-3-1341

Fluid Code: LO268869

Cycle Number: 4500

**PHASE B**

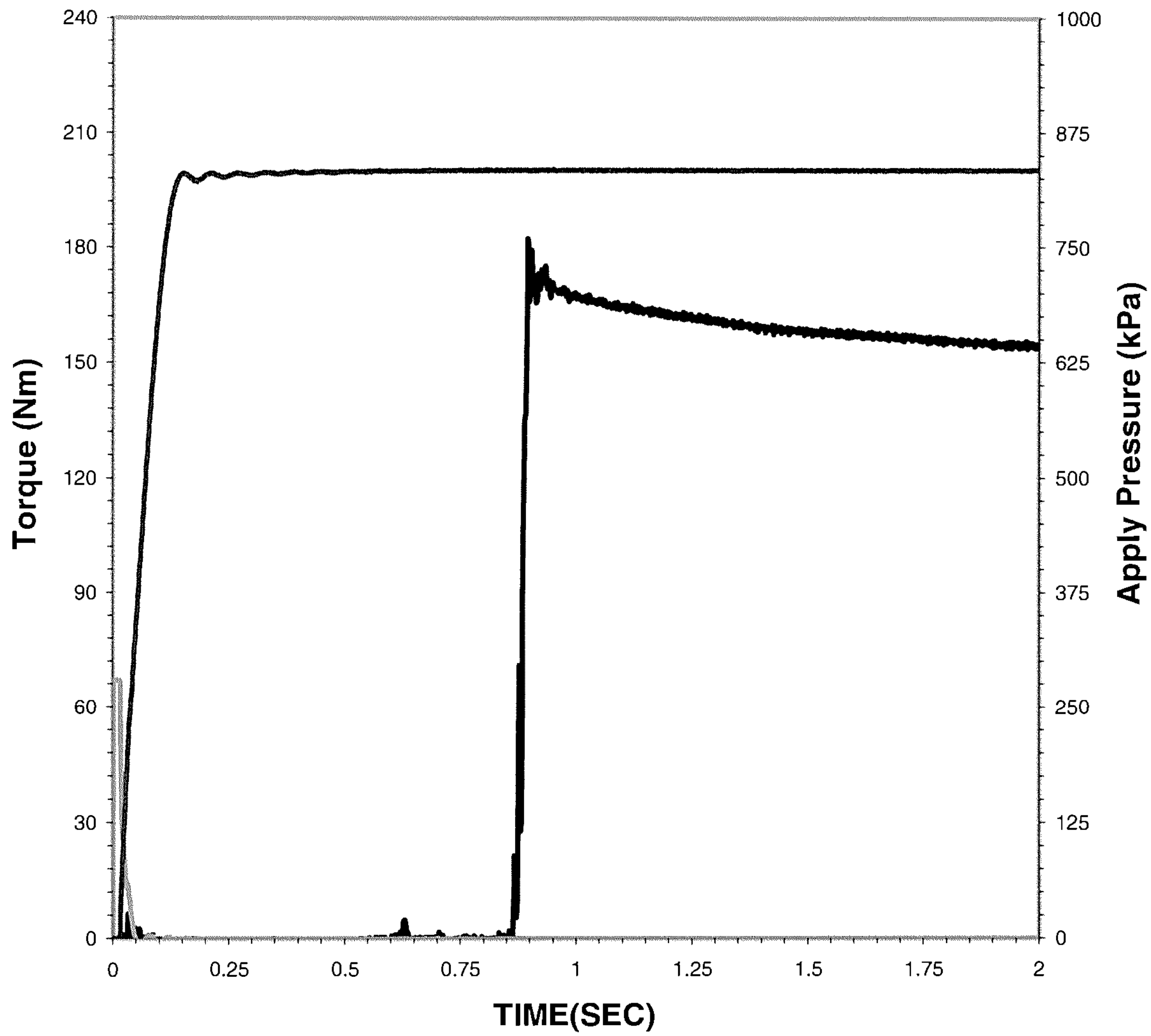
Apply Pressure:
At .25 Second: 830 kPa

**Torque**
Static Peak: 193 Nm
.25 Second: 168 Nm

**Coefficient of Friction**
Static Peak: 0.133
.25 Second: 0.116

# ALLISON C-4 GRAPHITE DATA

## STATIC CYCLE




Date of Test: 10/14/2011

Time of Test: 12:56:18

Test Number: C4-3-1341

Fluid Code: LO268869

Cycle Number: 5000

**PHASE B**

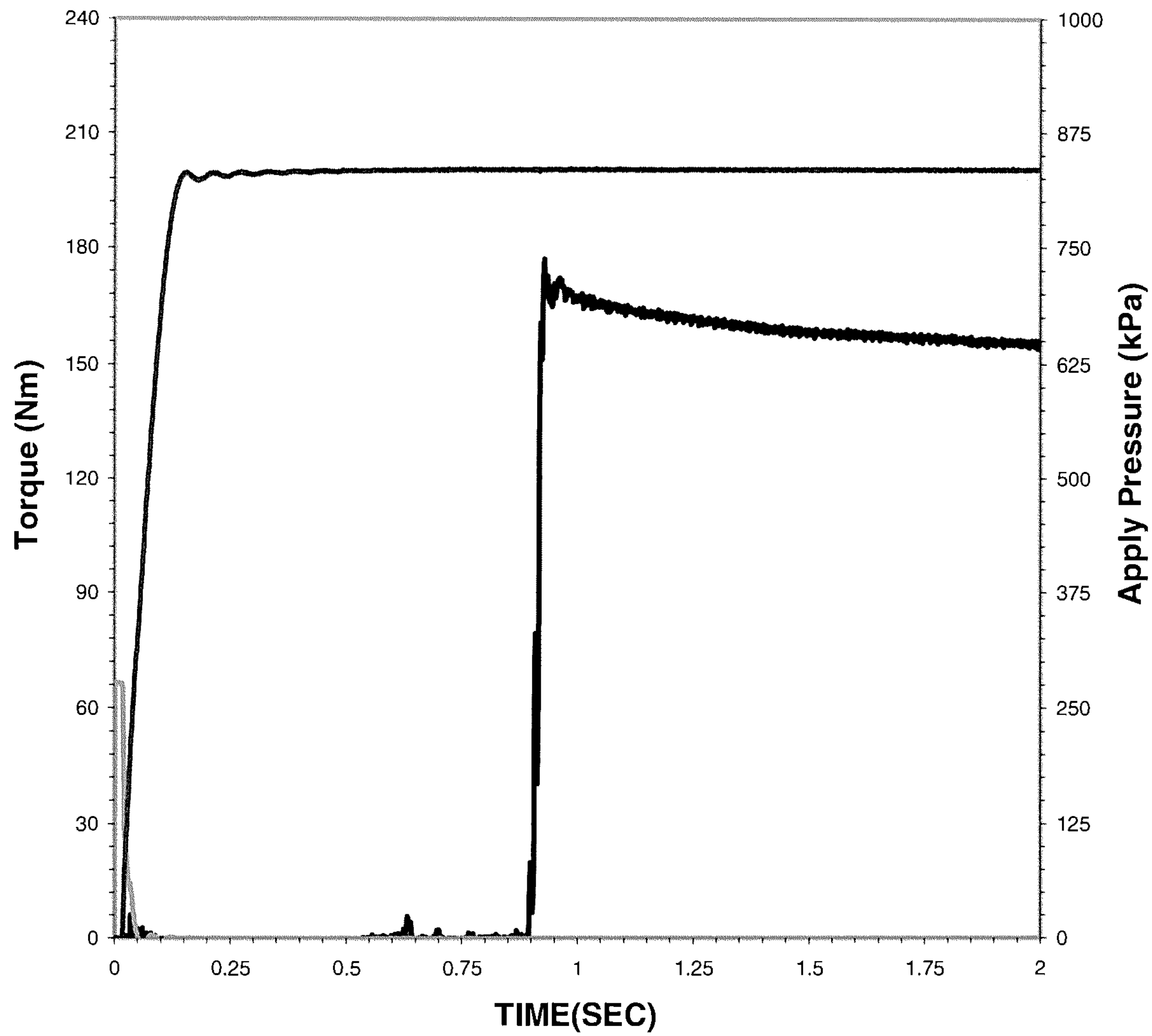
Apply Pressure:
At .25 Second: 832 kPa

**Torque**
Static Peak: 183 Nm
.25 Second: 165 Nm

**Coefficient of Friction**
Static Peak: 0.126
.25 Second: 0.114

# ALLISON C-4 GRAPHITE DATA

## STATIC CYCLE




Date of Test: 10/14/2011

Time of Test: 15:01:30

Test Number: C4-3-1341

Fluid Code: LO268869

Cycle Number: 5500

**PHASE B**

Apply Pressure:
At .25 Second: 833 kPa

**Torque**
Static Peak: 177 Nm
.25 Second: 163 Nm

**Coefficient of Friction**
Static Peak: 0.123
.25 Second: 0.113

# APPENDIX – D1 (Part 2)
# TYPE C-4 PAPER CLUTCH FRICTION TEST
# LO-268869

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

**Allison Heavy-Duty Transmission Fluid**
**TYPE C-4 PAPER CLUTCH FRICTION TEST**

Conducted for

**ARMY LAB**

**Oil Code:**
**LO268869**

**Test Number:**
**C2-3-1573**

**October 15, 2011**

Submitted by:

Matthew Jackson
Manager
Specialty & Driveline Fluid Evaluations

The results of this report relate only to the fluid tested.
This report shall not be reproduced, except in full, without the written approval of Southwest Research Institute®.

# IX. Paper Clutch Friction Test

| | | | |
|---|---|---|---|
| Test Laboratory: | SWRI | Lab Fluid Code: | LO-268869 |
| Test Number: | C2-3-1573 | Sponsor Fluid Code: | LO268869 |
| Friction Plate Batch: | LOT 6 | Completion Date: | 10/15/11 |
| Steel Plate Batch: | 10/9/2008 | | |

Clutch Wear Data
(units in mm)

| | Maximum | Average |
|---|---|---|
| Steel Plates | 0.0000 | 0.0000 |
| Clutch Plate | 0.0970 | 0.0903 |

| | Before | After |
|---|---|---|
| Pack Clearance | 0.9144 | 1.1684 |

Reference Tests

| Test Number | Test Date | Test Fluid |
|---|---|---|
| C2-0-1557 | 08/12/10 | RDL-2746 08-05 |
| C2-0-1568 | 12/10/10 | RDL-2746 08-05 |
| C2-0-1570 | 01/13/11 | RDL-2746 08-05 |

| | New | EOT |
|---|---|---|
| Viscosity at 40°C, cSt | 47.67 | 41.55 |
| Viscosity at 100°C, cSt | 8.78 | 7.86 |
| Iron Content, ppm | 2 | 139 |

| D5185 | New Fluid (ppm) |
|---|---|
| Ba | <1 |
| B | <1 |
| Ca | 3439 |
| Mg | 10 |
| P | 1279 |
| Si | 2 |
| Na | 5 |
| Zn | 1879 |

Name: Matthew Jackson

Signature:

Title: Manager

Date: 10/24/11

# ALLISON C- 4 PAPER FRICTION TEST

(Torque in N*m)

| | | | |
|---|---|---|---|
| Sponsor Fluid Code: | **LO268869** | Test Number: | **C2-3-1573** |
| Lab Fluid Code: | **LO-268869** | Fric. Plate Batch: | **LOT 6** |
| Completion Date: | **10/15/2011** | Steel Plate Batch: | **10/9/2008** |

## TORQUE

| CYCLE | SLIP TIME | TORQUE (MIDPOINT) | TORQUE STATIC PEAK | STATIC PEAK - MIDPOINT | LOW SPEED STATIC PEAK | LOWSPEED STATIC TORQUE |
|---|---|---|---|---|---|---|
| 100 | 0.53 | 190 | 212 | 22 | 210 | 196 |
| 500 | 0.52 | 198 | 201 | 3 | 195 | 189 |
| 1000 | 0.49 | 209 | 258 | 49 | 271 | 260 |
| 2500 | 0.46 | 223 | 286 | 63 | 306 | 280 |
| 5000 | 0.45 | 231 | 255 | 24 | 272 | 249 |
| 7500 | 0.46 | 227 | 235 | 8 | 251 | 229 |
| 10000 | 0.46 | 227 | 228 | 1 | 236 | 227 |

## COEFFICIENT OF FRICTION

| CYCLE | SLIP TIME | TORQUE (MIDPOINT) | TORQUE STATIC PEAK | STATIC PEAK - MIDPOINT | LOW SPEED STATIC PEAK | LOWSPEED STATIC TORQUE |
|---|---|---|---|---|---|---|
| 100 | 0.53 | 0.093 | 0.103 | 0.010 | 0.102 | 0.095 |
| 500 | 0.52 | 0.096 | 0.098 | 0.002 | 0.095 | 0.092 |
| 1000 | 0.49 | 0.102 | 0.126 | 0.024 | 0.132 | 0.127 |
| 2500 | 0.46 | 0.109 | 0.139 | 0.030 | 0.149 | 0.136 |
| 5000 | 0.45 | 0.112 | 0.124 | 0.012 | 0.132 | 0.121 |
| 7500 | 0.46 | 0.111 | 0.114 | 0.003 | 0.122 | 0.112 |
| 10000 | 0.46 | 0.111 | 0.111 | 0.000 | 0.115 | 0.111 |

| | Limits | | Results | | | |
|---|---|---|---|---|---|---|
| | Value | % Change | 100 N | 10,000 N | % Change | P/F |
| Slip Time Max. | 0.600 | N/A | 0.530 | 0.460 | -13.21 | **P** |
| Mid-Point Fric. Coeff. Min. | 0.096 | N/A | 0.093 | 0.111 | 19.35 | **F** |
| Static Friction Coeff. | N/A | N/A | 0.103 | 0.111 | 7.77 | |
| Low Speed Peak Fric. Coeff. | N/A | N/A | 0.102 | 0.115 | 12.75 | |
| 0.25 Second Low Speed Coeff. | N/A | N/A | 0.095 | 0.111 | 16.84 | |

SOUTHWEST RESEARCH INSTITUTE®

# ALLISON C4-PAPER FRICTION TEST

**(all units in mm)**

**Candidate Fluid: LO268869** | **Test Number : C2-3-1573** | **Completion Date : 10/15/2011**

**Lab Fluid Code : LO-268869** | **Steel Plate Batch: 10/09/2008** | **Fric Plate Batch : LOT 6**

| Plates | Location of Tooth (Clockwise) | Near Inner Diameter Before | Near Inner Diameter After | Near Outer Diameter Before | Near Outer Diameter After | Inner Diameter Change | Average Overall Change | Outer Diameter Change |
|---|---|---|---|---|---|---|---|---|
| FRICTION MATERIAL | | | | | | | | |
| 2 | Top | 2.0740 | 1.9810 | 2.0660 | 1.9690 | 0.0930 | | 0.0970 |
| | 120 | 2.0760 | 1.9850 | 2.0690 | 1.9810 | 0.0910 | | 0.0880 |
| | 240 | 2.0760 | 1.9820 | 2.0730 | 1.9820 | 0.0940 | | 0.0910 |
| | Average | | | | | 0.0927 | 0.0923 | 0.0920 |
| 5 | Top | 2.0780 | 1.9920 | 2.0760 | 1.9930 | 0.0860 | | 0.0830 |
| | 120 | 2.0700 | 1.9770 | 2.0620 | 1.9730 | 0.0930 | | 0.0890 |
| | 240 | 2.0800 | 1.9910 | 2.0780 | 1.9890 | 0.0890 | | 0.0890 |
| | Average | | | | | 0.0893 | 0.0882 | 0.0870 |
| STEELS SEPARATORS | | | | | | | | |
| 1 | Top | 1.7500 | 1.7500 | 1.7500 | 1.7500 | 0.0000 | | 0.0000 |
| | 120 | 1.7500 | 1.7500 | 1.7500 | 1.7500 | 0.0000 | | 0.0000 |
| | 240 | 1.7500 | 1.7500 | 1.7500 | 1.7500 | 0.0000 | | 0.0000 |
| | Average | | | | | 0.0000 | 0.0000 | 0.0000 |
| 3 | Top | 1.7580 | 1.7580 | 1.7590 | 1.7590 | 0.0000 | | 0.0000 |
| | 120 | 1.7560 | 1.7560 | 1.7560 | 1.7560 | 0.0000 | | 0.0000 |
| | 240 | 1.7590 | 1.7590 | 1.7590 | 1.7590 | 0.0000 | | 0.0000 |
| | Average | | | | | 0.0000 | 0.0000 | 0.0000 |
| 4 | Top | 1.7580 | 1.7580 | 1.7570 | 1.7570 | 0.0000 | | 0.0000 |
| | 120 | 1.7540 | 1.7540 | 1.7540 | 1.7540 | 0.0000 | | 0.0000 |
| | 240 | 1.7570 | 1.7570 | 1.7580 | 1.7580 | 0.0000 | | 0.0000 |
| | Average | | | | | 0.0000 | 0.0000 | 0.0000 |
| 6 | Top | 1.7560 | 1.7560 | 1.7560 | 1.7560 | 0.0000 | | 0.0000 |
| | 120 | 1.7570 | 1.7570 | 1.7570 | 1.7570 | 0.0000 | | 0.0000 |
| | 240 | 1.7590 | 1.7590 | 1.7590 | 1.7590 | 0.0000 | | 0.0000 |
| | Average | | | | | 0.0000 | 0.0000 | 0.0000 |

**PLATE CONDITION AT E.O.T.:** STEEL PLATES NO UNUSUAL DISCOLORATION
(Anything Unusual) NORMAL WEAR

Test Date and Operator's Name: 9/28/2011 JOE M

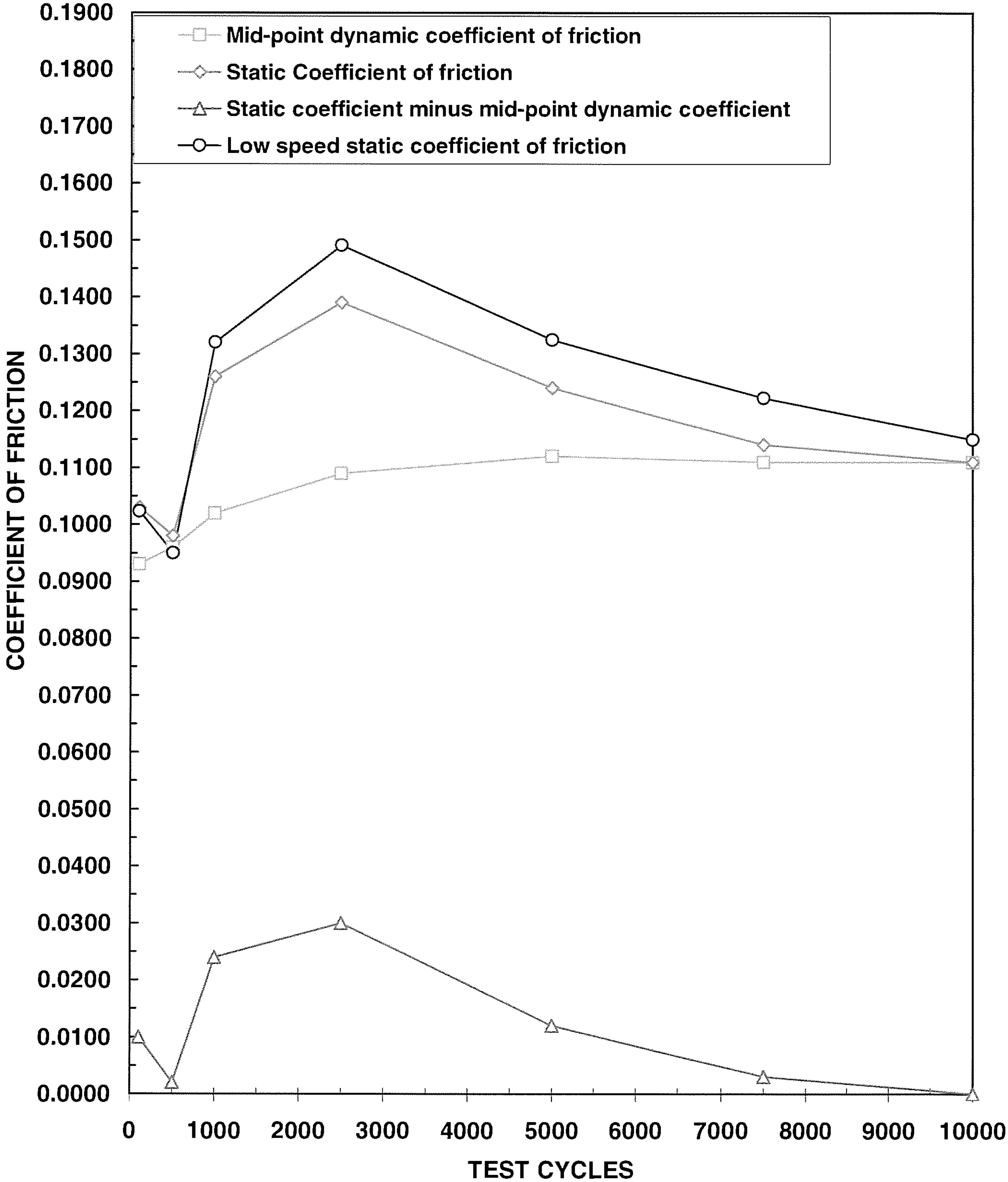
Reviewed By (Signature and Date)

10/24/11

Pack ID#: 4658

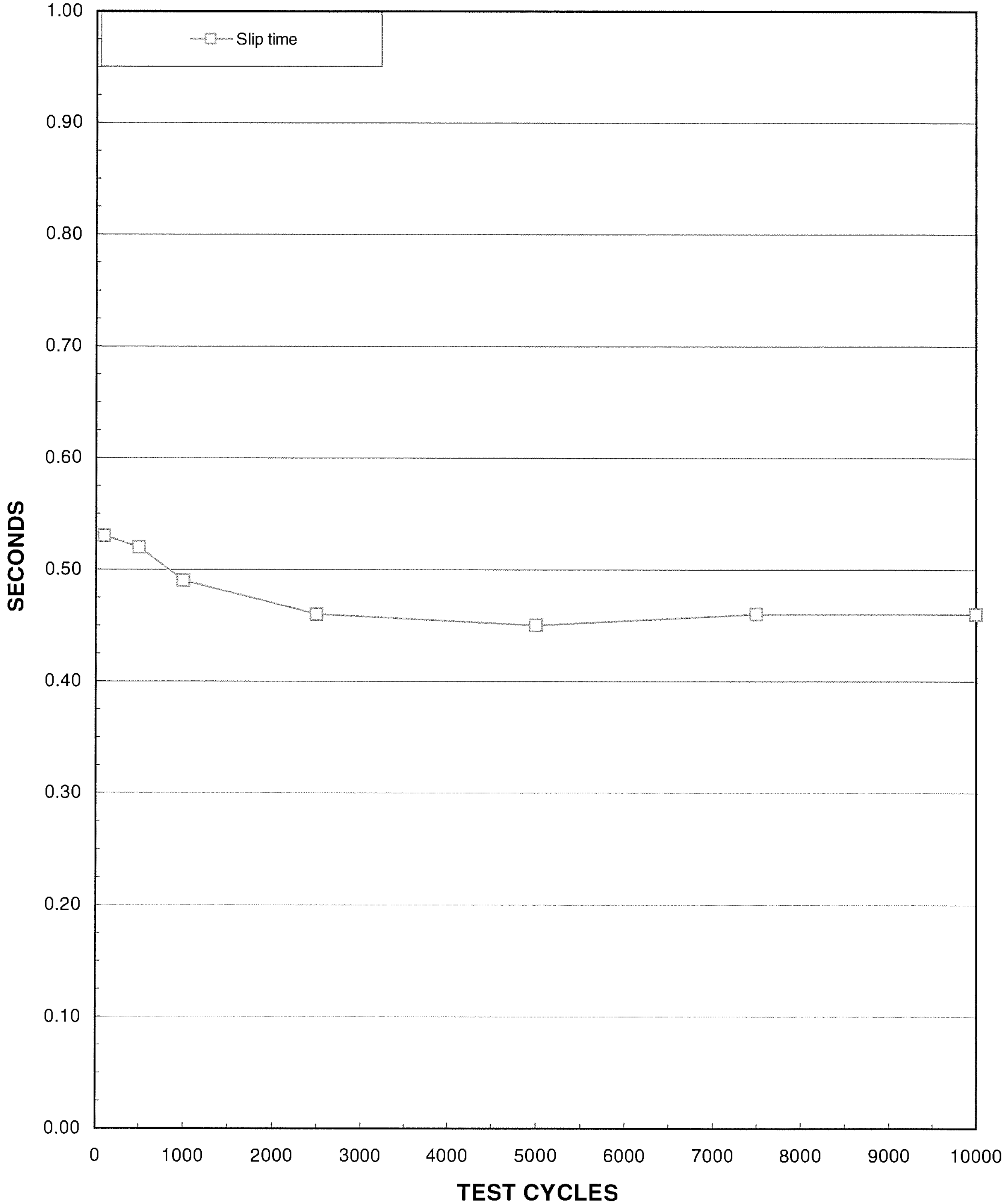
## ALLISON HYDRAULIC TRANSMISSION FLUID
## TYPE C-4 PAPER FRICTION TEST

**Fluid Code: LO268869** **Test Number: C2-3-1573**



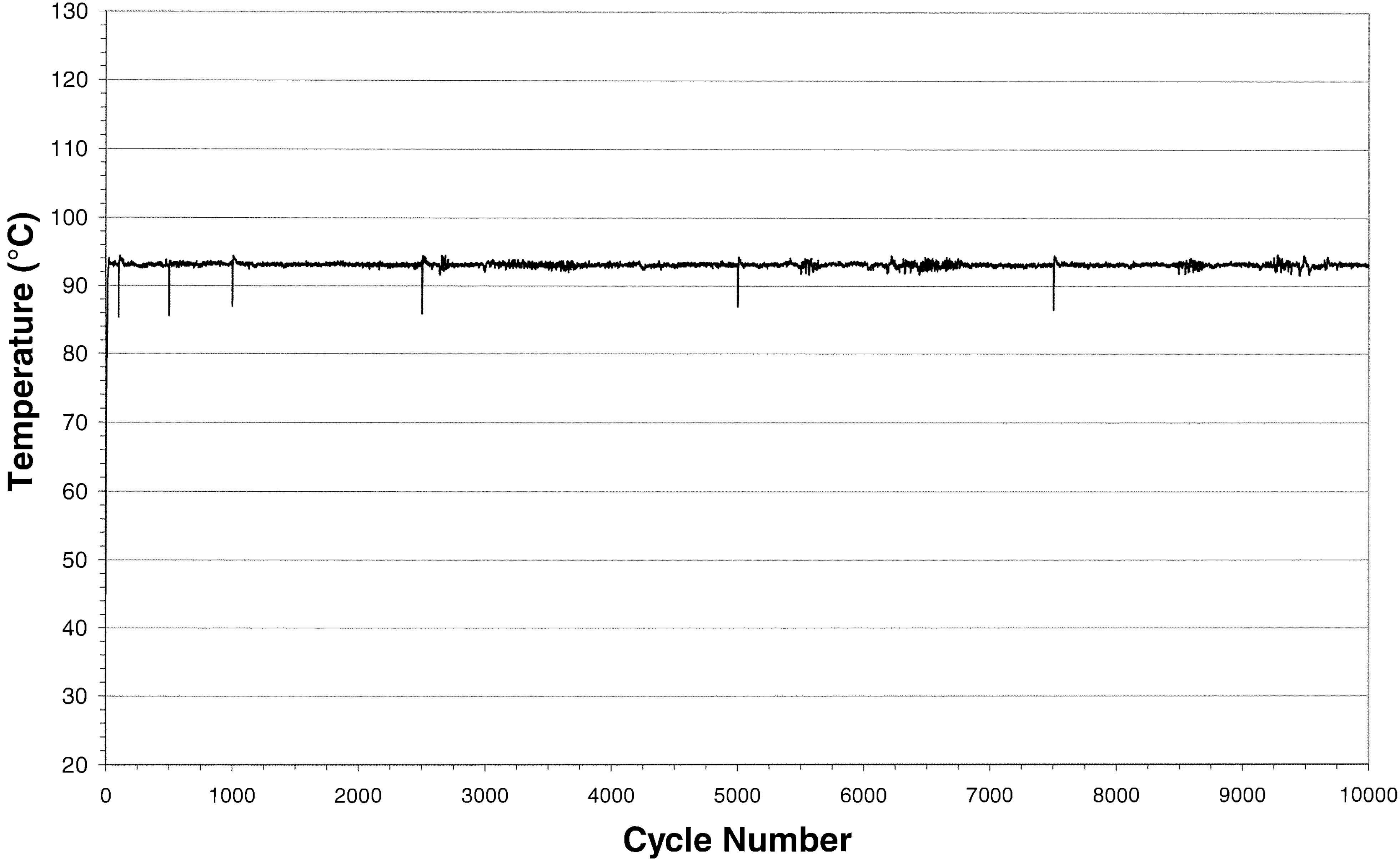
## ALLISON HYDRAULIC TRANSMISSION FLUID
## TYPE C-4 PAPER FRICTION TEST

**Fluid Code: LO268869** **Test Number: C2-3-1573**



# C2-3-1573 LO268869

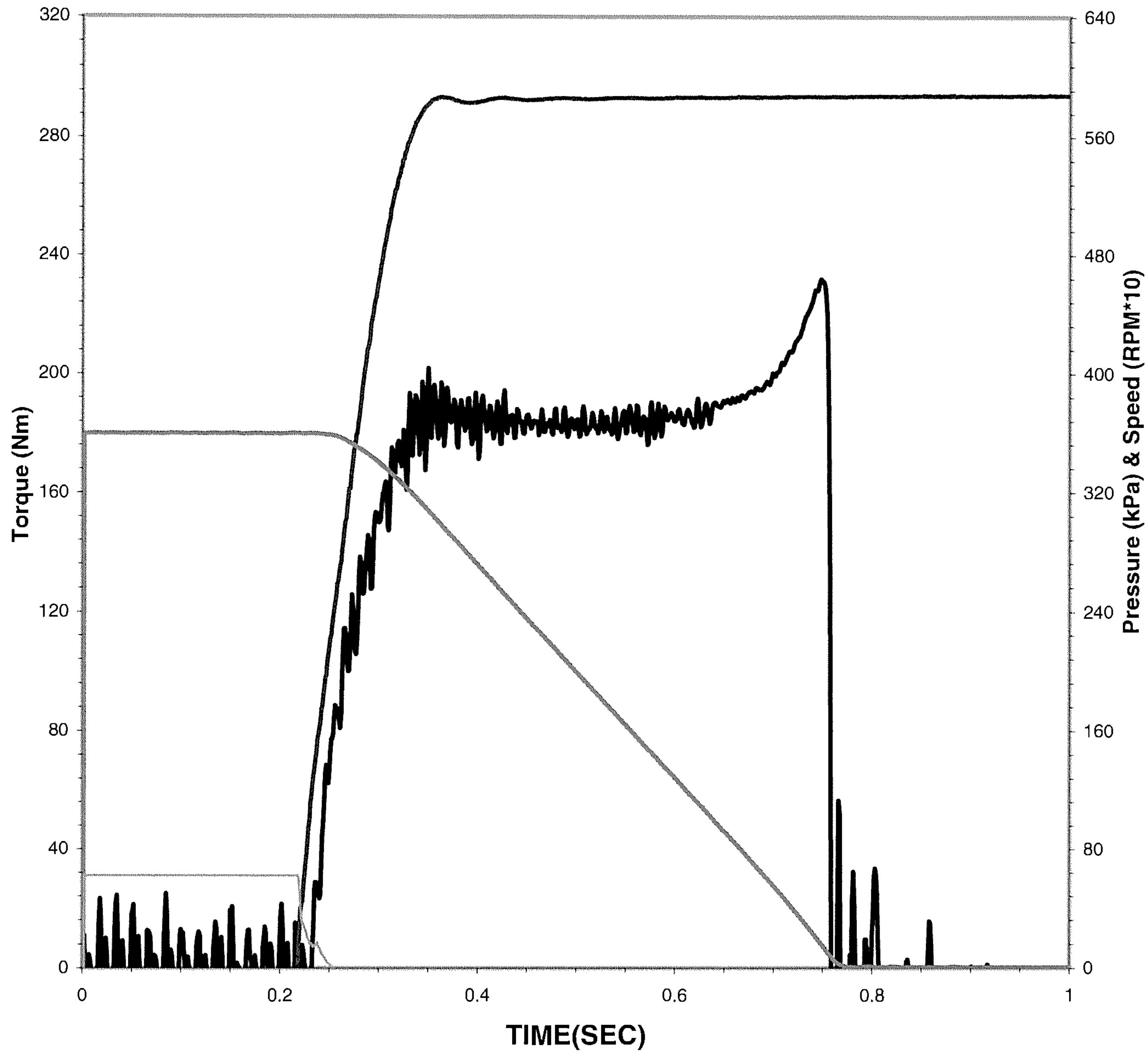
Temp: Max=94.6°C Min=45.0°C Avg=93.1°C



DYNAMIC TRACES

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/13/2011 |
| Time of Test: | 14:55:08 |
| Test Number: | C2-3-1573 |
| Fluid Code: | LO268869 |
| Cycle Number: | 10 |
| Temperature: | 84.5 °C |
| | (93.3 ± 3.0 °C) |
| Apply Pressure: | 588 kPa |
| | (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec |
| | (0.15 ± 0.02 Sec) |
| Energy: | 18.3 KJ |
| | (18.7 ± 0.40 KJ) |
| Engage Time: | 0.54 Sec |

**Torque**

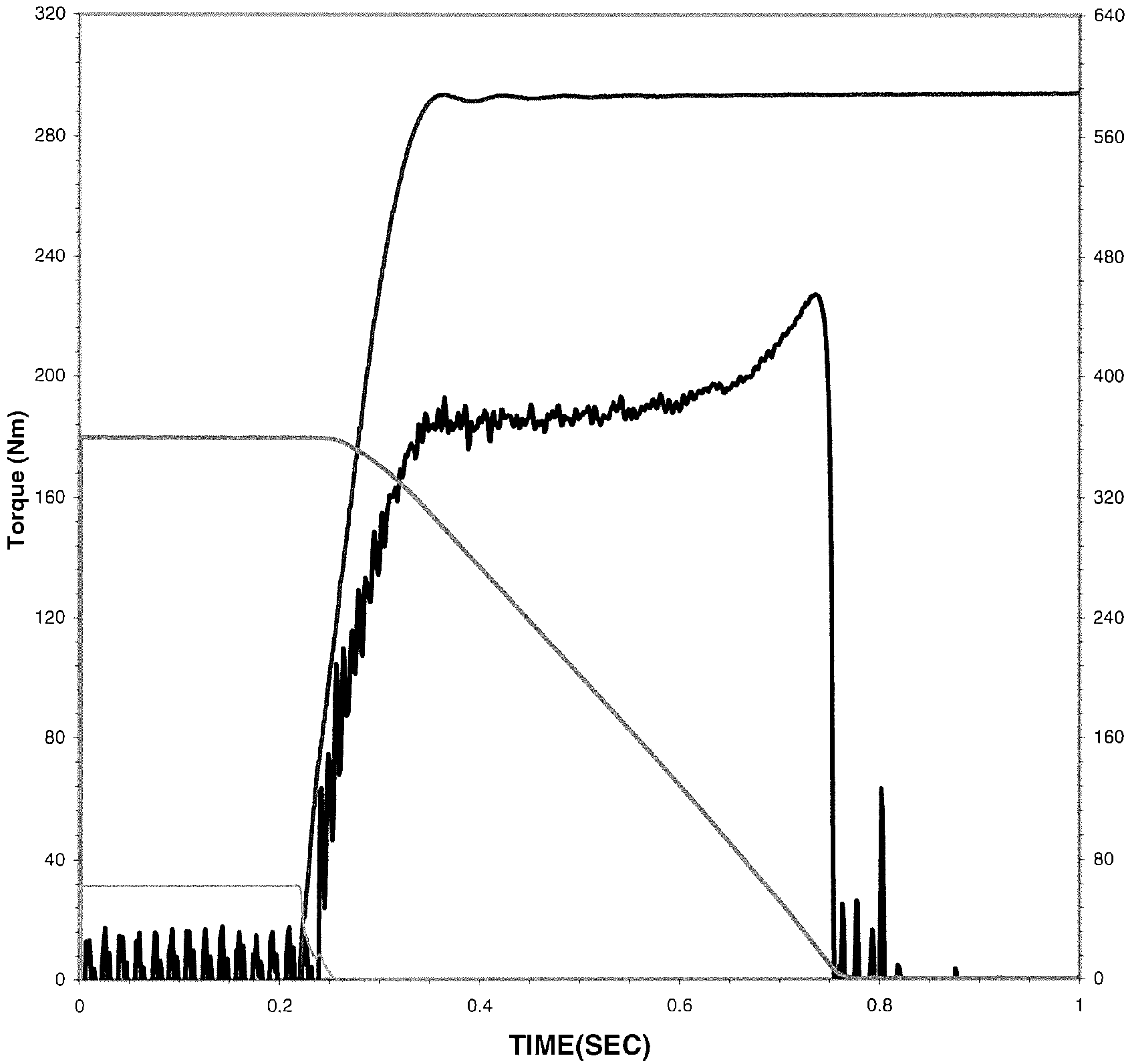
| | |
|---|---|
| 0.2 Sec Dyn: | 189 N*m |
| Midpoint Dyn: | 187 N*m |
| LwSpd Dynamic: | 223 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.092 |
| Midpoint Dyn: | 0.091 |
| LwSpd Dynamic: | 0.109 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/13/2011 |
| Time of Test: | 15:17:39 |
| Test Number: | C2-3-1573 |
| Fluid Code: | LO268869 |
| Cycle Number: | 99 |
| Temperature: | 93.2 °C<br>(93.3 ± 3.0 °C) |
| Apply Pressure: | 588 kPa<br>(586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ<br>(18.7 ± 0.40 KJ) |
| Engage Time: | 0.534 Sec |

**Torque**

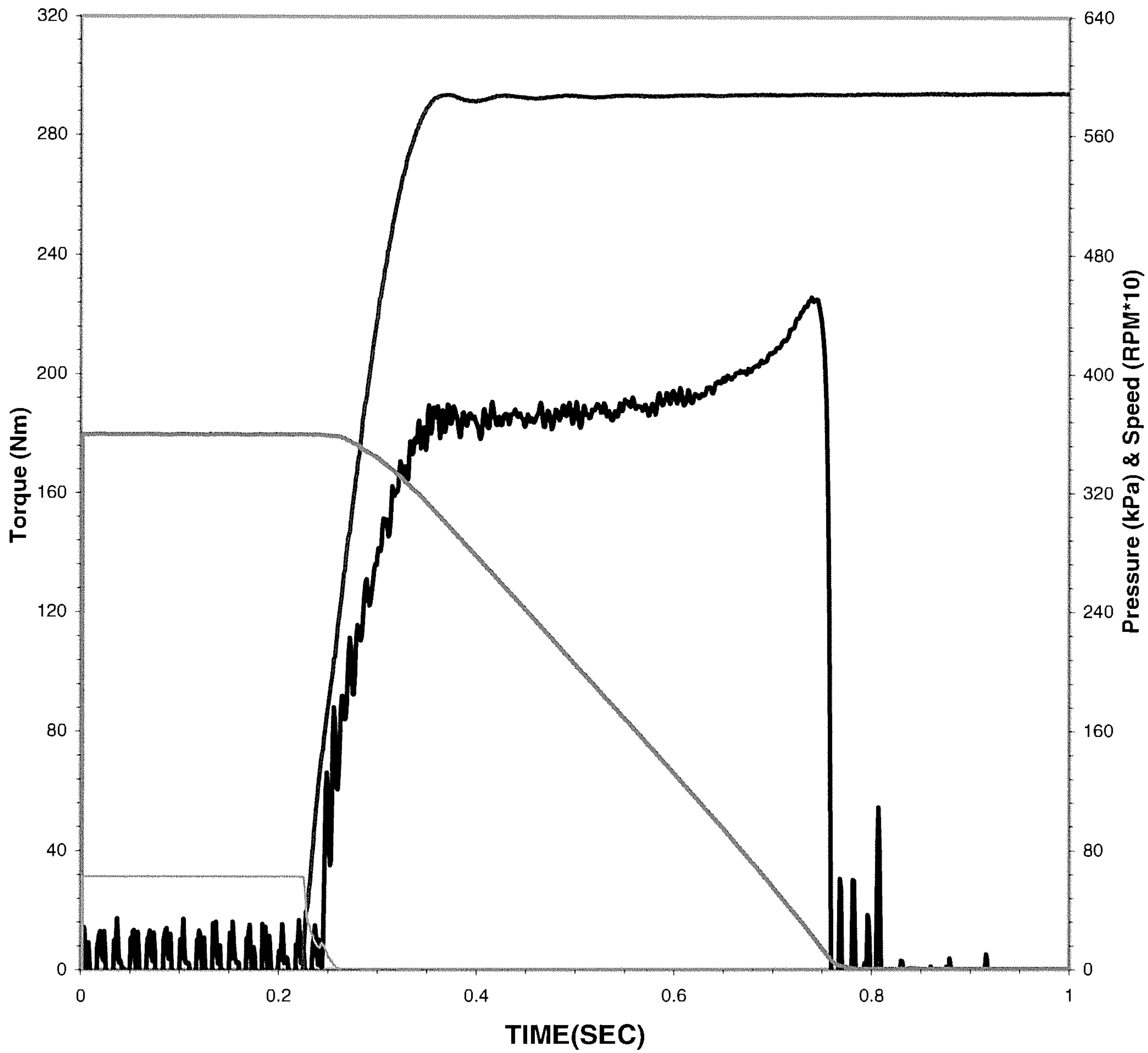
| | |
|---|---|
| 0.2 Sec Dyn: | 190 N*m |
| Midpoint Dyn: | 190 N*m |
| LwSpd Dynamic: | 213 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.092 |
| Midpoint Dyn: | 0.093 |
| LwSpd Dynamic: | 0.103 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




Date of Test: 10/13/2011

Time of Test: 15:17:55

Test Number: C2-3-1573

Fluid Code: LO268869

Cycle Number: 100

Temperature: 93.2 °C
(93.3 ± 3.0 °C)

Apply Pressure: 588 kPa
(586 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.3 KJ
(18.7 ± 0.40 KJ)

Engage Time: 0.533 Sec

**Torque**

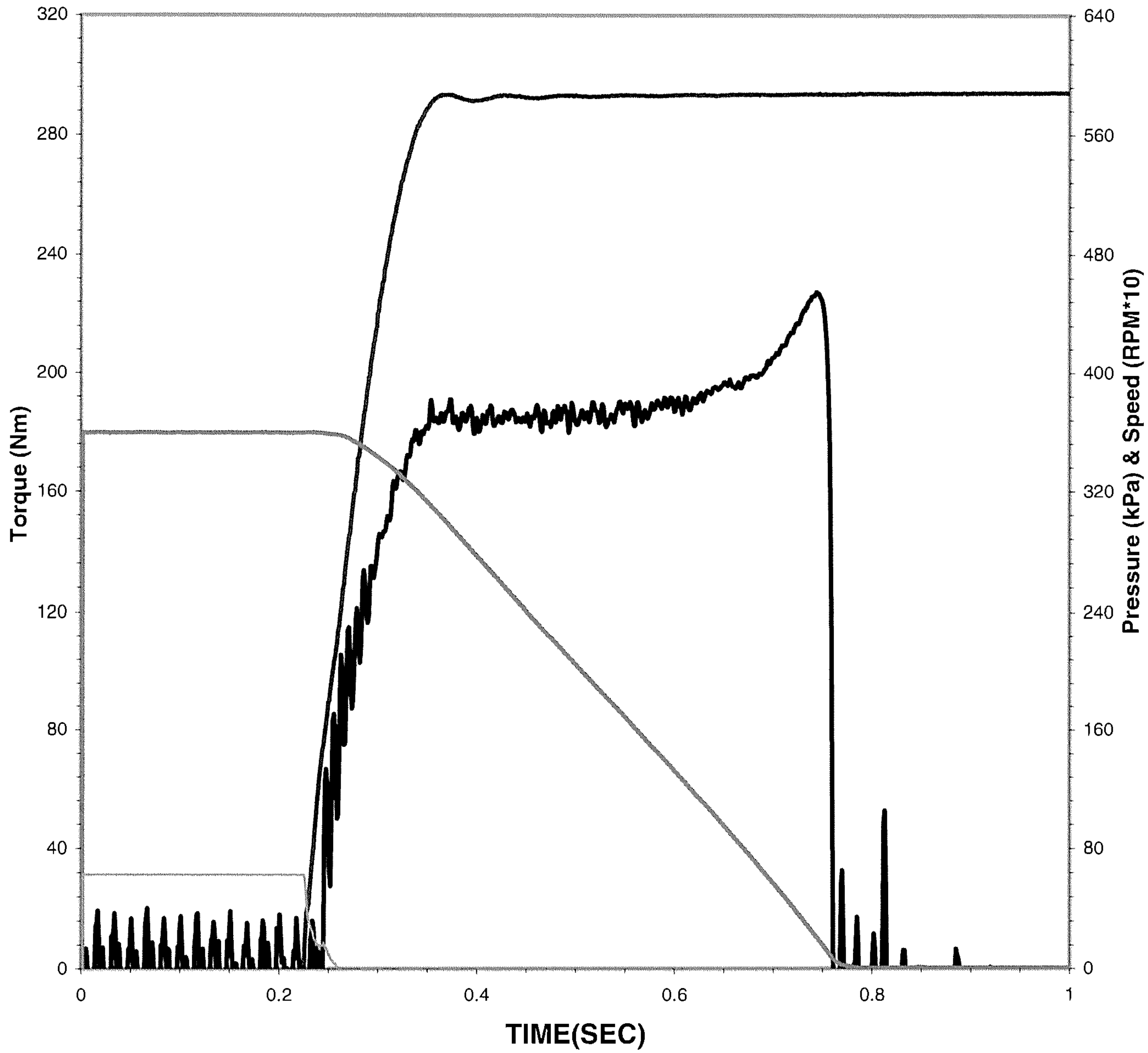
0.2 Sec Dyn: 189 N*m
Midpoint Dyn: 190 N*m
LwSpd Dynamic: 210 N*m

**Coefficient of Friction**

.2 Sec Dyn: 0.092
Midpoint Dyn: 0.093
LwSpd Dynamic: 0.102

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/13/2011 |
| Time of Test: | 15:18:26 |
| Test Number: | C2-3-1573 |
| Fluid Code: | LO268869 |
| Cycle Number: | 101 |
| Temperature: | 85.4 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 588 kPa (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.3 KJ (18.7 ± 0.40 KJ) |
| Engage Time: | 0.535 Sec |

**Torque**

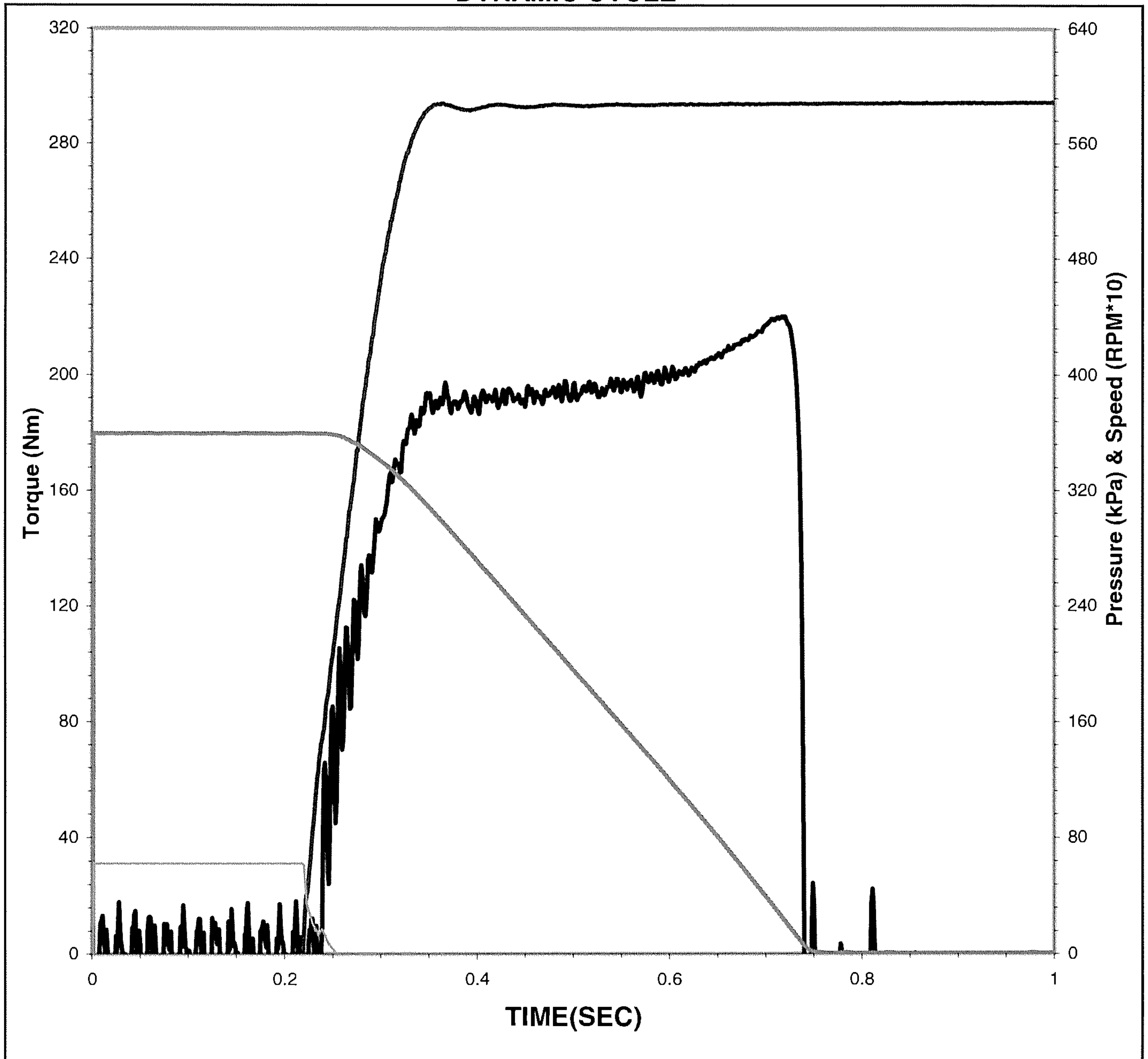
| | |
|---|---|
| 0.2 Sec Dyn: | 189 N*m |
| Midpoint Dyn: | 189 N*m |
| LwSpd Dynamic: | 214 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.092 |
| Midpoint Dyn: | 0.092 |
| LwSpd Dynamic: | 0.104 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/13/2011 |
| Time of Test: | 16:57:56 |
| Test Number: | C2-3-1573 |
| Fluid Code: | LO268869 |
| Cycle Number: | 499 |
| Temperature: | 92.7 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 588 kPa (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ (18.7 ± 0.40 KJ) |
| Engage Time: | 0.52 Sec |

**Torque**

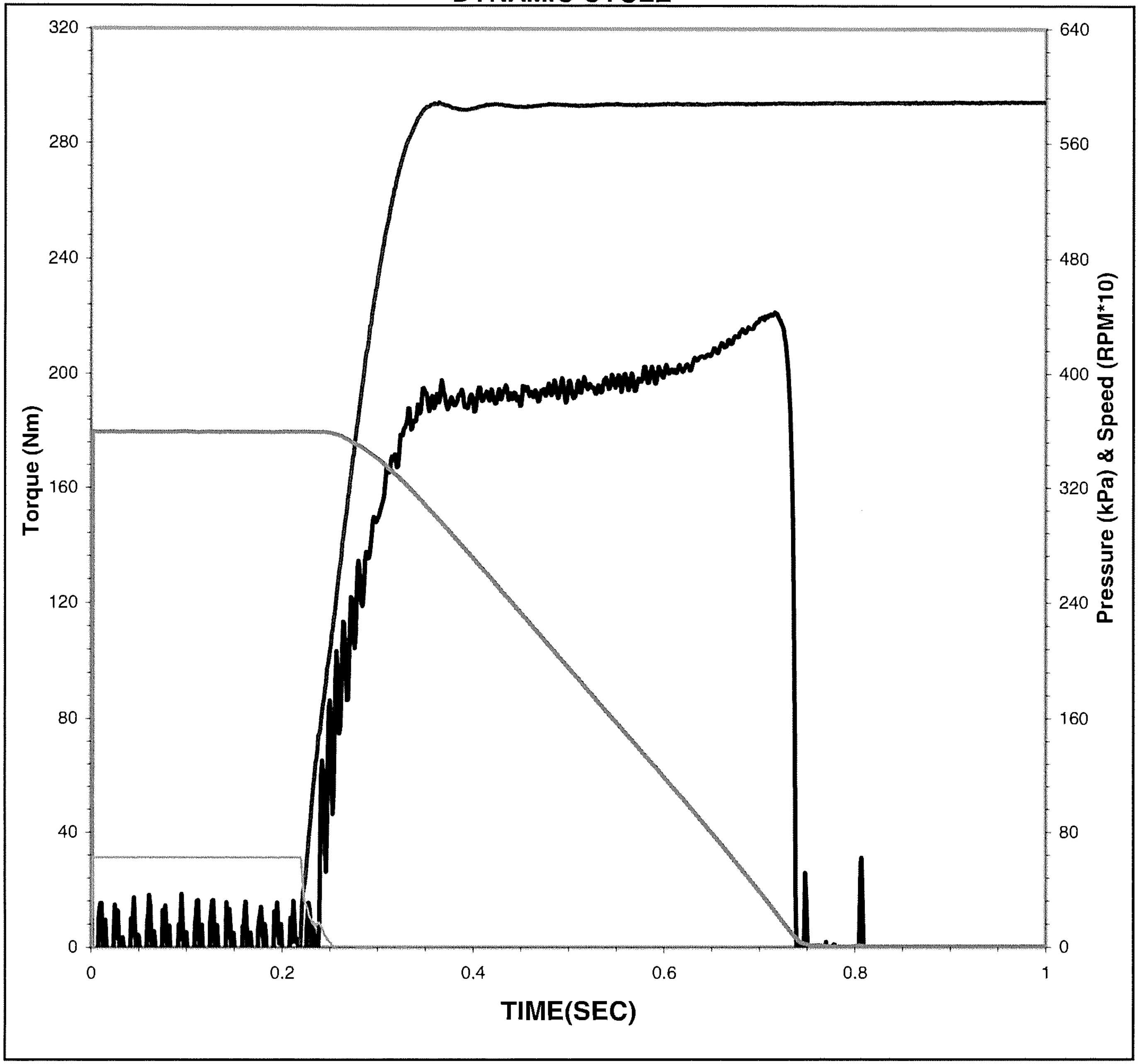
| | |
|---|---|
| 0.2 Sec Dyn: | 196 N*m |
| Midpoint Dyn: | 198 N*m |
| LwSpd Dynamic: | 201 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.096 |
| Midpoint Dyn: | 0.096 |
| LwSpd Dynamic: | 0.098 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/13/2011 |
| Time of Test: | 16:58:11 |
| Test Number: | C2-3-1573 |
| Fluid Code: | LO268869 |
| Cycle Number: | 500 |
| Temperature: | 92.7 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 588 kPa (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ (18.7 ± 0.40 KJ) |
| Engage Time: | 0.519 Sec |

**Torque**

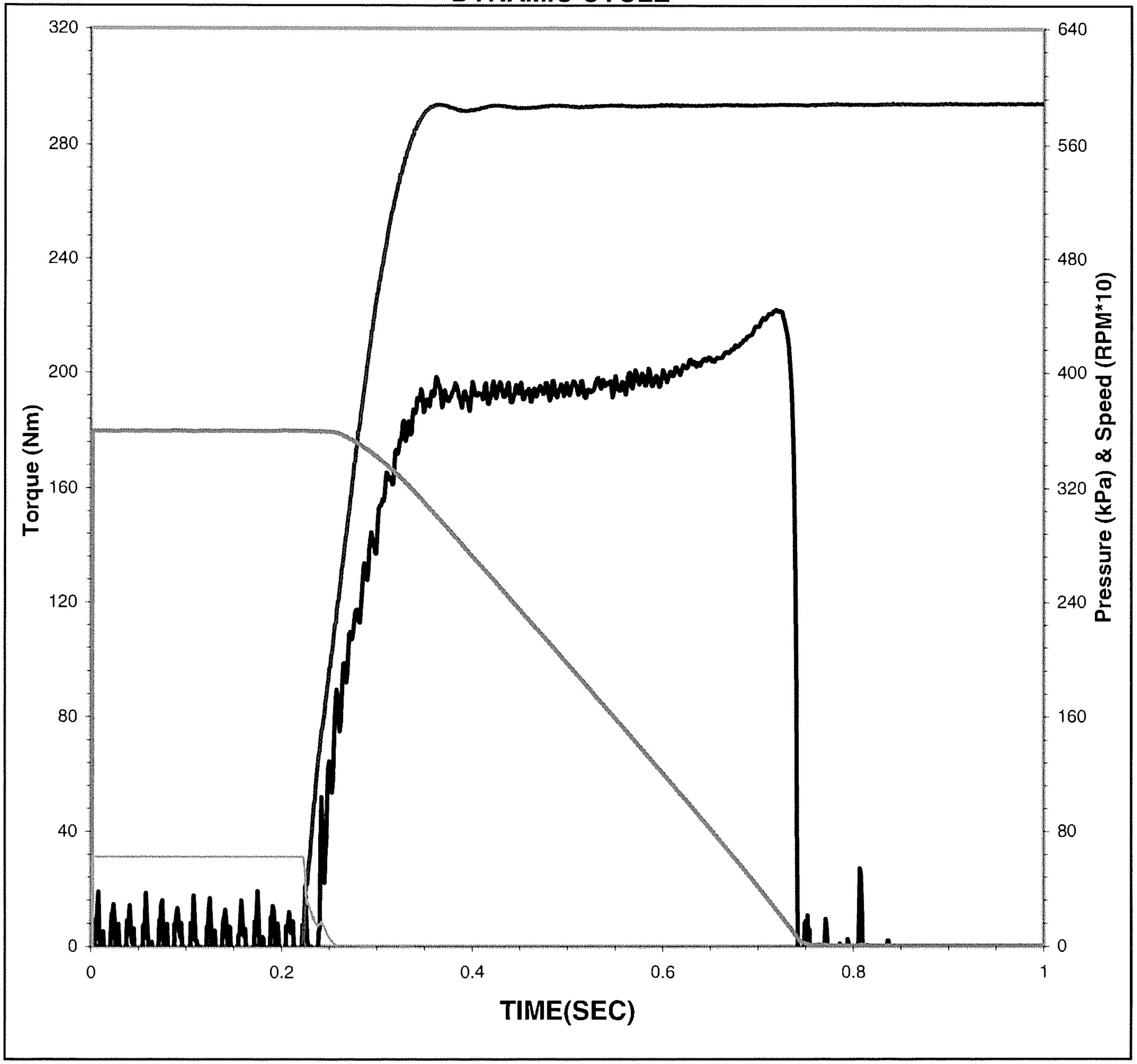
| | |
|---|---|
| 0.2 Sec Dyn: | 197 N*m |
| Midpoint Dyn: | 198 N*m |
| LwSpd Dynamic: | 198 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.096 |
| Midpoint Dyn: | 0.097 |
| LwSpd Dynamic: | 0.096 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/13/2011 |
| Time of Test: | 16:58:42 |
| Test Number: | C2-3-1573 |
| Fluid Code: | LO268869 |
| Cycle Number: | 501 |
| Temperature: | 85.6 °C<br>(93.3 ± 3.0 °C) |
| Apply Pressure: | 588 kPa<br>(586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.3 KJ<br>(18.7 ± 0.40 KJ) |
| Engage Time: | 0.519 Sec |

**Torque**

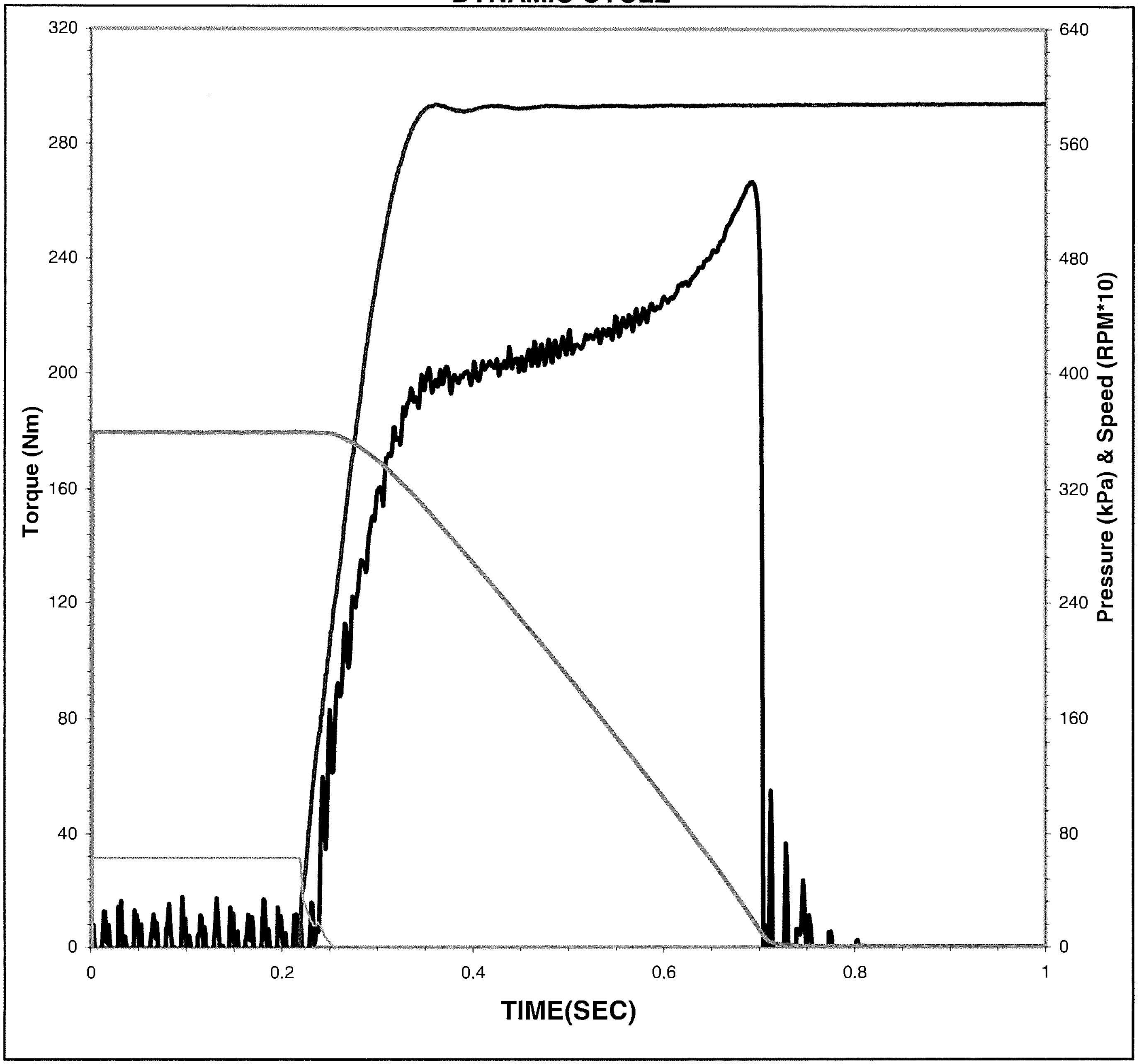
| | |
|---|---|
| 0.2 Sec Dyn: | 198 N*m |
| Midpoint Dyn: | 198 N*m |
| LwSpd Dynamic: | 204 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.096 |
| Midpoint Dyn: | 0.096 |
| LwSpd Dynamic: | 0.099 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/13/2011 |
| Time of Test: | 19:03:12 |
| Test Number: | C2-3-1573 |
| Fluid Code: | LO268869 |
| Cycle Number: | 999 |
| Temperature: | 93.4 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 587 kPa (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ (18.7 ± 0.40 KJ) |
| Engage Time: | 0.486 Sec |

**Torque**

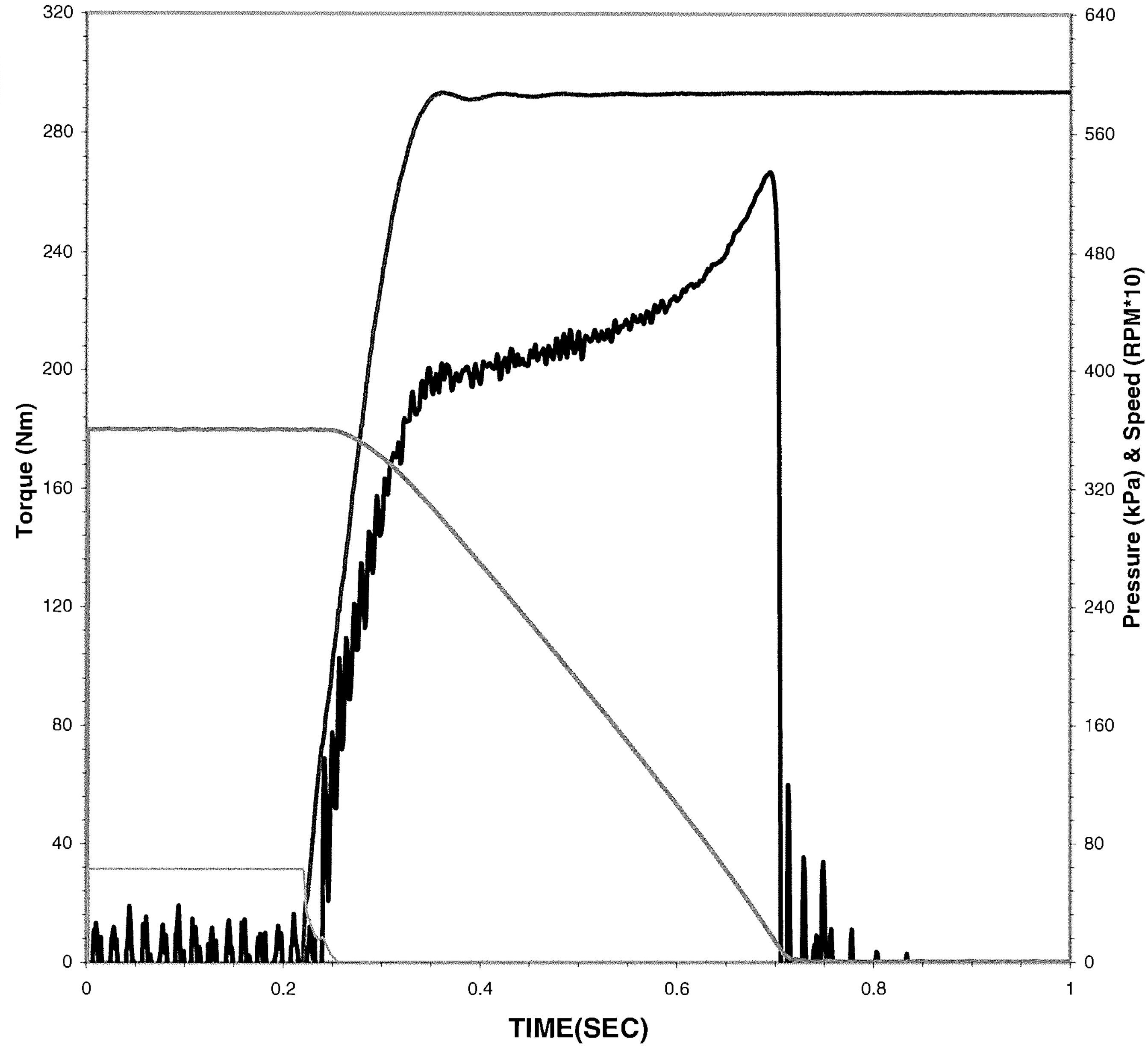
| | |
|---|---|
| 0.2 Sec Dyn: | 207 N*m |
| Midpoint Dyn: | 210 N*m |
| LwSpd Dynamic: | 256 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.101 |
| Midpoint Dyn: | 0.102 |
| LwSpd Dynamic: | 0.124 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/13/2011 |
| Time of Test: | 19:03:27 |
| Test Number: | C2-3-1573 |
| Fluid Code: | LO268869 |
| Cycle Number: | 1000 |
| Temperature: | 93.4 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 587 kPa (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ (18.7 ± 0.40 KJ) |
| Engage Time: | 0.485 Sec |

**Torque**

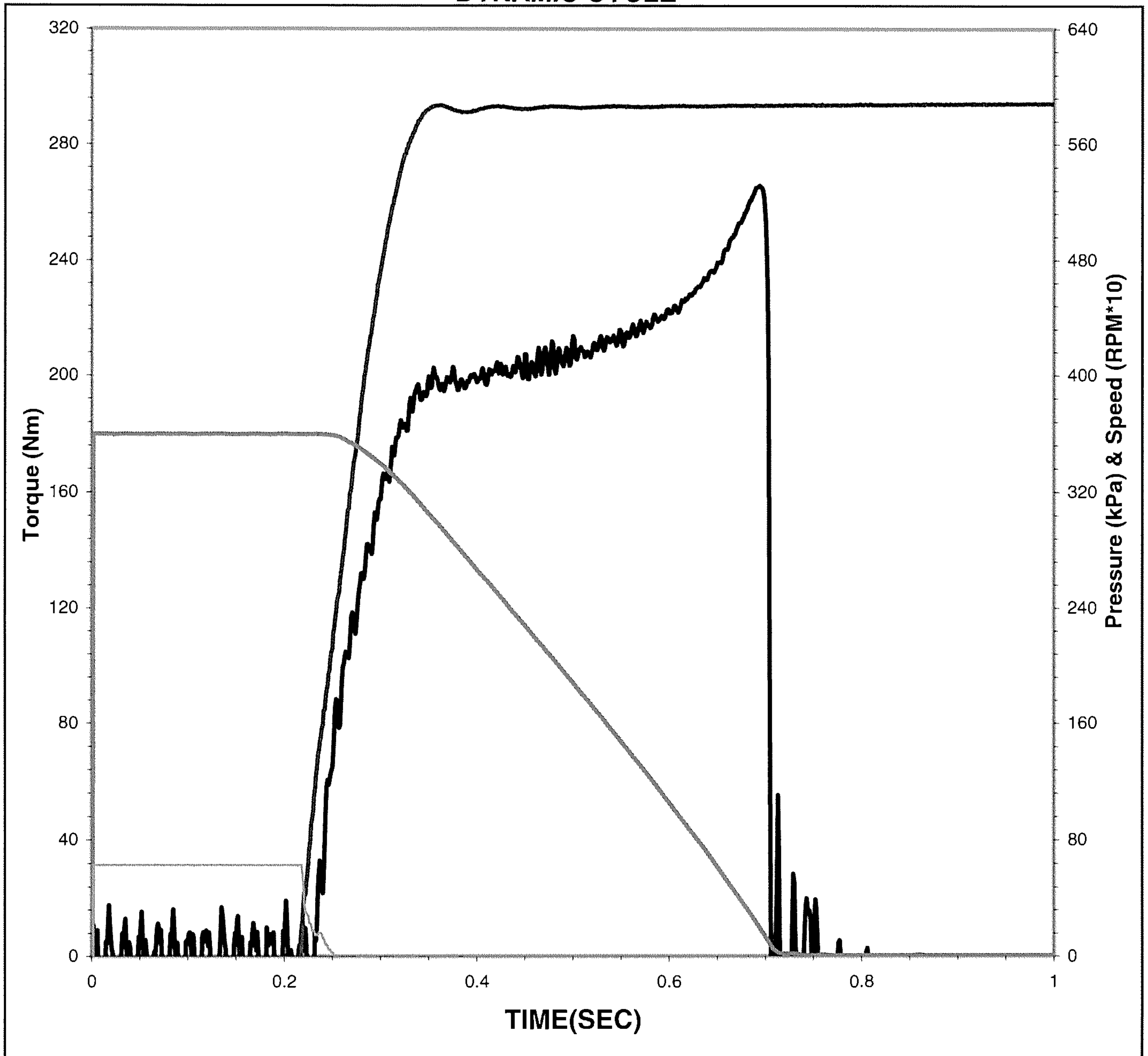
| | |
|---|---|
| 0.2 Sec Dyn: | 206 N*m |
| Midpoint Dyn: | 210 N*m |
| LwSpd Dynamic: | 260 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.100 |
| Midpoint Dyn: | 0.102 |
| LwSpd Dynamic: | 0.126 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/13/2011 |
| Time of Test: | 19:03:58 |
| Test Number: | C2-3-1573 |
| Fluid Code: | LO268869 |
| Cycle Number: | 1001 |
| Temperature: | 87.0 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 587 kPa (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ (18.7 ± 0.40 KJ) |
| Engage Time: | 0.488 Sec |

**Torque**

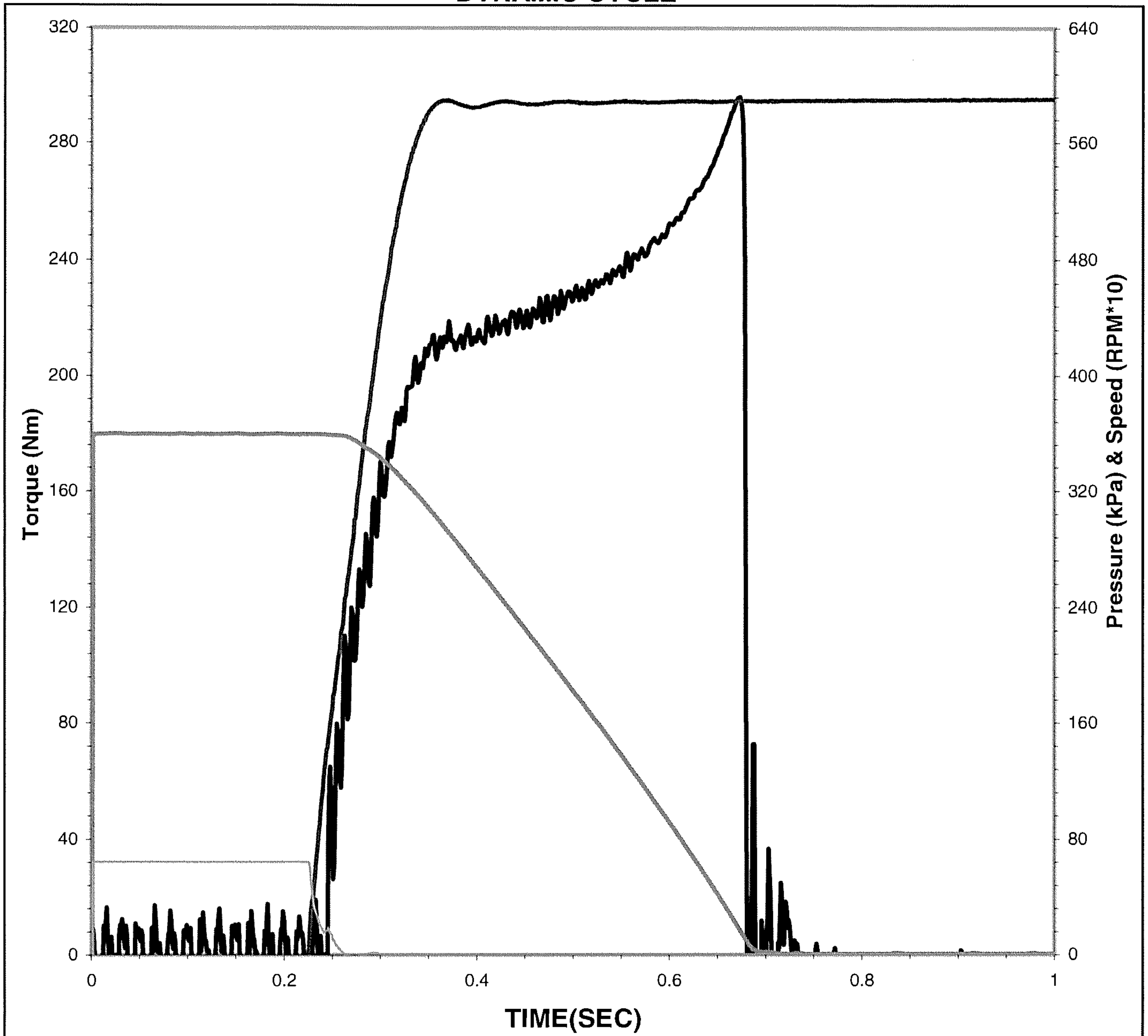
| | |
|---|---|
| 0.2 Sec Dyn: | 206 N*m |
| Midpoint Dyn: | 208 N*m |
| LwSpd Dynamic: | 258 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.100 |
| Midpoint Dyn: | 0.101 |
| LwSpd Dynamic: | 0.126 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 1:18:28 |
| Test Number: | C2-3-1573 |
| Fluid Code: | LO268869 |
| Cycle Number: | 2499 |
| Temperature: | 93.3 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 589 kPa (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.5 KJ (18.7 ± 0.40 KJ) |
| Engage Time: | 0.454 Sec |

**Torque**

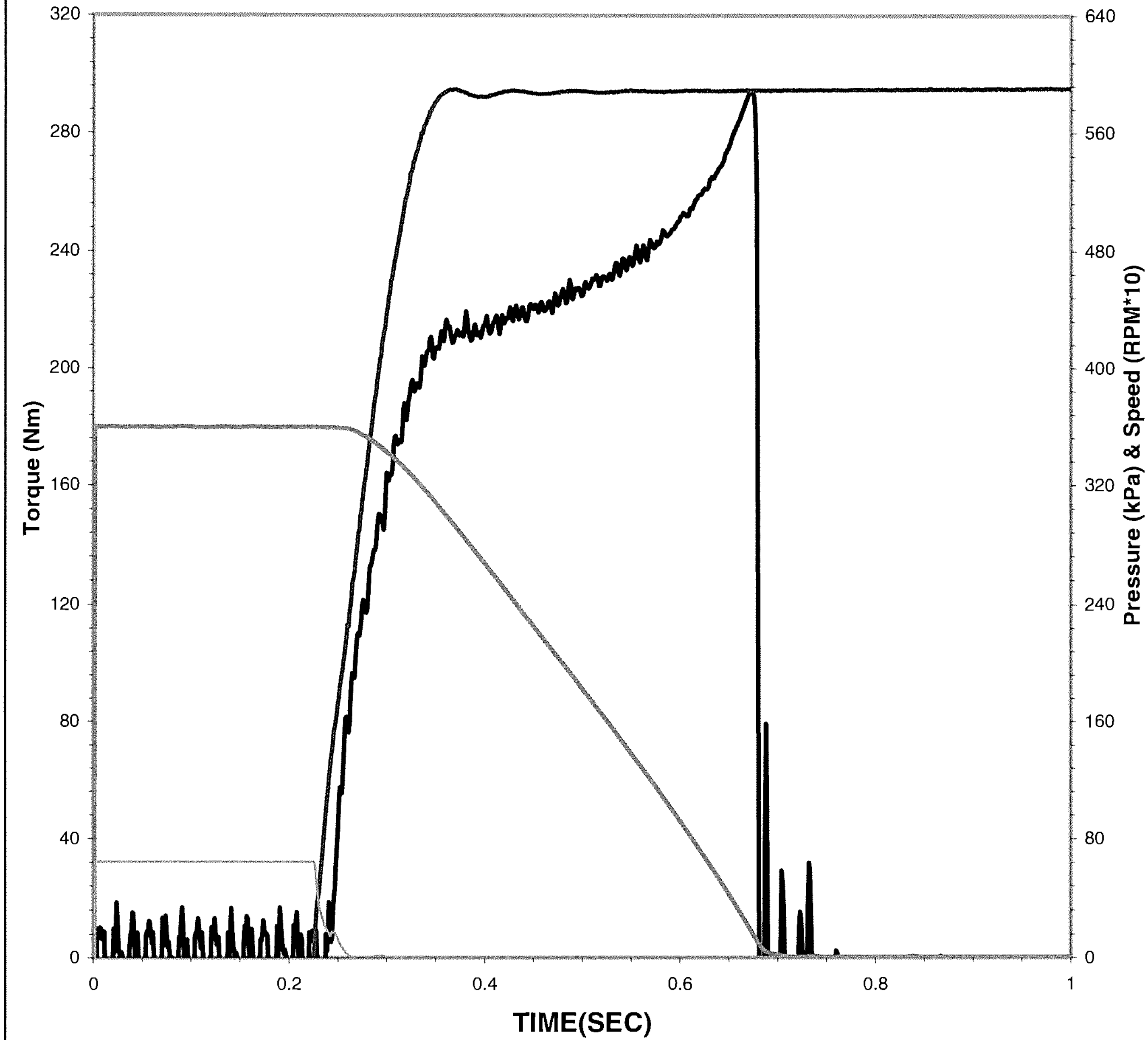
| | |
|---|---|
| 0.2 Sec Dyn: | 221 N*m |
| Midpoint Dyn: | 224 N*m |
| LwSpd Dynamic: | 291 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.108 |
| Midpoint Dyn: | 0.109 |
| LwSpd Dynamic: | 0.141 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 1:18:43 |
| Test Number: | C2-3-1573 |
| Fluid Code: | LO268869 |
| Cycle Number: | 2500 |
| Temperature: | 93.1 °C<br>(93.3 ± 3.0 °C) |
| Apply Pressure: | 589 kPa<br>(586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.5 KJ<br>(18.7 ± 0.40 KJ) |
| Engage Time: | 0.454 Sec |

**Torque**

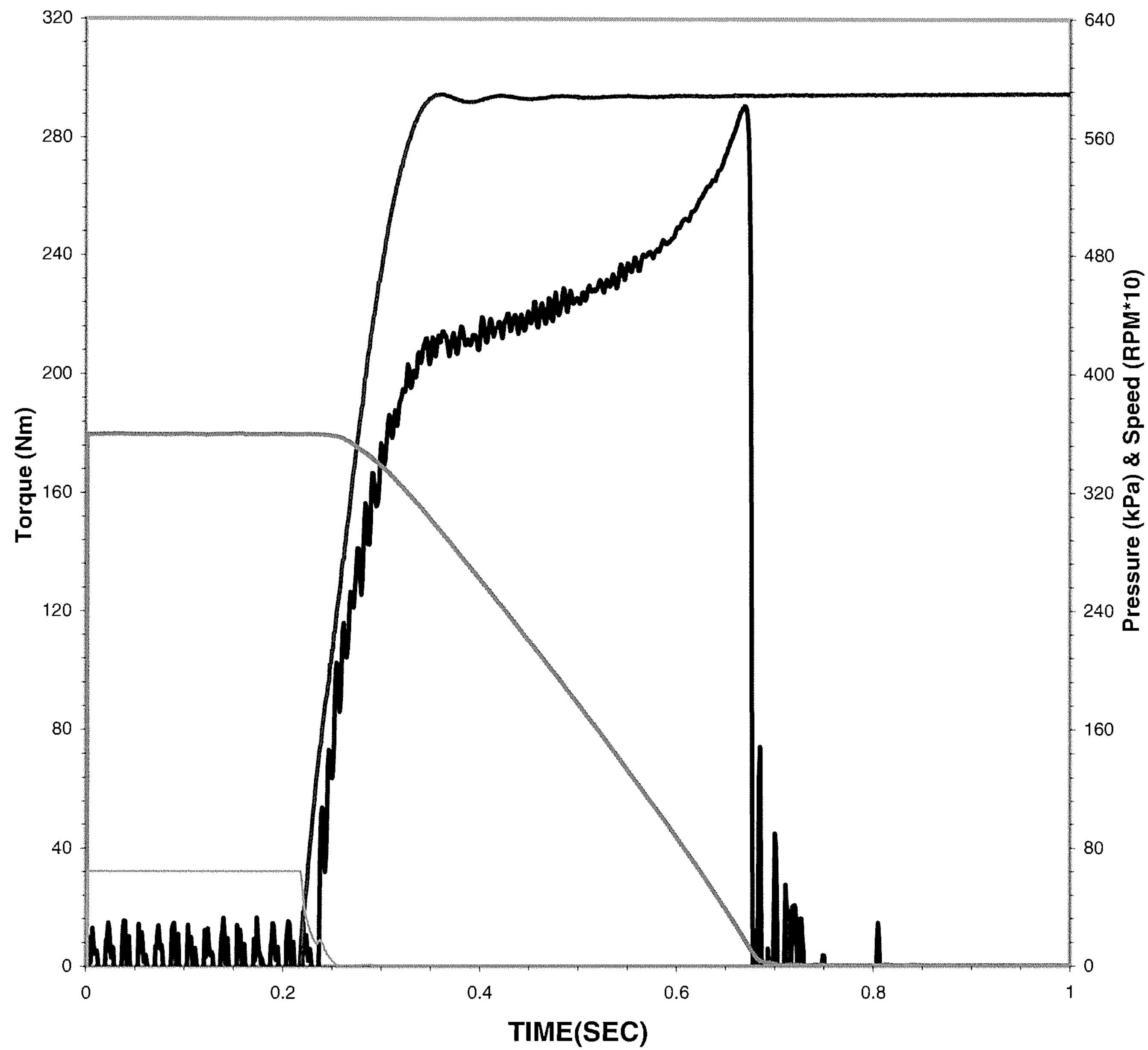
| | |
|---|---|
| 0.2 Sec Dyn: | 222 N*m |
| Midpoint Dyn: | 224 N*m |
| LwSpd Dynamic: | 285 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.108 |
| Midpoint Dyn: | 0.109 |
| LwSpd Dynamic: | 0.139 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 1:19:15 |
| Test Number: | C2-3-1573 |
| Fluid Code: | LO268869 |
| Cycle Number: | 2501 |
| Temperature: | 85.9 °C<br>(93.3 ± 3.0 °C) |
| Apply Pressure: | 589 kPa<br>(586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.5 KJ<br>(18.7 ± 0.40 KJ) |
| Engage Time: | 0.459 Sec |

**Torque**

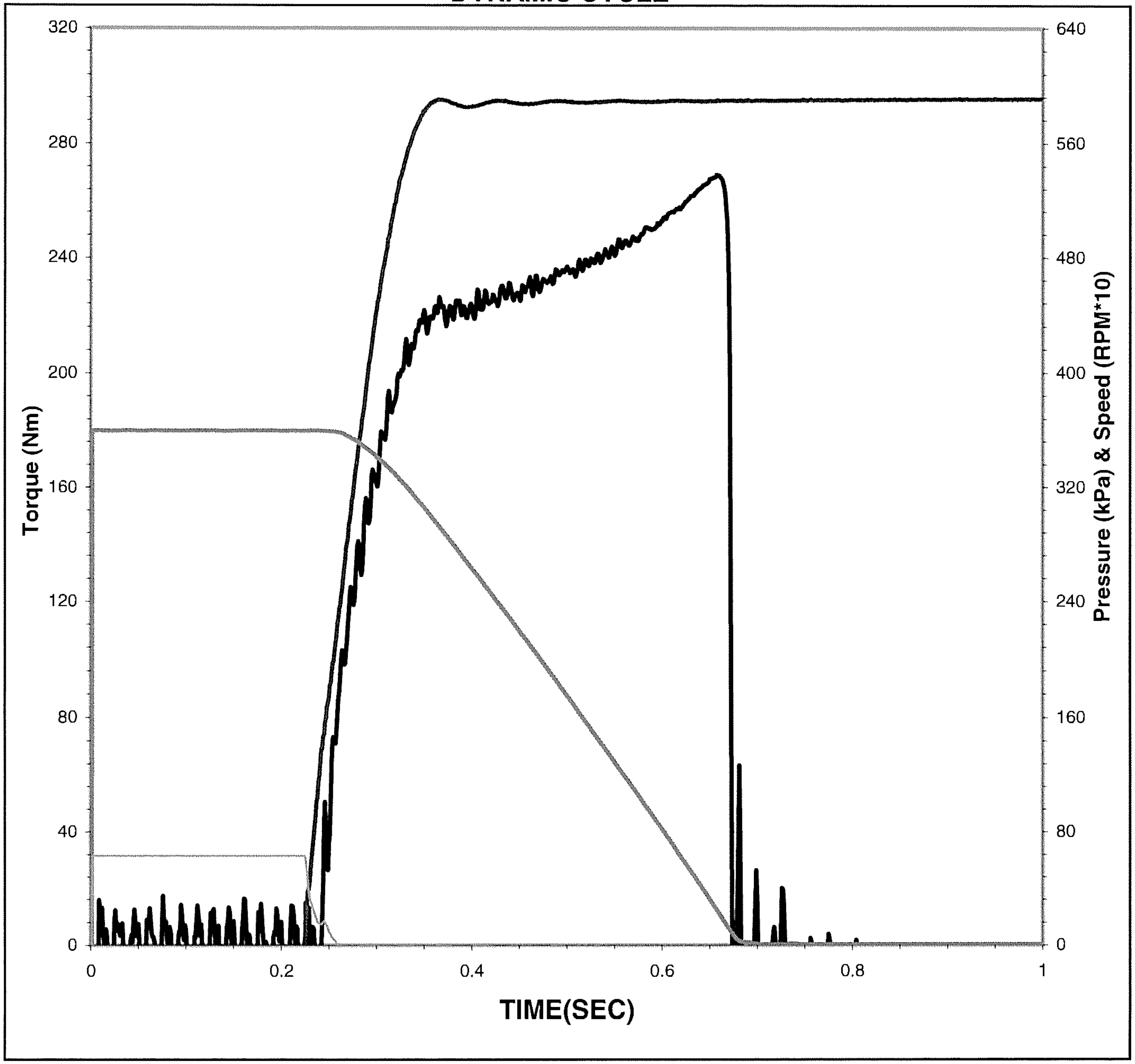
| | |
|---|---|
| 0.2 Sec Dyn: | 219 N*m |
| Midpoint Dyn: | 222 N*m |
| LwSpd Dynamic: | 283 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.107 |
| Midpoint Dyn: | 0.108 |
| LwSpd Dynamic: | 0.138 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 11:42:34 |
| Test Number: | C2-3-1573 |
| Fluid Code: | LO268869 |
| Cycle Number: | 4999 |
| Temperature: | 92.9 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 589 kPa (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.5 KJ (18.7 ± 0.40 KJ) |
| Engage Time: | 0.448 Sec |

**Torque**

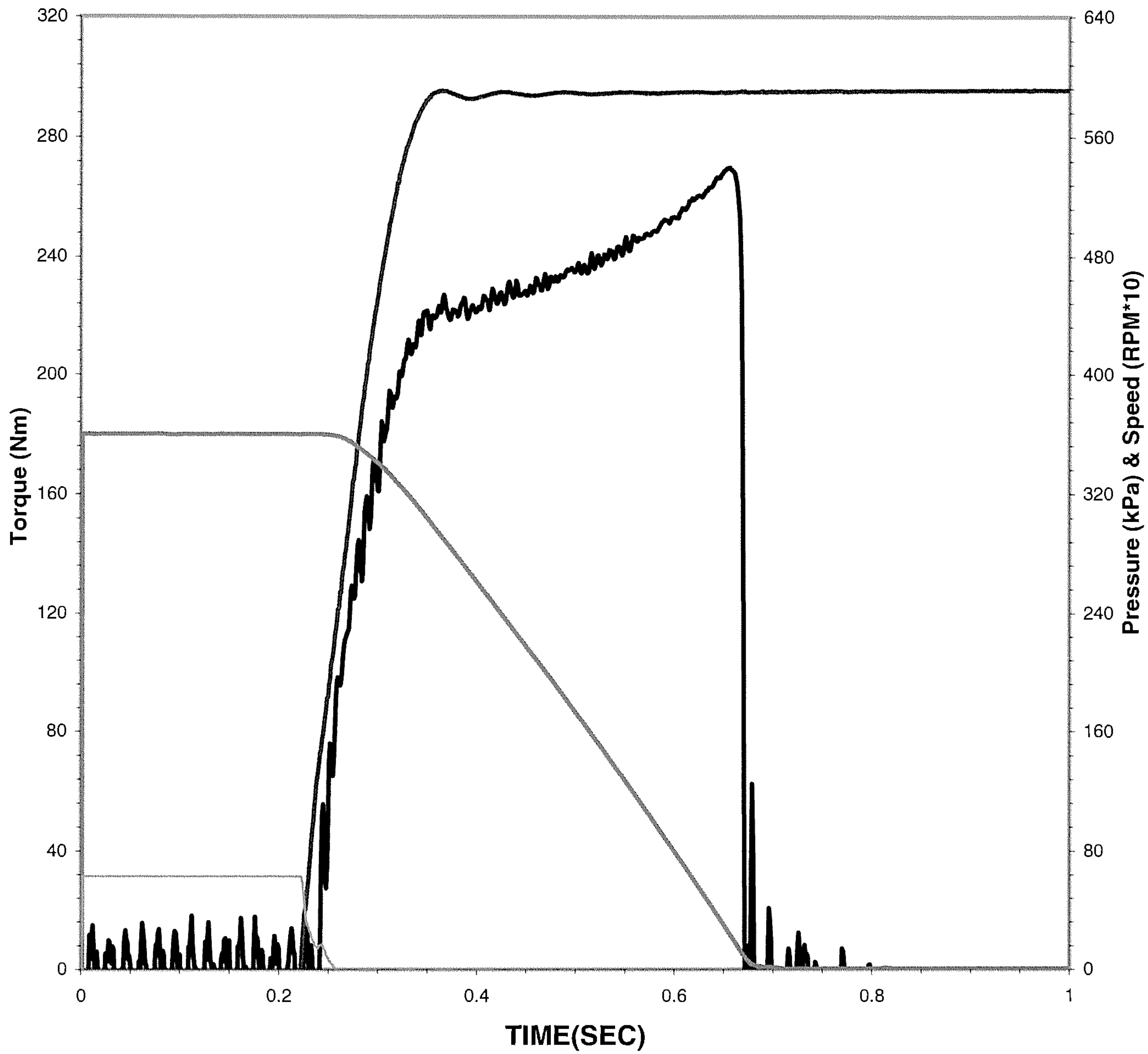
| | |
|---|---|
| 0.2 Sec Dyn: | 230 N*m |
| Midpoint Dyn: | 232 N*m |
| LwSpd Dynamic: | 257 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.112 |
| Midpoint Dyn: | 0.113 |
| LwSpd Dynamic: | 0.125 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 11:42:49 |
| Test Number: | C2-3-1573 |
| Fluid Code: | LO268869 |
| Cycle Number: | 5000 |
| Temperature: | 92.8 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 590 kPa (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.6 KJ (18.7 ± 0.40 KJ) |
| Engage Time: | 0.448 Sec |

**Torque**

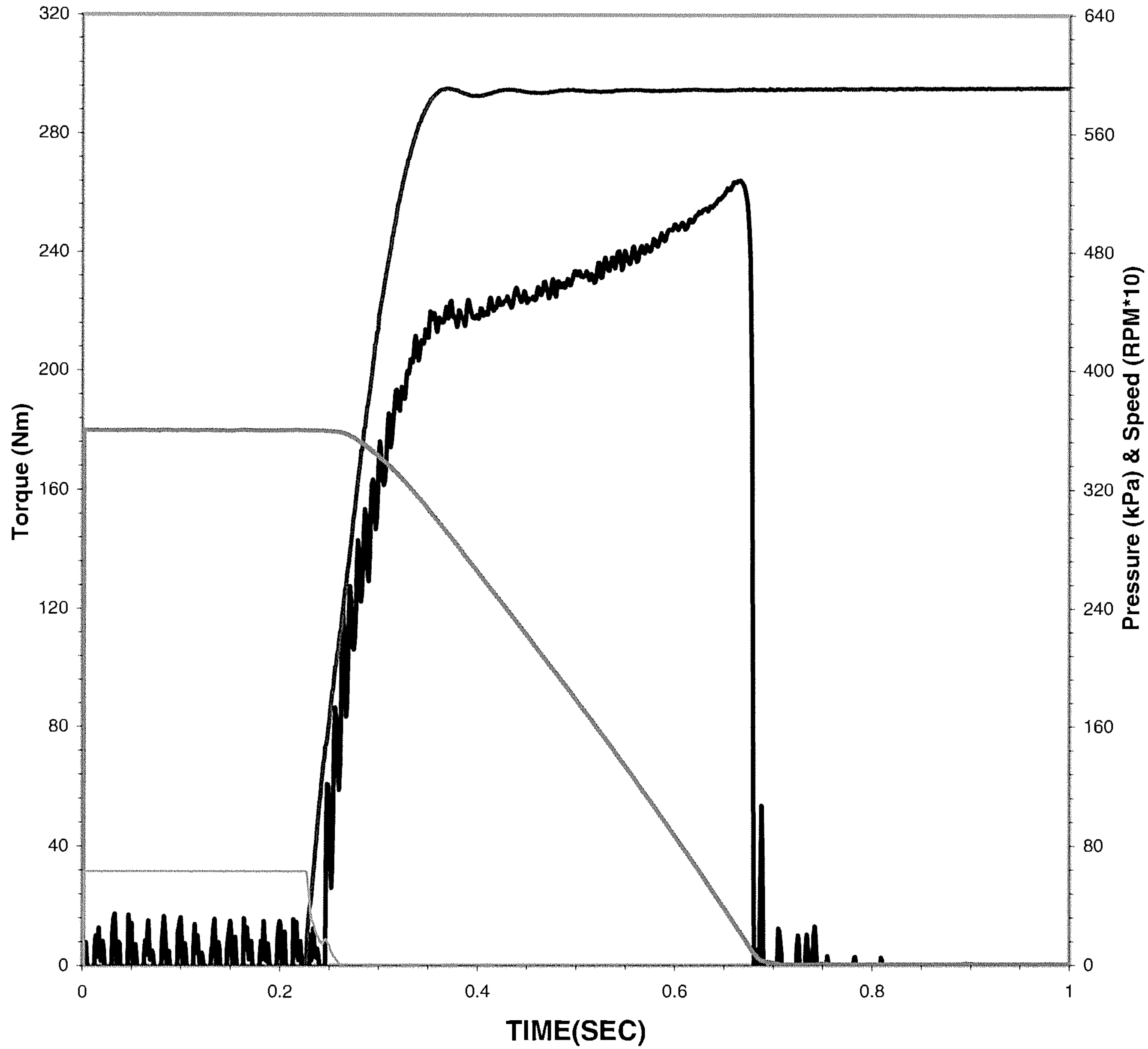
| | |
|---|---|
| 0.2 Sec Dyn: | 230 N*m |
| Midpoint Dyn: | 232 N*m |
| LwSpd Dynamic: | 257 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.112 |
| Midpoint Dyn: | 0.113 |
| LwSpd Dynamic: | 0.125 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




**Date of Test:** 10/14/2011

**Time of Test:** 11:43:20

**Test Number:** C2-3-1573

**Fluid Code:** LO268869

**Cycle Number:** 5001

**Temperature:** 87.0 °C
(93.3 ± 3.0 °C)

**Apply Pressure:** 590 kPa
(586 ± 7 KPa)

**Apply Rate:** 0.13 Sec
(0.15 ± 0.02 Sec)

**Energy:** 18.5 KJ
(18.7 ± 0.40 KJ)

**Engage Time:** 0.453 Sec

**Torque**

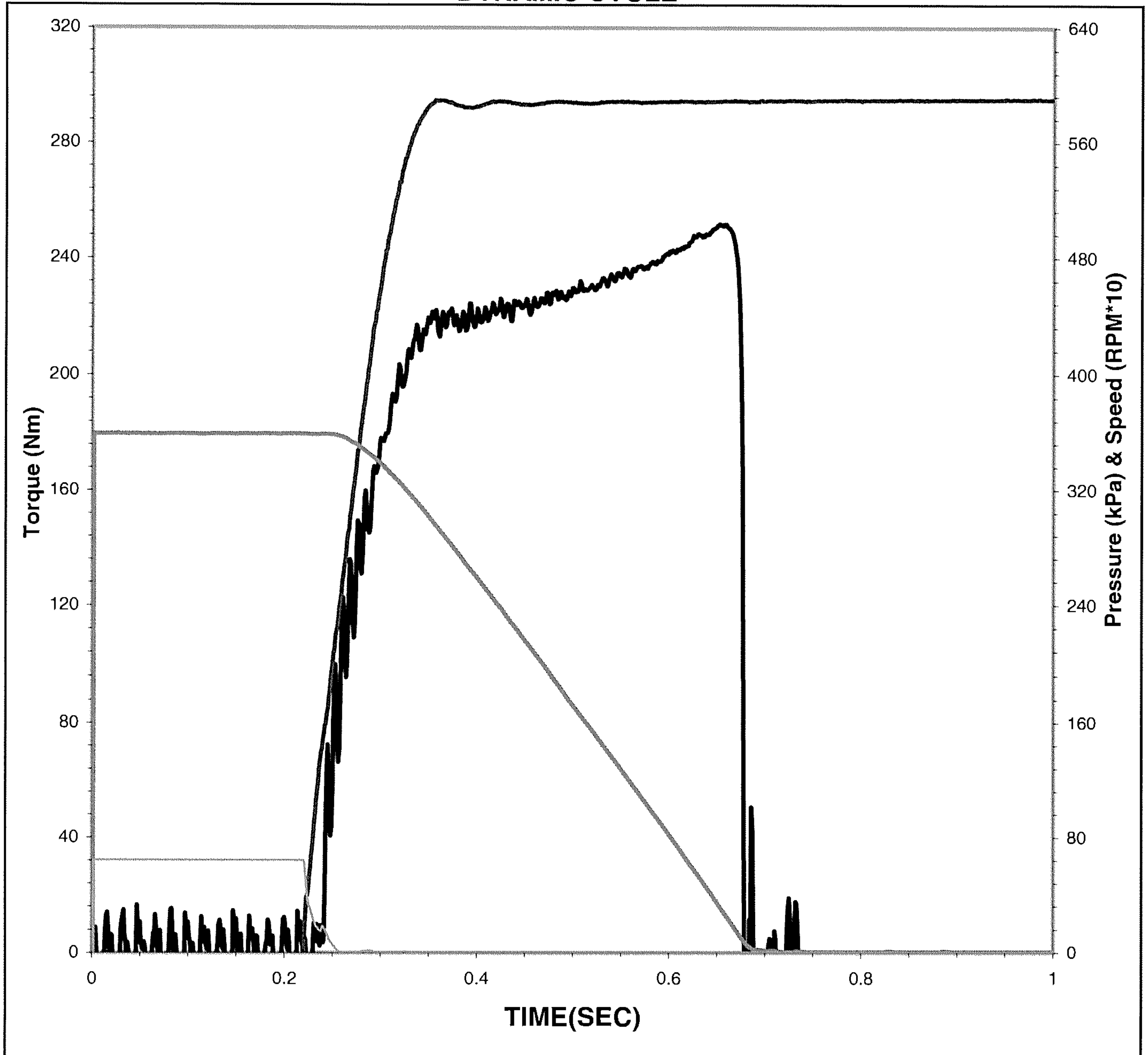
**0.2 Sec Dyn:** 227 N*m
**Midpoint Dyn:** 229 N*m
**LwSpd Dynamic:** 251 N*m

**Coefficient of Friction**

**.2 Sec Dyn:** 0.110
**Midpoint Dyn:** 0.112
**LwSpd Dynamic:** 0.122

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 22:07:50 |
| Test Number: | C2-3-1573 |
| Fluid Code: | LO268869 |
| Cycle Number: | 7499 |
| Temperature: | 93.1 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 589 kPa (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.5 KJ (18.7 ± 0.40 KJ) |
| Engage Time: | 0.458 Sec |

**Torque**

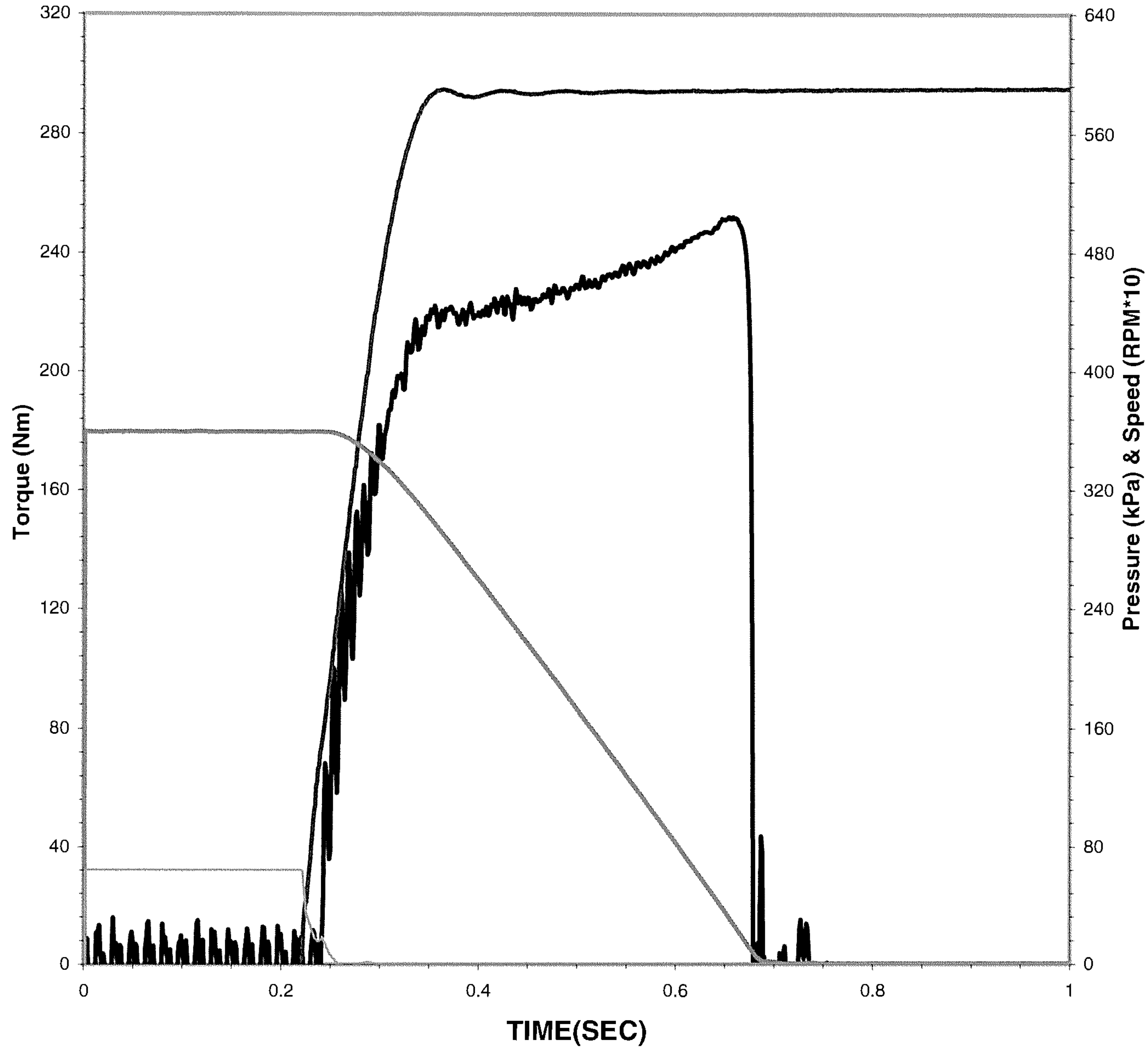
| | |
|---|---|
| 0.2 Sec Dyn: | 227 N*m |
| Midpoint Dyn: | 228 N*m |
| LwSpd Dynamic: | 236 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.110 |
| Midpoint Dyn: | 0.111 |
| LwSpd Dynamic: | 0.115 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 22:08:05 |
| Test Number: | C2-3-1573 |
| Fluid Code: | LO268869 |
| Cycle Number: | 7500 |
| Temperature: | 93.1 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 589 kPa (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.5 KJ (18.7 ± 0.40 KJ) |
| Engage Time: | 0.457 Sec |

**Torque**

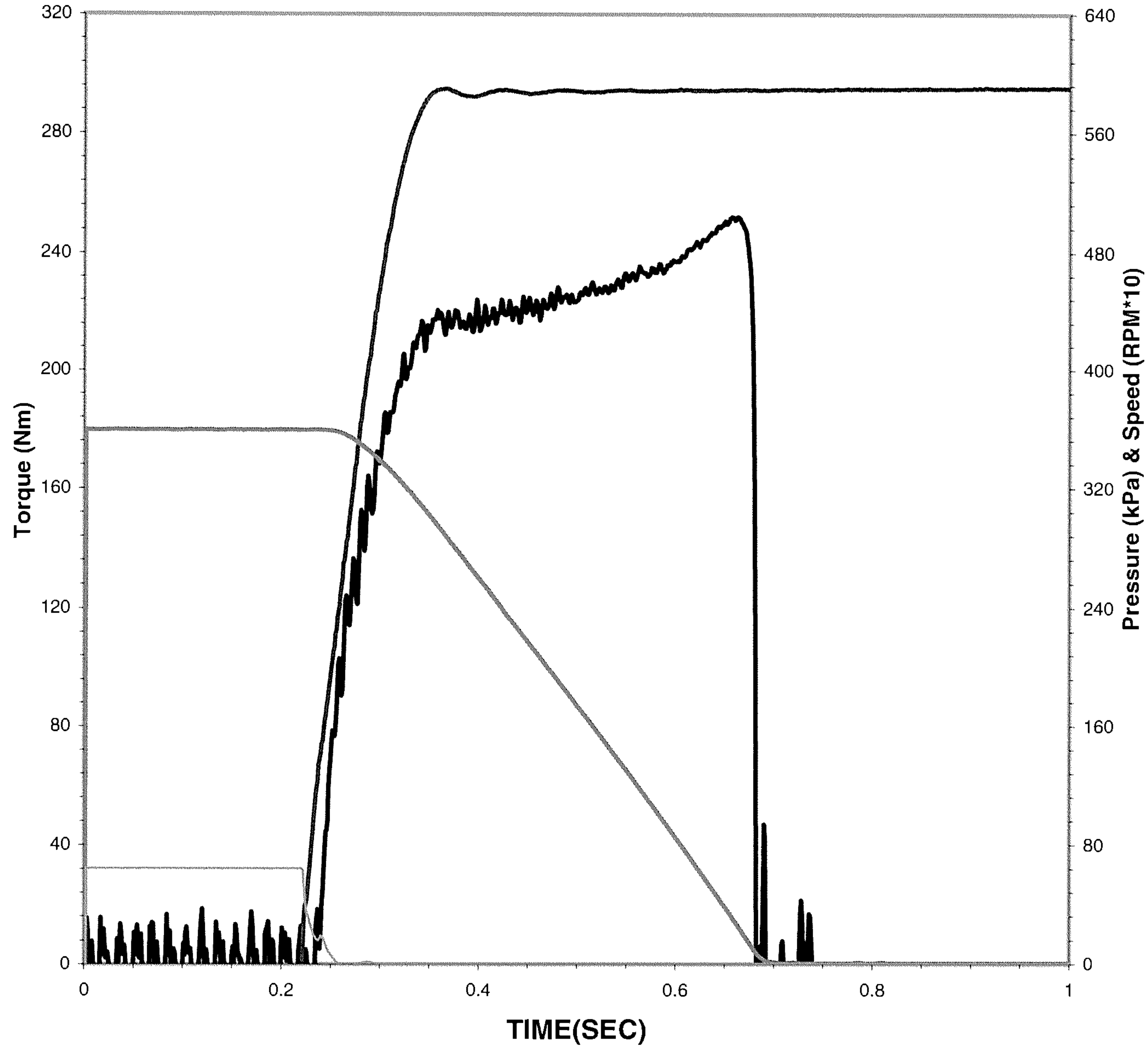
| | |
|---|---|
| 0.2 Sec Dyn: | 227 N*m |
| Midpoint Dyn: | 228 N*m |
| LwSpd Dynamic: | 235 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.110 |
| Midpoint Dyn: | 0.111 |
| LwSpd Dynamic: | 0.114 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 22:08:36 |
| Test Number: | C2-3-1573 |
| Fluid Code: | LO268869 |
| Cycle Number: | 7501 |
| Temperature: | 86.5 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 589 kPa (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ (18.7 ± 0.40 KJ) |
| Engage Time: | 0.46 Sec |

**Torque**

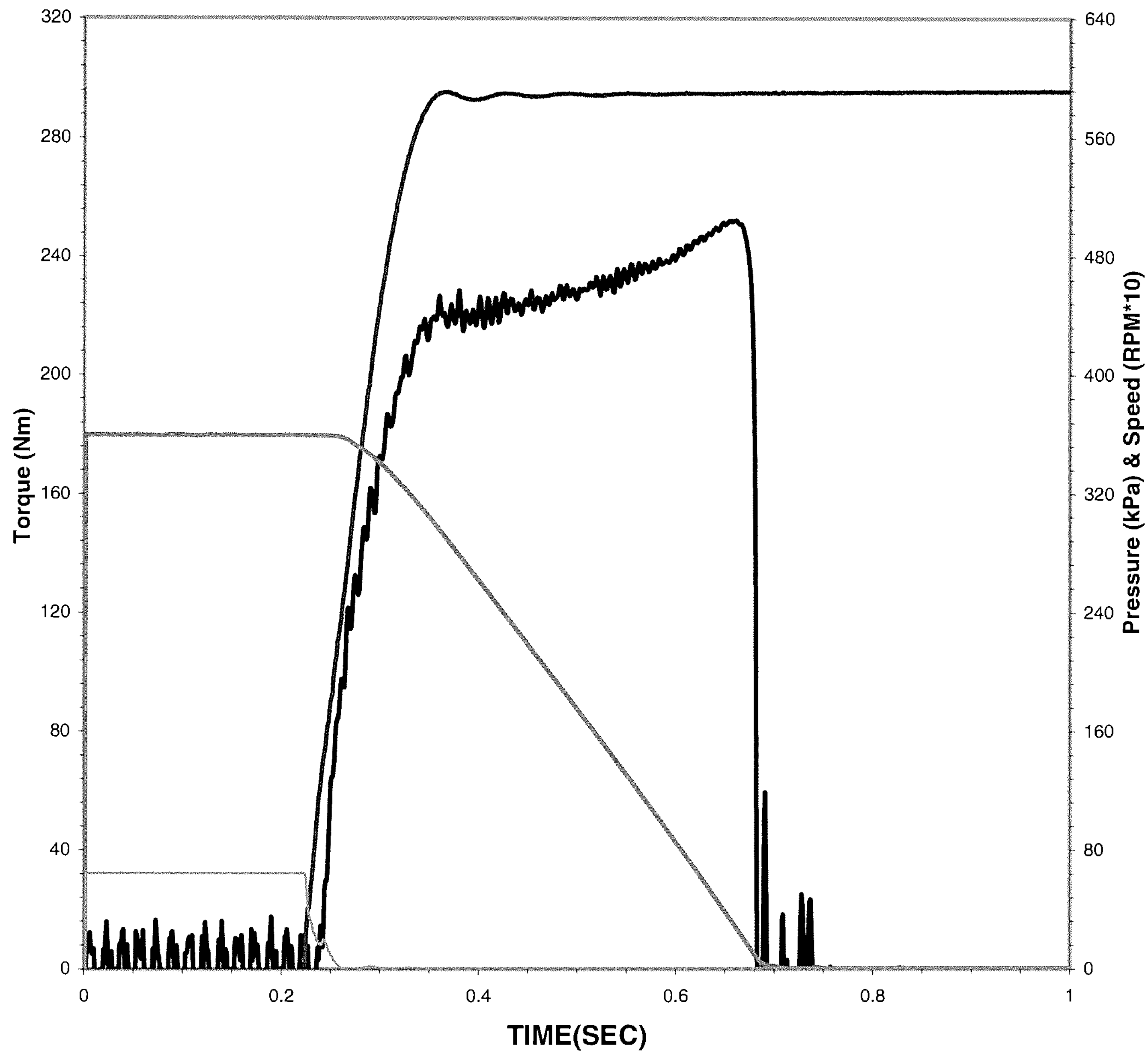
| | |
|---|---|
| 0.2 Sec Dyn: | 224 N*m |
| Midpoint Dyn: | 225 N*m |
| LwSpd Dynamic: | 236 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.109 |
| Midpoint Dyn: | 0.110 |
| LwSpd Dynamic: | 0.115 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 8:32:51 |
| Test Number: | C2-3-1573 |
| Fluid Code: | LO268869 |
| Cycle Number: | 9998 |
| Temperature: | 93.1 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 590 kPa (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.5 KJ (18.7 ± 0.40 KJ) |
| Engage Time: | 0.458 Sec |

**Torque**

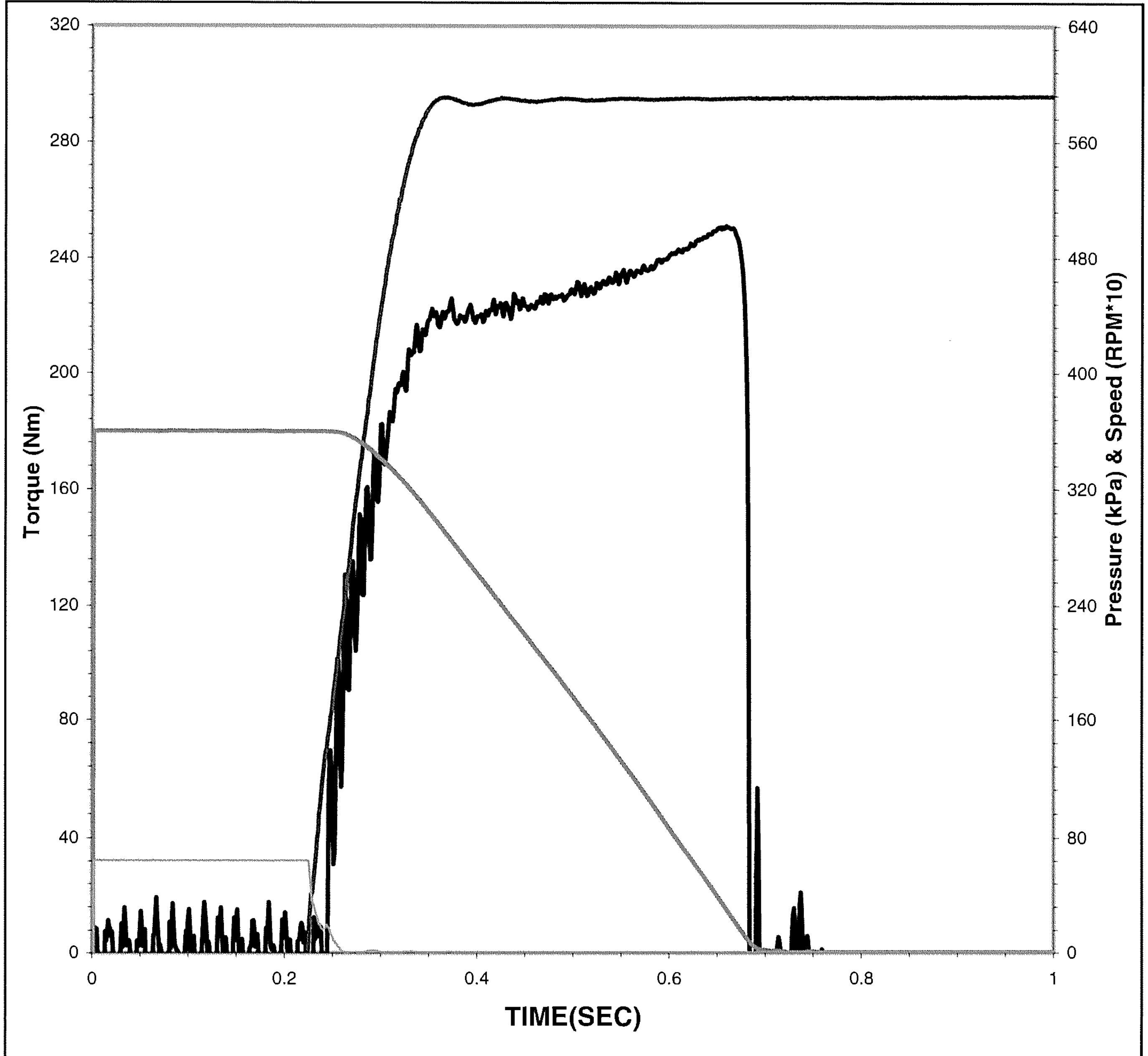
| | |
|---|---|
| 0.2 Sec Dyn: | 227 N*m |
| Midpoint Dyn: | 227 N*m |
| LwSpd Dynamic: | 226 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.110 |
| Midpoint Dyn: | 0.111 |
| LwSpd Dynamic: | 0.110 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 8:33:06 |
| Test Number: | C2-3-1573 |
| Fluid Code: | LO268869 |
| Cycle Number: | 9999 |
| Temperature: | 93.2 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 590 kPa (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.5 KJ (18.7 ± 0.40 KJ) |
| Engage Time: | 0.458 Sec |

**Torque**

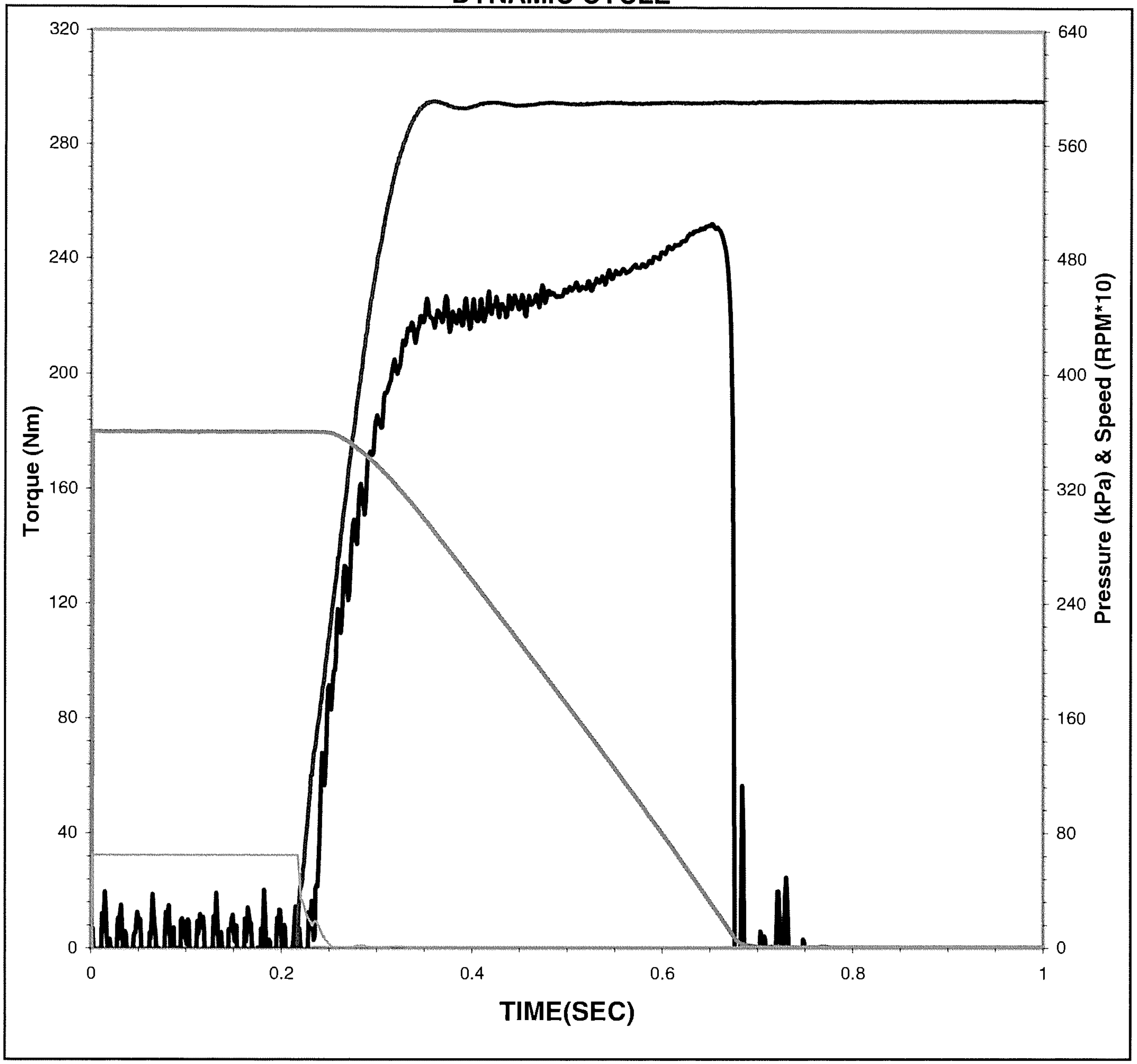
| | |
|---|---|
| 0.2 Sec Dyn: | 225 N*m |
| Midpoint Dyn: | 227 N*m |
| LwSpd Dynamic: | 227 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.110 |
| Midpoint Dyn: | 0.111 |
| LwSpd Dynamic: | 0.111 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 8:33:21 |
| Test Number: | C2-3-1573 |
| Fluid Code: | LO268869 |
| Cycle Number: | 10000 |
| Temperature: | 93.2 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 590 kPa (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.5 KJ (18.7 ± 0.40 KJ) |
| Engage Time: | 0.458 Sec |

**Torque**

| | |
|---|---|
| 0.2 Sec Dyn: | 226 N*m |
| Midpoint Dyn: | 227 N*m |
| LwSpd Dynamic: | 229 N*m |

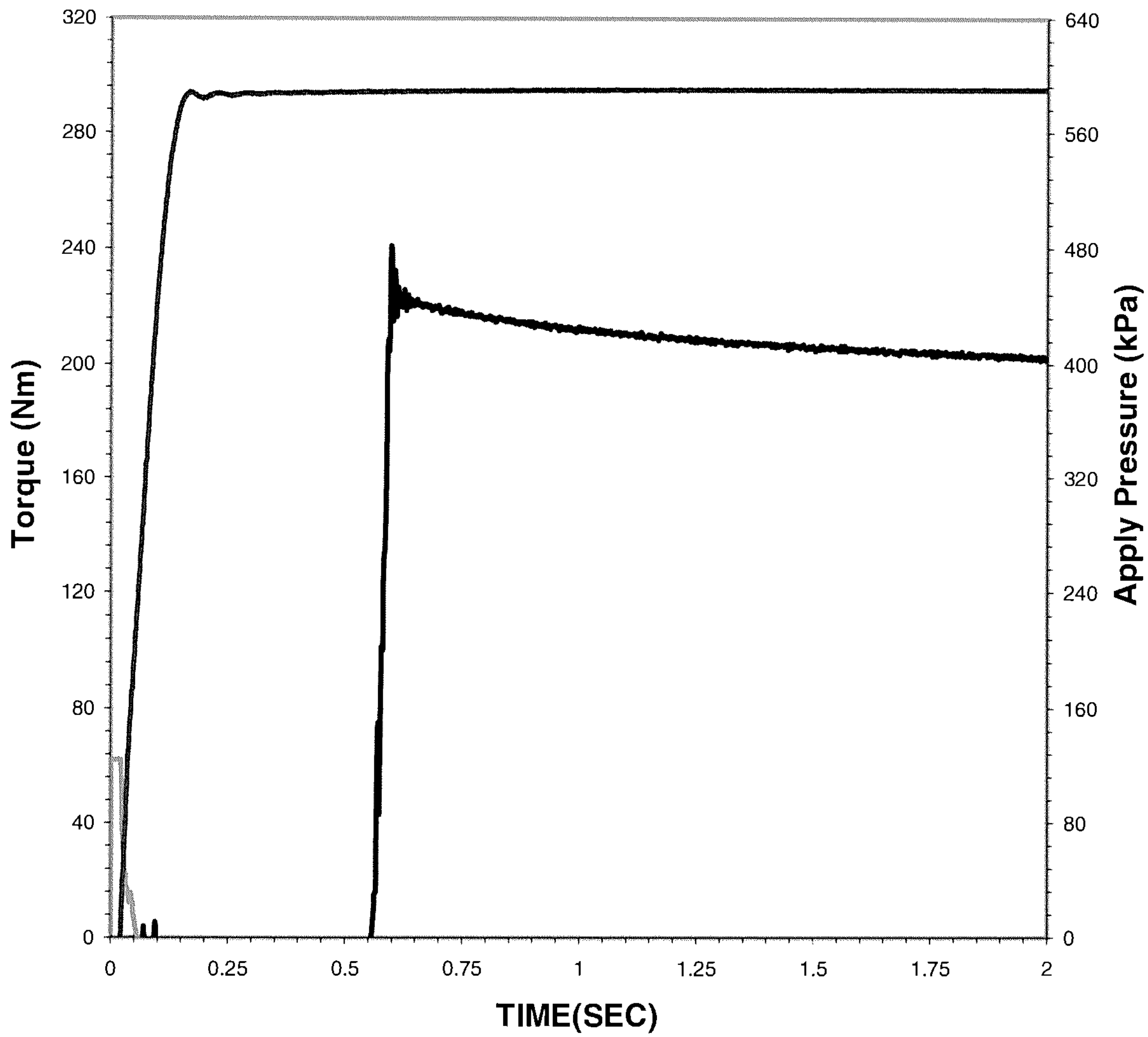
**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.110 |
| Midpoint Dyn: | 0.111 |
| LwSpd Dynamic: | 0.112 |

**STATIC TRACES**

# ALLISON C-4 PAPER DATA

## STATIC CYCLE




Date of Test: 10/13/2011

Time of Test: 14:55:24

Test Number: C2-3-1573

Fluid Code: LO268869

Cycle Number: 10

**STATIC CYCLE**

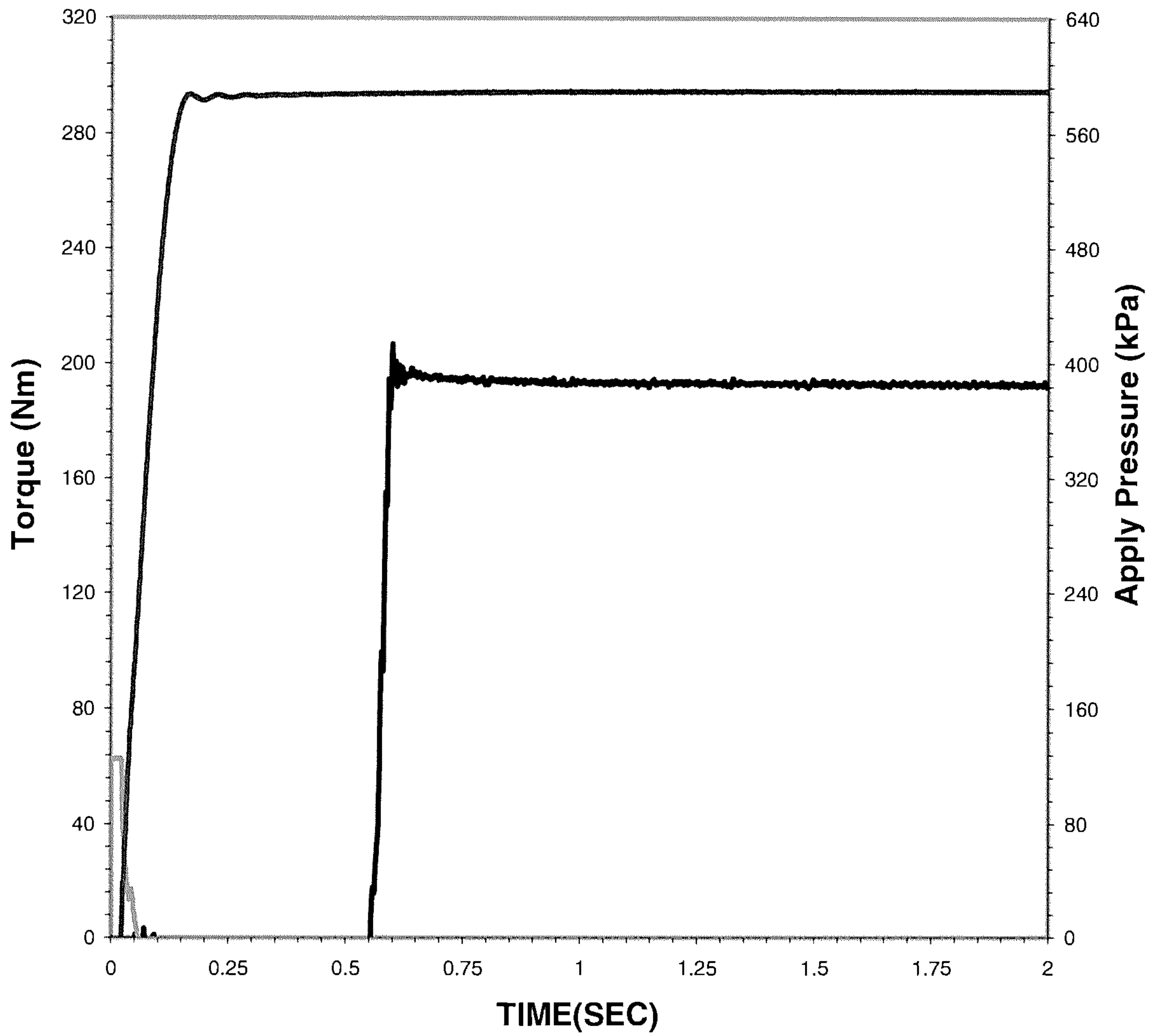
Apply Pressure:
At .25 Second: 588 kPa

**Torque**
Static Peak: 244 Nm
.25 Second: 219 Nm

**Coefficient of Friction**
Static Peak: 0.119
.25 Second: 0.107

# ALLISON C-4 PAPER DATA

## STATIC CYCLE




Date of Test: 10/13/2011

Time of Test: 15:18:11

Test Number: C2-3-1573

Fluid Code: LO268869

Cycle Number: 100

**STATIC CYCLE**

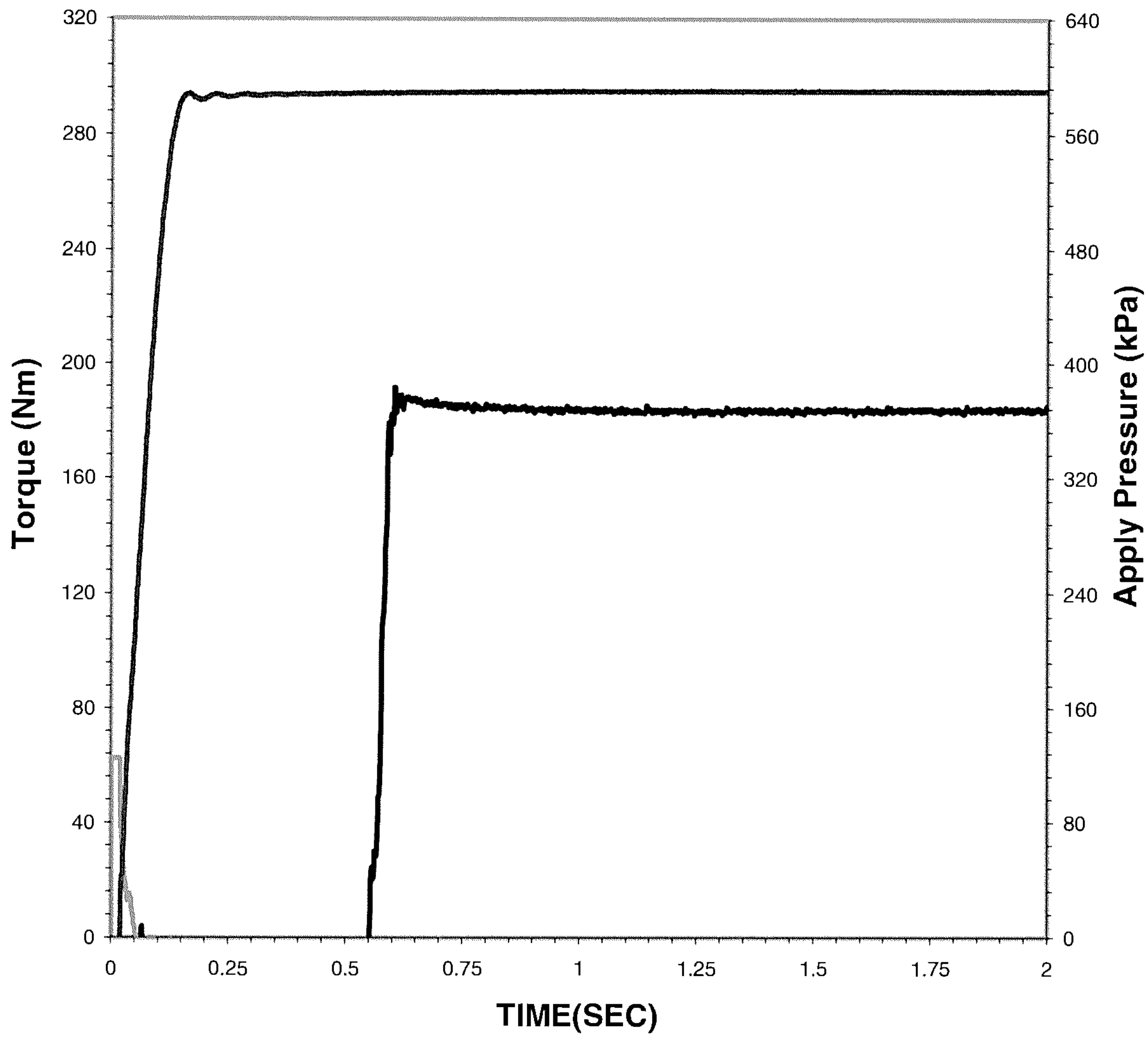
Apply Pressure:
At .25 Second: 588 kPa

**Torque**
Static Peak: 210 Nm
.25 Second: 196 Nm

**Coefficient of Friction**
Static Peak: 0.102
.25 Second: 0.095

# ALLISON C-4 PAPER DATA

## STATIC CYCLE




Date of Test: 10/13/2011

Time of Test: 16:58:27

Test Number: C2-3-1573

Fluid Code: LO268869

Cycle Number: 500

**STATIC CYCLE**

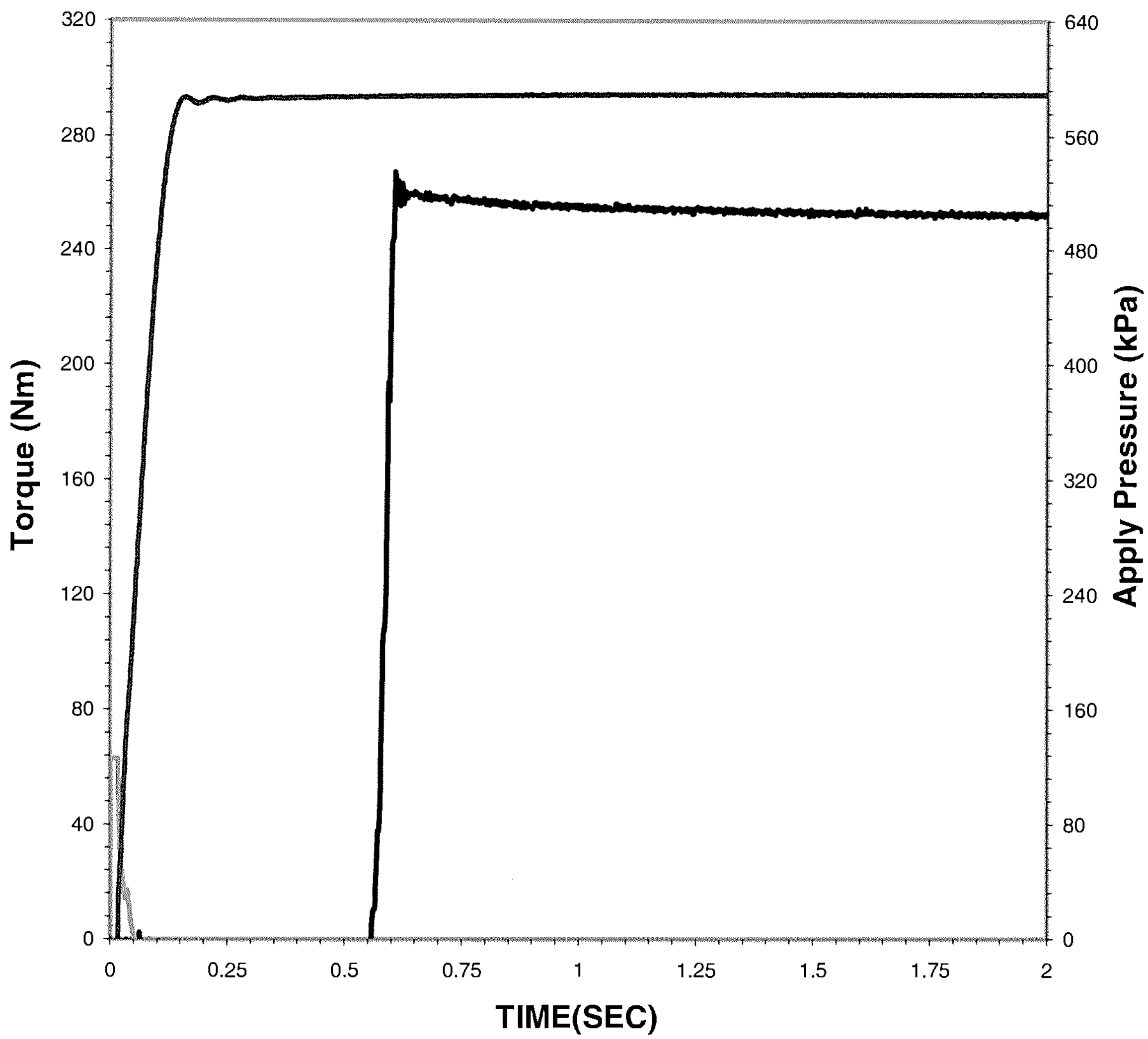
Apply Pressure:
At .25 Second: 588 kPa

**Torque**
Static Peak: 195 Nm
.25 Second: 189 Nm

**Coefficient of Friction**
Static Peak: 0.095
.25 Second: 0.092

# ALLISON C-4 PAPER DATA

## STATIC CYCLE




Date of Test: 10/13/2011

Time of Test: 19:03:43

Test Number: C2-3-1573

Fluid Code: LO268869

Cycle Number: 1000

**STATIC CYCLE**

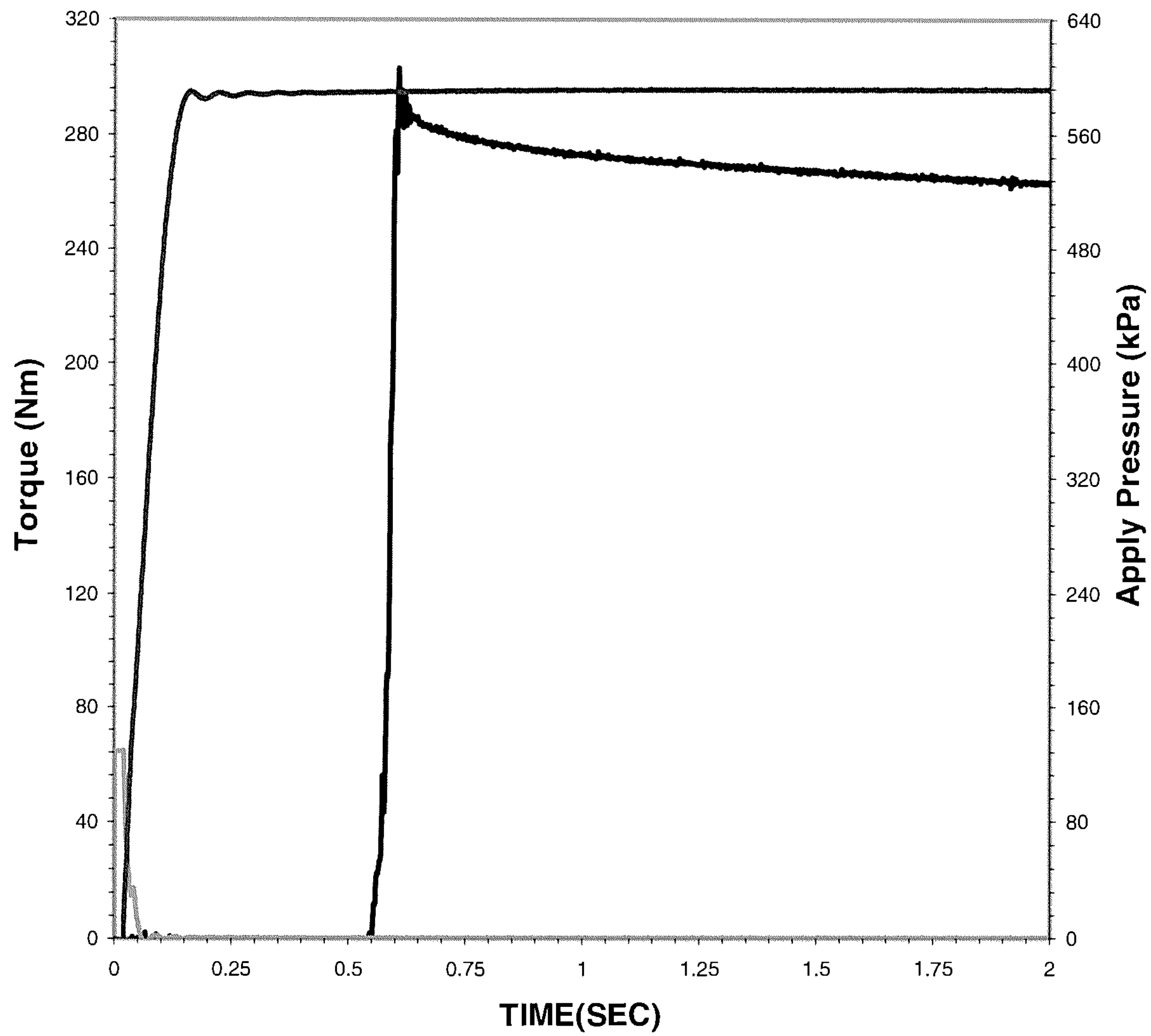
Apply Pressure:
At .25 Second: 587 kPa

**Torque**
Static Peak: 271 Nm
.25 Second: 260 Nm

**Coefficient of Friction**
Static Peak: 0.132
.25 Second: 0.127

# ALLISON C-4 PAPER DATA

## STATIC CYCLE




Date of Test: 10/14/2011

Time of Test: 1:18:59

Test Number: C2-3-1573

Fluid Code: LO268869

Cycle Number: 2500

**STATIC CYCLE**

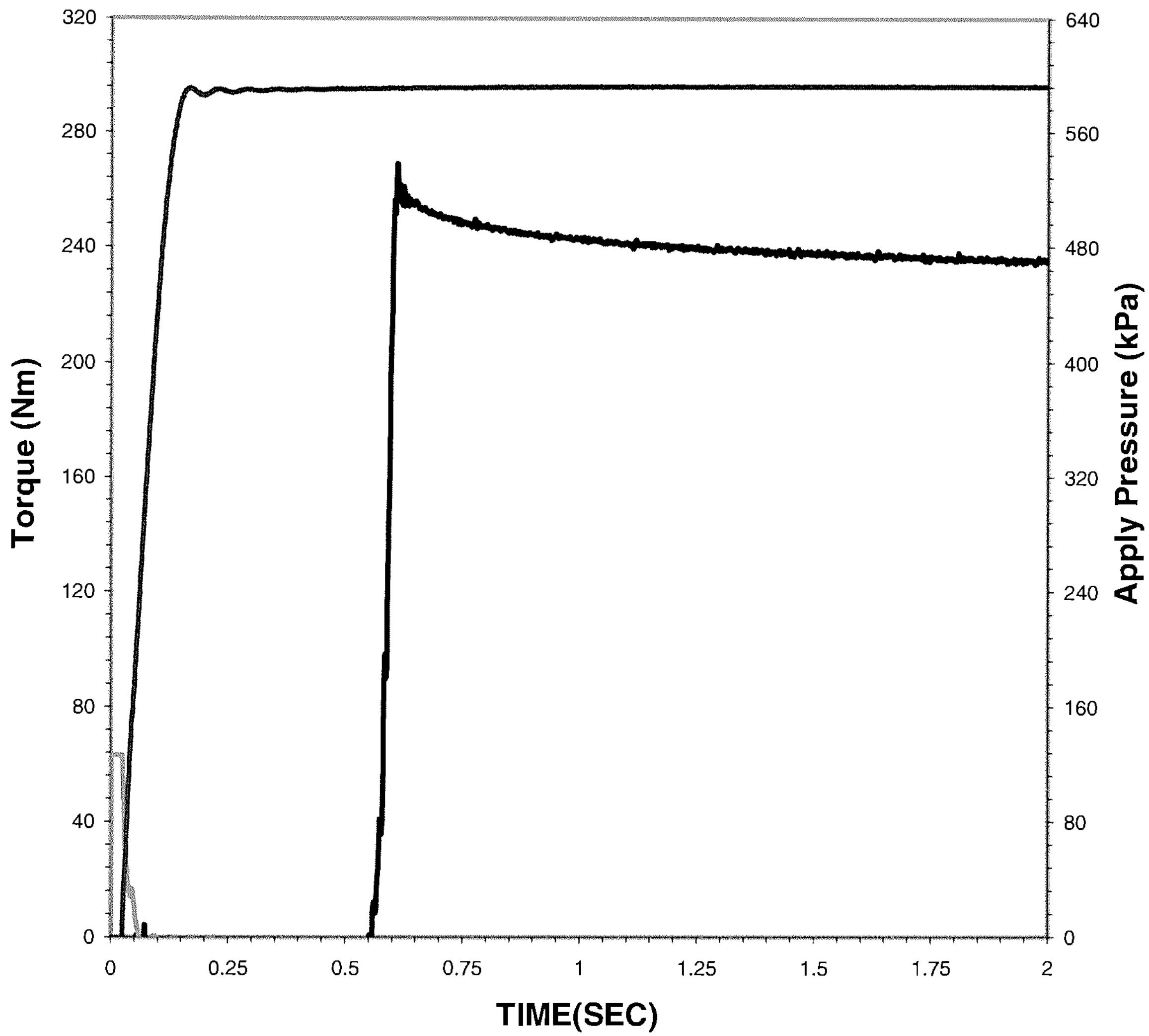
Apply Pressure:
At .25 Second: 589 kPa

**Torque**
Static Peak: 306 Nm
.25 Second: 280 Nm

**Coefficient of Friction**
Static Peak: 0.149
.25 Second: 0.136

# ALLISON C-4 PAPER DATA

## STATIC CYCLE




Date of Test: 10/14/2011

Time of Test: 11:43:05

Test Number: C2-3-1573

Fluid Code: LO268869

Cycle Number: 5000

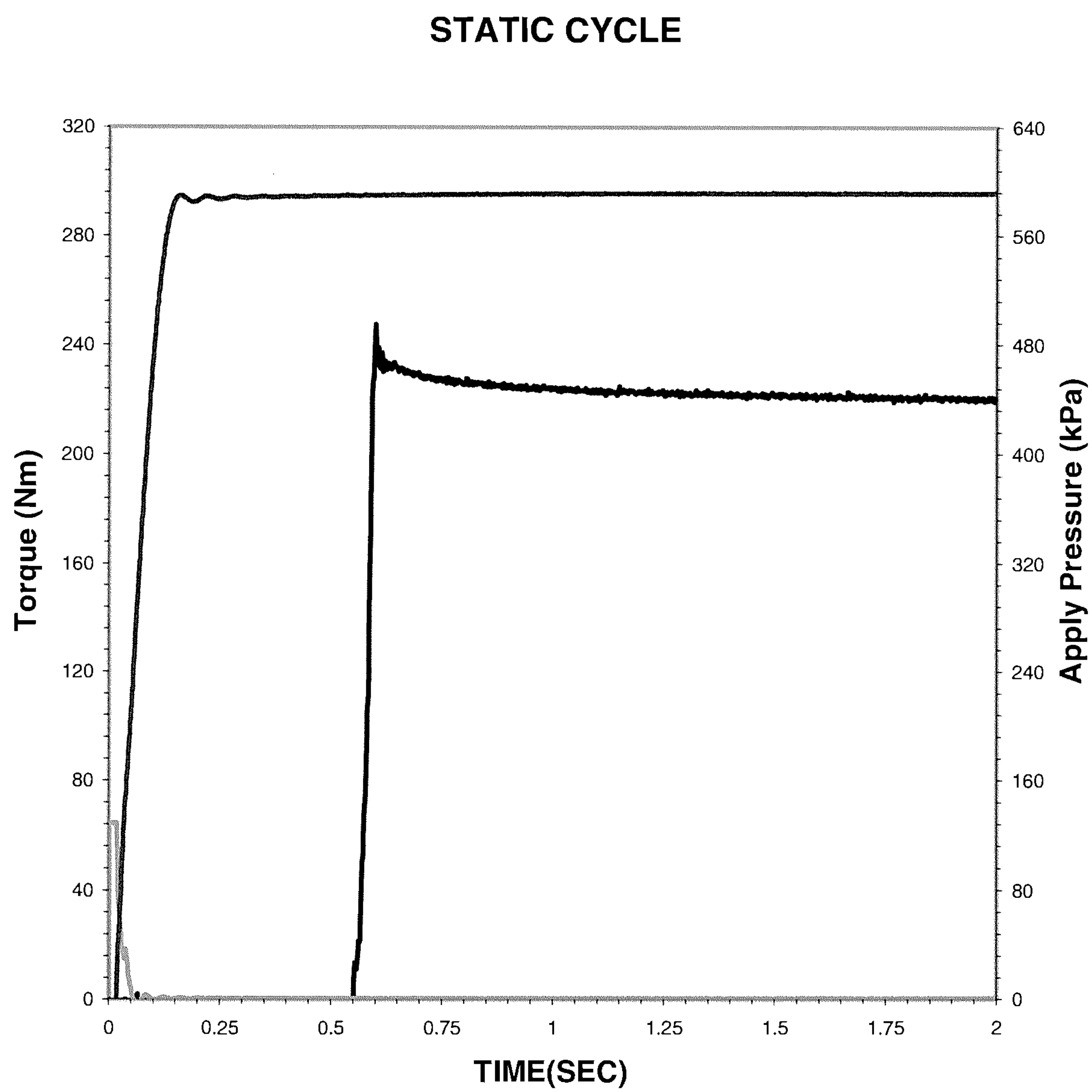
**STATIC CYCLE**

Apply Pressure:
At .25 Second: 590 kPa

**Torque**
Static Peak: 272 Nm
.25 Second: 249 Nm

**Coefficient of Friction**
Static Peak: 0.133
.25 Second: 0.121

# ALLISON C-4 PAPER DATA




Date of Test: 10/14/2011

Time of Test: 22:08:21

Test Number: C2-3-1573

Fluid Code: LO268869

Cycle Number: 7500

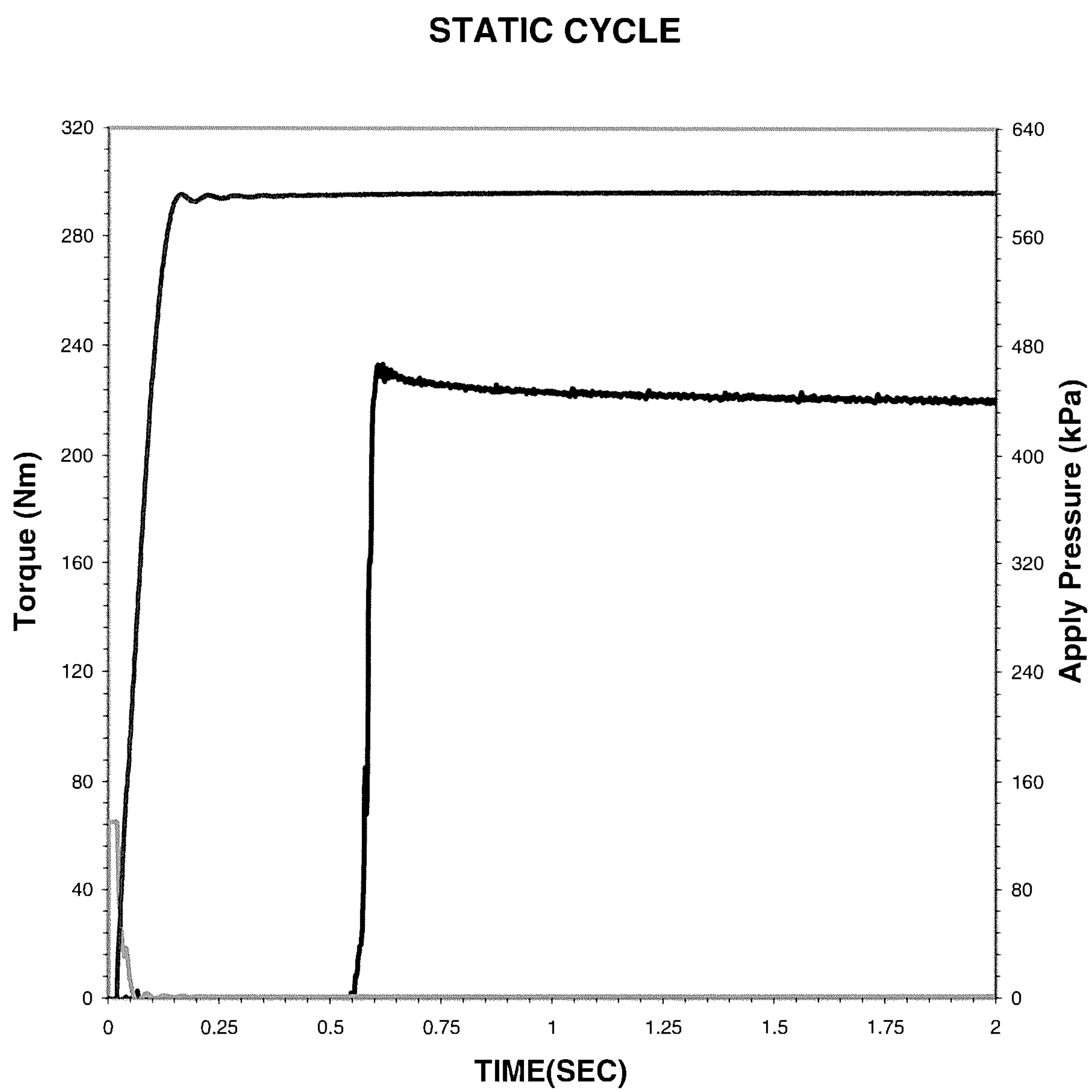
**STATIC CYCLE**

Apply Pressure:
At .25 Second: 589 kPa

**Torque**
Static Peak: 251 Nm
.25 Second: 229 Nm

**Coefficient of Friction**
Static Peak: 0.122
.25 Second: 0.112

# ALLISON C-4 PAPER DATA




Date of Test: 10/15/2011

Time of Test: 8:33:37

Test Number: C2-3-1573

Fluid Code: LO268869

Cycle Number: 10000

**STATIC CYCLE**

Apply Pressure:
At .25 Second: 590 kPa

**Torque**
Static Peak: 236 Nm
.25 Second: 227 Nm

**Coefficient of Friction**
Static Peak: 0.115
.25 Second: 0.111

# APPENDIX – D2 (PART 1)
# TYPE C-4 GRAPHITE CLUTCH FRICTION TEST
# LO271510

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

**Allison Heavy-Duty Transmission Fluid**
**TYPE C-4 GRAPHITE CLUTCH FRICTION TEST**

Conducted for

**ARMY LAB**

**Oil Code:**
**LO271510**

**Test Number:**
**C4-4-1342**

**October 15, 2011**

Submitted by:

Matthew Jackson
Manager
Specialty & Driveline Fluid Evaluations

The results of this report relate only to the fluid tested.
This report shall not be reproduced, except in full, without he written approval of Southwest Research Institute®.

# VIII. Graphite Clutch Friction Test

| | | | |
|---|---|---|---|
| Test Laboratory: | SWRI | Lab Fluid Code: | LO-271510 |
| Test Number: | C4-4-1342 | Sponsor Fluid Code: | LO271510 |
| Friction Plate Batch: | LOT 44 | Completion Date: | 10/15/11 |
| Steel Plate Batch: | 10/9/2008 | | |

Clutch Wear Data
(units in mm)

| | Maximum | Average |
|---|---|---|
| Steel Plates | 0.0000 | 0.0000 |
| Clutch Plate | 0.0840 | 0.0762 |

| | Before | After |
|---|---|---|
| Pack Clearance | 0.4826 | 0.6096 |

Reference Tests

| Test Number | Test Date | Test Fluid |
|---|---|---|
| C4-0-1304 | 12/09/10 | PASS REF-L-06-04 |
| C4-0-1315 | 03/30/11 | MIL-PRF-2104H |
| C4-0-1338 | 10/05/11 | MIL-PRF-2104H |

| | New | EOT |
|---|---|---|
| Viscosity at 40°C, cSt | 45.26 | 39.12 |
| Viscosity at 100°C, cSt | 8.45 | 7.55 |
| Iron Content, ppm | 1 | 83 |

| D5185 | New Fluid (ppm) |
|---|---|
| Ba | <1 |
| B | 18 |
| Ca | 904 |
| Mg | 1261 |
| P | 1063 |
| Si | 6 |
| Na | <5 |
| Zn | 1261 |

Name: Matthew Jackson

Signature:

Title: Manager

Date: 10/25/11

# ALLISON C-4 GRAPHITE FRICTION TEST SUMMARY

(Torque in Ft-Lbs)

Sponsor Fluid Code: **LO271510**
Lab Fluid Code: **LO-271510**
Completion Date: **10/15/2011**

Test Number: **C4-4-1342**
Fric. Plate Batch: **LOT 44**
Steel Plate Batch: **10/9/2008**

**PHASE A**

| CYCLE | SLIP TIME | TORQUE (MIDPOINT) | TORQUE STATIC PEAK | TORQUE (.2 Second) | STATIC PEAK - 0.2 TORQUE | LOW SPEED STATIC PEAK | LOWSPEED STATIC TORQUE |
|---|---|---|---|---|---|---|---|
| 500 | 1.21 | 50 | 73 | 39 | 34 | 88 | 72 |
| 1000 | 1.26 | 48 | 71 | 35 | 36 | 91 | 71 |

**PHASE B**

| CYCLE | SLIP TIME | TORQUE (MIDPOINT) | TORQUE STATIC PEAK | TORQUE (0.2 Second) | STATIC PEAK - 0.2 TORQUE | LOW SPEED STATIC PEAK | LOWSPEED STATIC TORQUE |
|---|---|---|---|---|---|---|---|
| 1500 | 0.76 | 104 | 149 | 92 | 57 | 175 | 157 |
| 2000 | 0.80 | 99 | 145 | 83 | 62 | 162 | 154 |
| 2500 | 0.82 | 96 | 143 | 78 | 65 | 167 | 154 |
| 3500 | 0.84 | 95 | 140 | 77 | 63 | 164 | 152 |
| 4000 | 0.83 | 96 | 141 | 75 | 66 | 164 | 150 |
| 4500 | 0.85 | 94 | 137 | 75 | 62 | 164 | 150 |
| 5000 | 0.83 | 97 | 141 | 75 | 66 | 162 | 149 |
| 5500 | 0.81 | 100 | 137 | 82 | 55 | 158 | 149 |

| | Limits | | Results | | | |
|---|---|---|---|---|---|---|
| | Max | Max Change | 1,500 N | 5,500 N | % Change | P/F |
| Slip Time Max. | 0.89 | N/A | 0.76 | 0.81 | 6.58 | P |
| 0.2 Second Dynamic Coeff. | N/A | N/A | 0.086 | 0.077 | -10.465 | |
| Mid-Point Fric. Coeff. Min. | 0.089 | N/A | 0.097 | 0.094 | -3.093 | P |
| Static Friction Coeff. | N/A | N/A | 0.140 | 0.128 | -8.571 | |
| Low Speed Peak Fric. Coeff. | N/A | N/A | 0.164 | 0.148 | -9.756 | |
| 0.25 Second Low Speed Coeff. | N/A | N/A | 0.147 | 0.140 | -4.762 | |

SOUTHWEST RESEARCH INSTITUTE®

# ALLISON C4-GRAPHITE FRICTION TEST

**Candidate Fluid: LO271510** **Test Number : C4-4-1342** **Completion Date : 10/15/2011**

**Lab Fluid Code : LO-271510** **Steel Plate Batch: 10/09/2008** **Fric Plate Batch : LOT 44**

**(all units in mm)**

| Plates | Location of Tooth (Clockwise) | Near Inner Diameter Before | Near Inner Diameter After | Near Outer Diameter Before | Near Outer Diameter After | Inner Diameter Change | Average Overall Change | Outer Diameter Change |
|---|---|---|---|---|---|---|---|---|
| FRICTION MATERIAL | | | | | | | | |
| 2 | Top | 2.2050 | 2.1220 | 2.2200 | 2.1430 | 0.0830 | | 0.0770 |
| | 120 | 2.2180 | 2.1340 | 2.2190 | 2.1460 | 0.0840 | | 0.0730 |
| | 240 | 2.2100 | 2.1340 | 2.2090 | 2.1450 | 0.0760 | | 0.0640 |
| | Average | | | | | 0.0810 | 0.0762 | 0.0713 |
| STEEL SEPARATORS | | | | | | | | |
| 1 | Top | 1.7630 | 1.7630 | 1.7630 | 1.7630 | 0.0000 | | 0.0000 |
| | 120 | 1.7600 | 1.7600 | 1.7600 | 1.7600 | 0.0000 | | 0.0000 |
| | 240 | 1.7620 | 1.7620 | 1.7620 | 1.7620 | 0.0000 | | 0.0000 |
| | Average | | | | | 0.0000 | 0.0000 | 0.0000 |
| 3 | Top | 1.7590 | 1.7590 | 1.7590 | 1.7590 | 0.0000 | | 0.0000 |
| | 120 | 1.7580 | 1.7580 | 1.7580 | 1.7580 | 0.0000 | | 0.0000 |
| | 240 | 1.7590 | 1.7590 | 1.7590 | 1.7590 | 0.0000 | | 0.0000 |
| | Average | | | | | 0.0000 | 0.0000 | 0.0000 |

PLATE CONDITION AT E.O.T. STEEL PLATES HAVE NO UNUSUAL DISCOLORATION
(Anything Unusual)

Test Date: 10/15/2011

Operator's Name: JOE M

Reviewed By (Signature and Date)

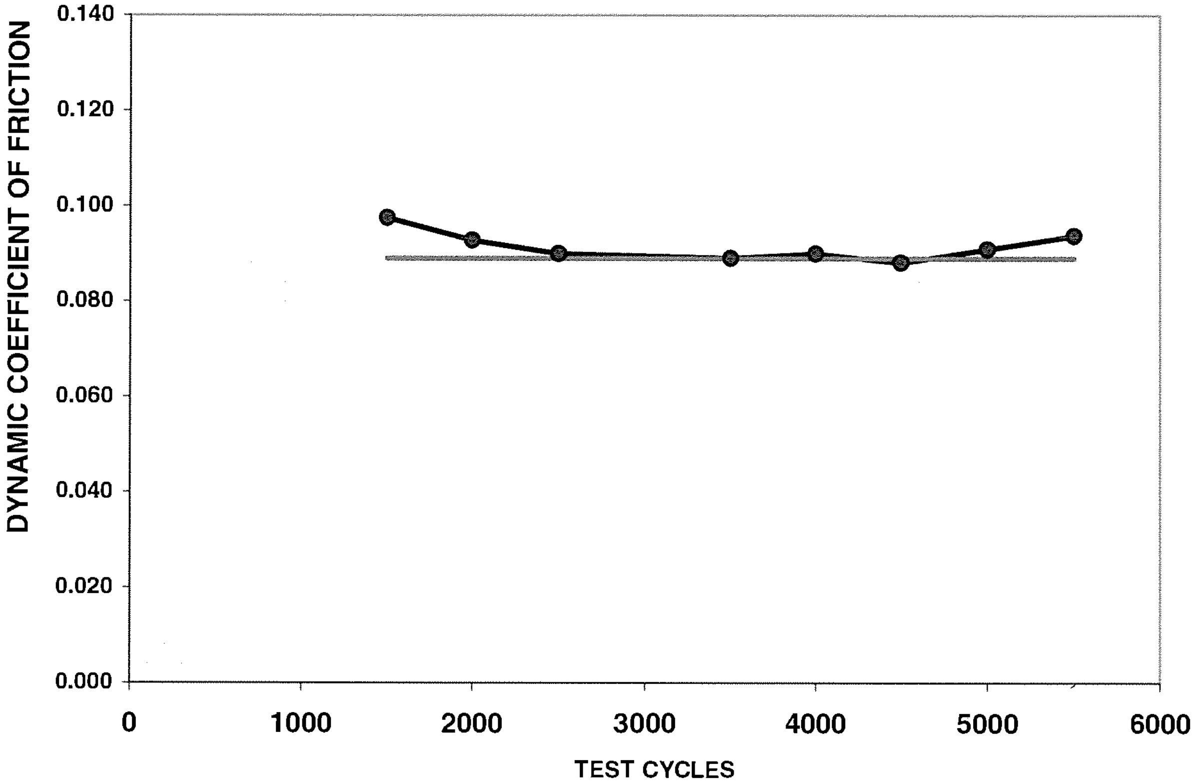
10/24/11

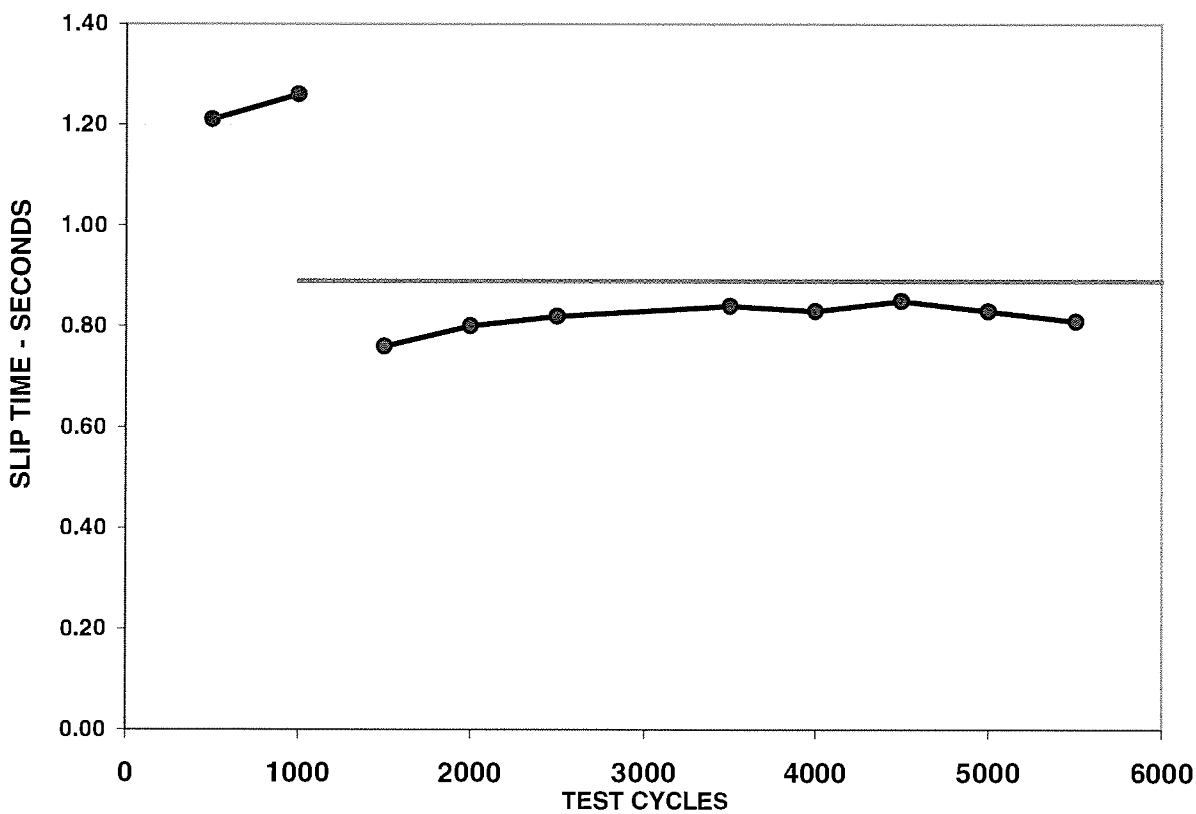
Pack ID#: 4668

ALLISON HYDRAULIC TRANSMISSION FLUID
TYPE C-4 GRAPHITE FRICTION TEST

EOT Date: 10/15/2011
Test Number: C4-4-1342

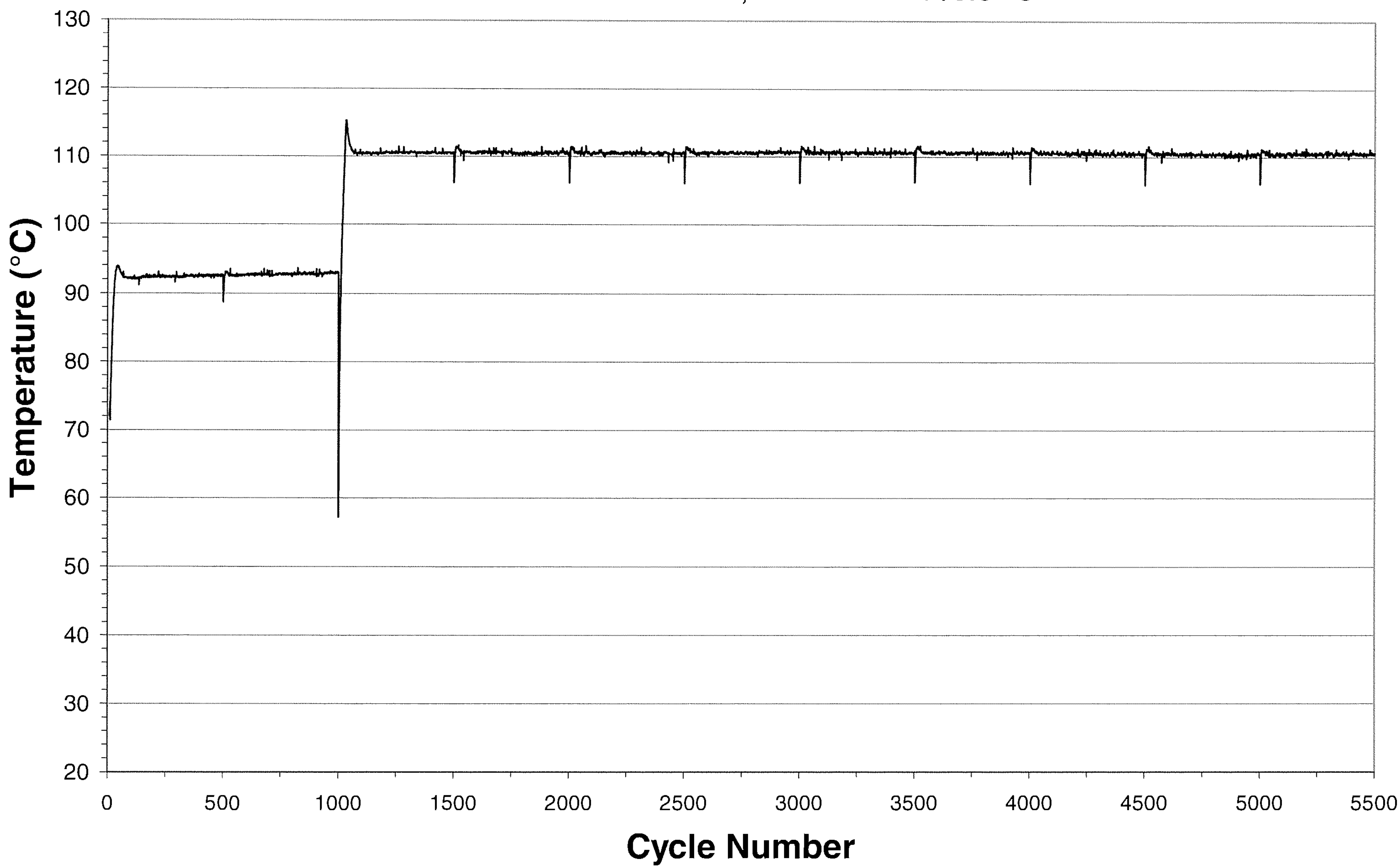
Fluid Code: LO271510
Plate Batch: LOT 44
Steel Batch: 10/9/2008



# C4-4-1342 LO271510

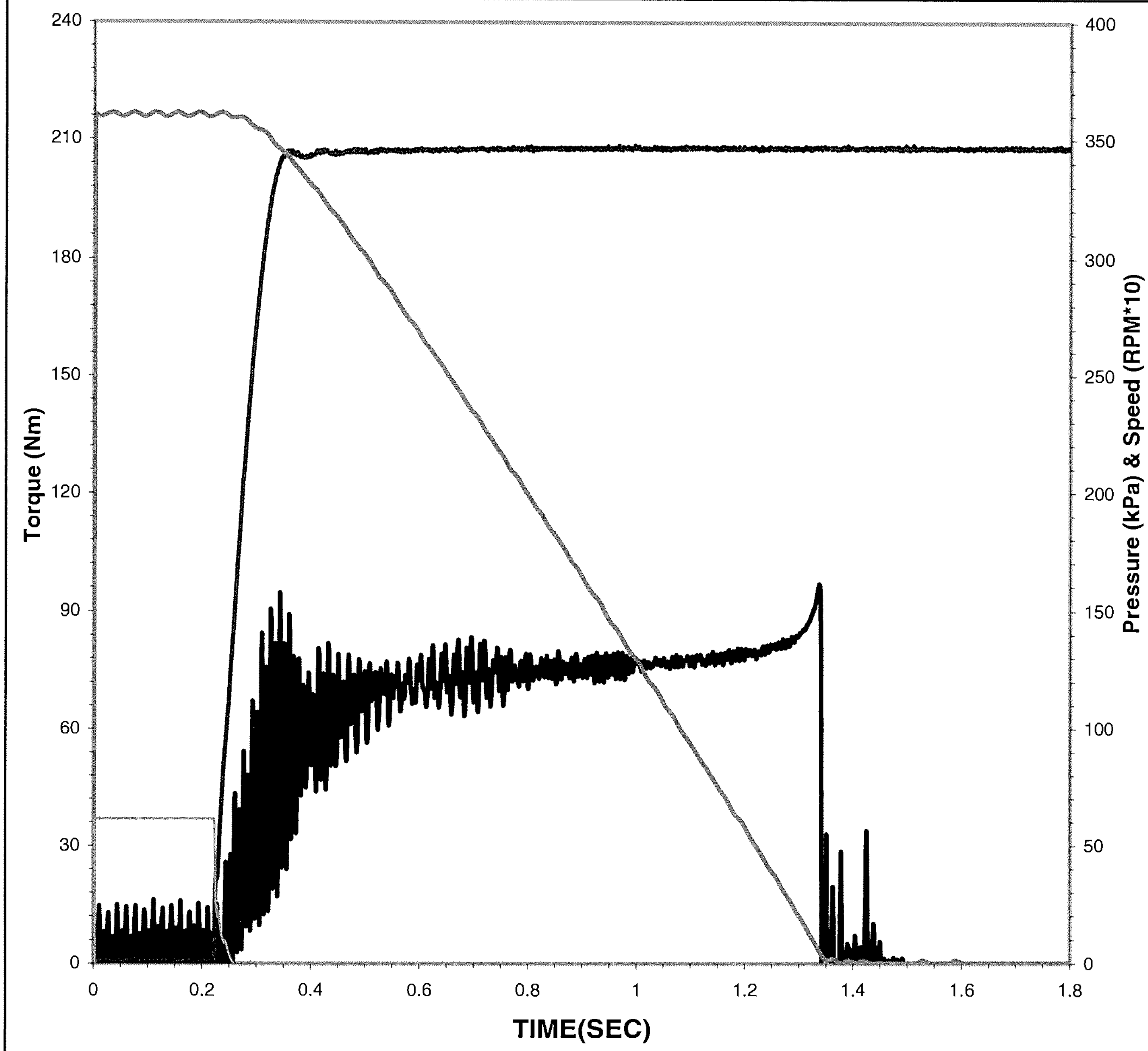
AVG: Phase A = 92.2 °C, Phase B = 110.5 °C



## DYNAMIC TRACES

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE A




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 16:27:01 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 10 |
| Temperature: | 74.0 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 345 kPa (345 ± 7 KPa) |
| Apply Rate: | 0.12 Sec (0.15 ± 0.02 Sec) |
| Energy: | 14.3 KJ (14.50 ± 0.40 KJ) |
| Engage Time: | 1.118 Sec |

**Torque**

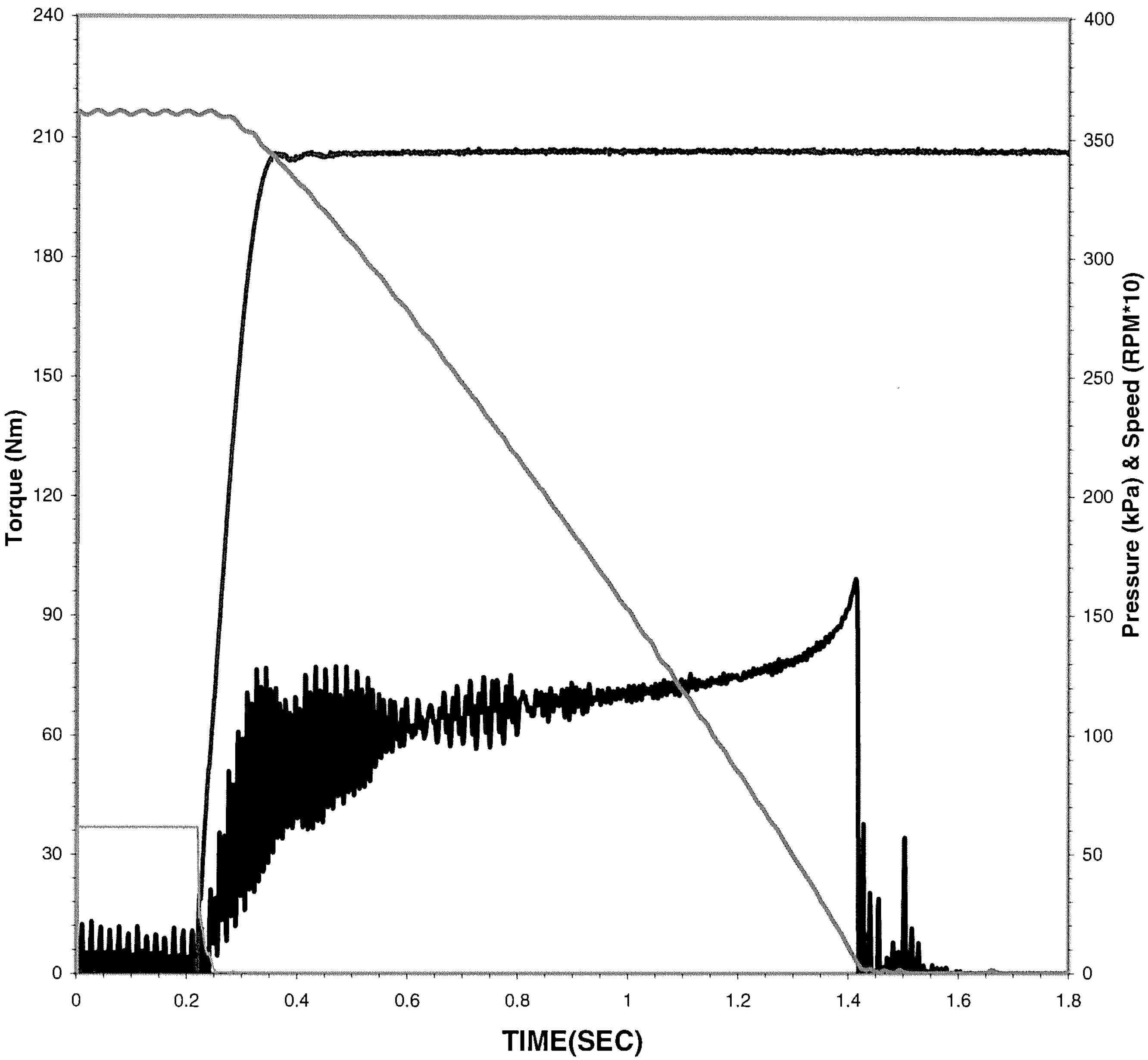
| | |
|---|---|
| 0.2 Sec Dyn: | 62 N*m |
| Midpoint Dyn: | 76 N*m |
| LwSpd Dynamic: | 95 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.102 |
| Midpoint Dyn: | 0.125 |
| LwSpd Dynamic: | 0.157 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE A




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 18:29:27 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 499 |
| Temperature: | 92.5 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 345 kPa (345 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 14.3 KJ (14.50 ± 0.40 KJ) |
| Engage Time: | 1.197 Sec |

**Torque**

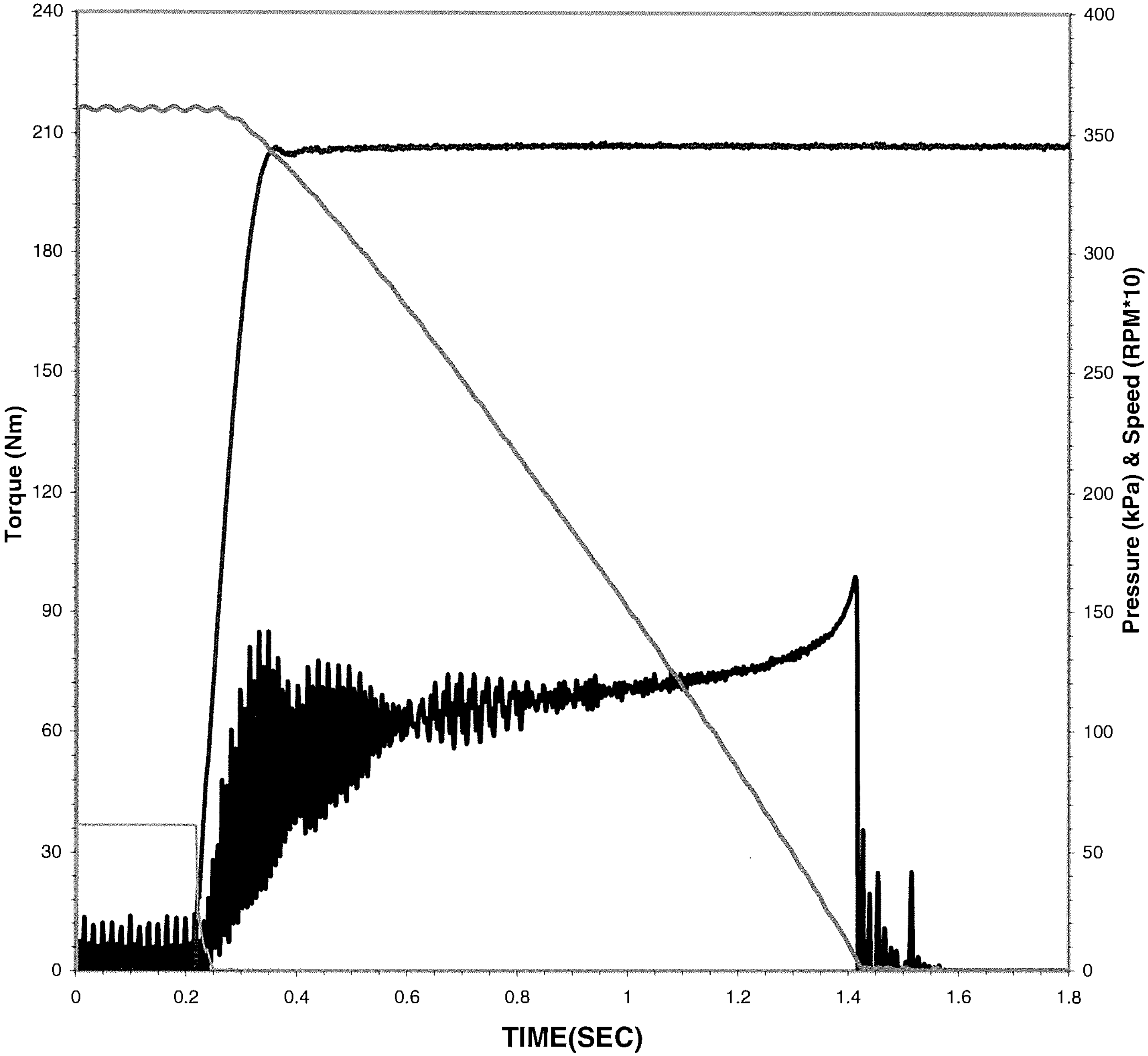
| | |
|---|---|
| 0.2 Sec Dyn: | 54 N*m |
| Midpoint Dyn: | 68 N*m |
| LwSpd Dynamic: | 97 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.090 |
| Midpoint Dyn: | 0.113 |
| LwSpd Dynamic: | 0.160 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE A




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 18:29:43 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 500 |
| Temperature: | 92.4 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 346 kPa (345 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 14.3 KJ (14.50 ± 0.40 KJ) |
| Engage Time: | 1.198 Sec |

**Torque**

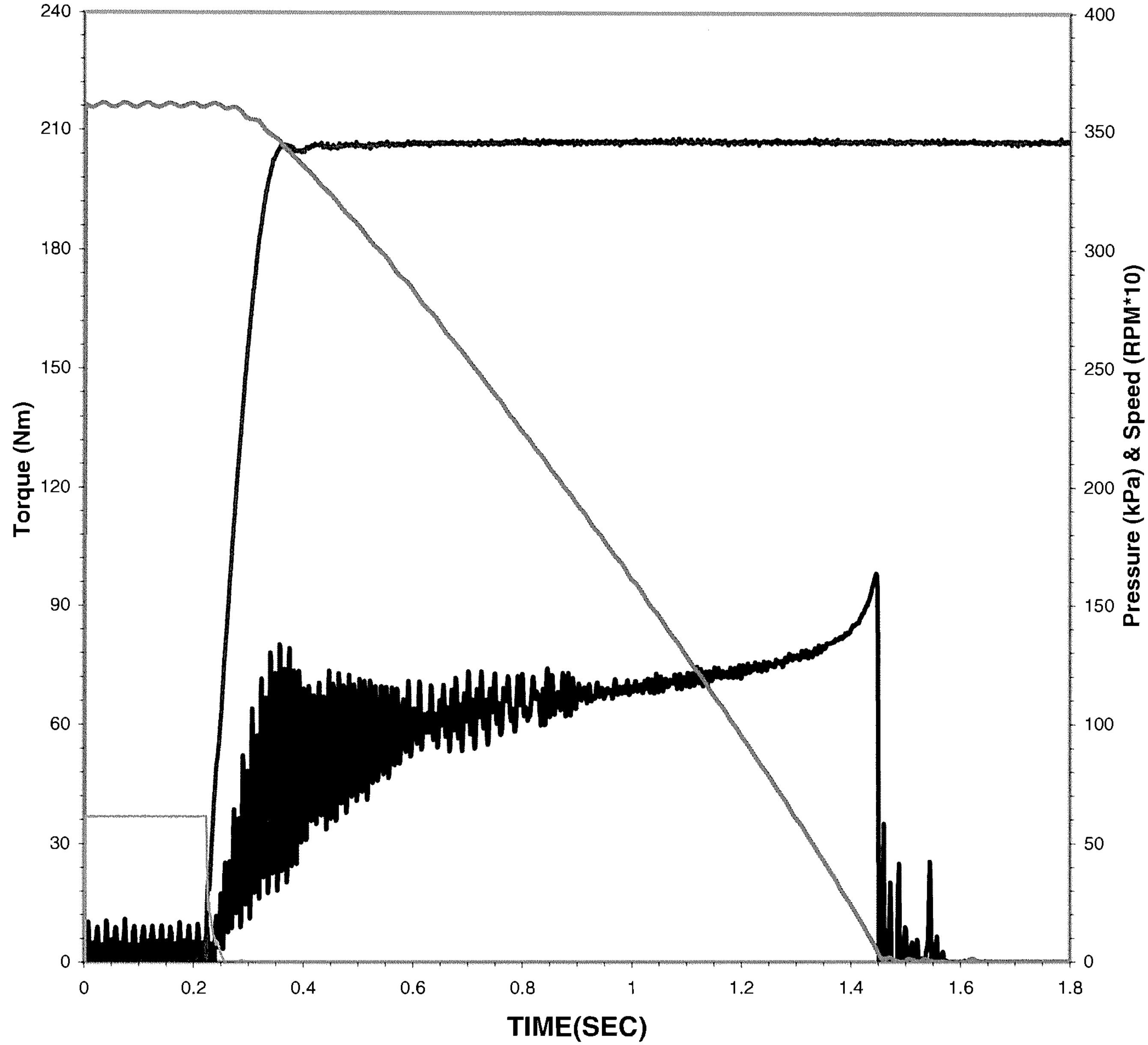
| | |
|---|---|
| 0.2 Sec Dyn: | 54 N*m |
| Midpoint Dyn: | 68 N*m |
| LwSpd Dynamic: | 99 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.089 |
| Midpoint Dyn: | 0.113 |
| LwSpd Dynamic: | 0.164 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE A




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 18:30:09 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 501 |
| Temperature: | 88.7 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 346 kPa (345 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 14.3 KJ (14.50 ± 0.40 KJ) |
| Engage Time: | 1.226 Sec |

**Torque**

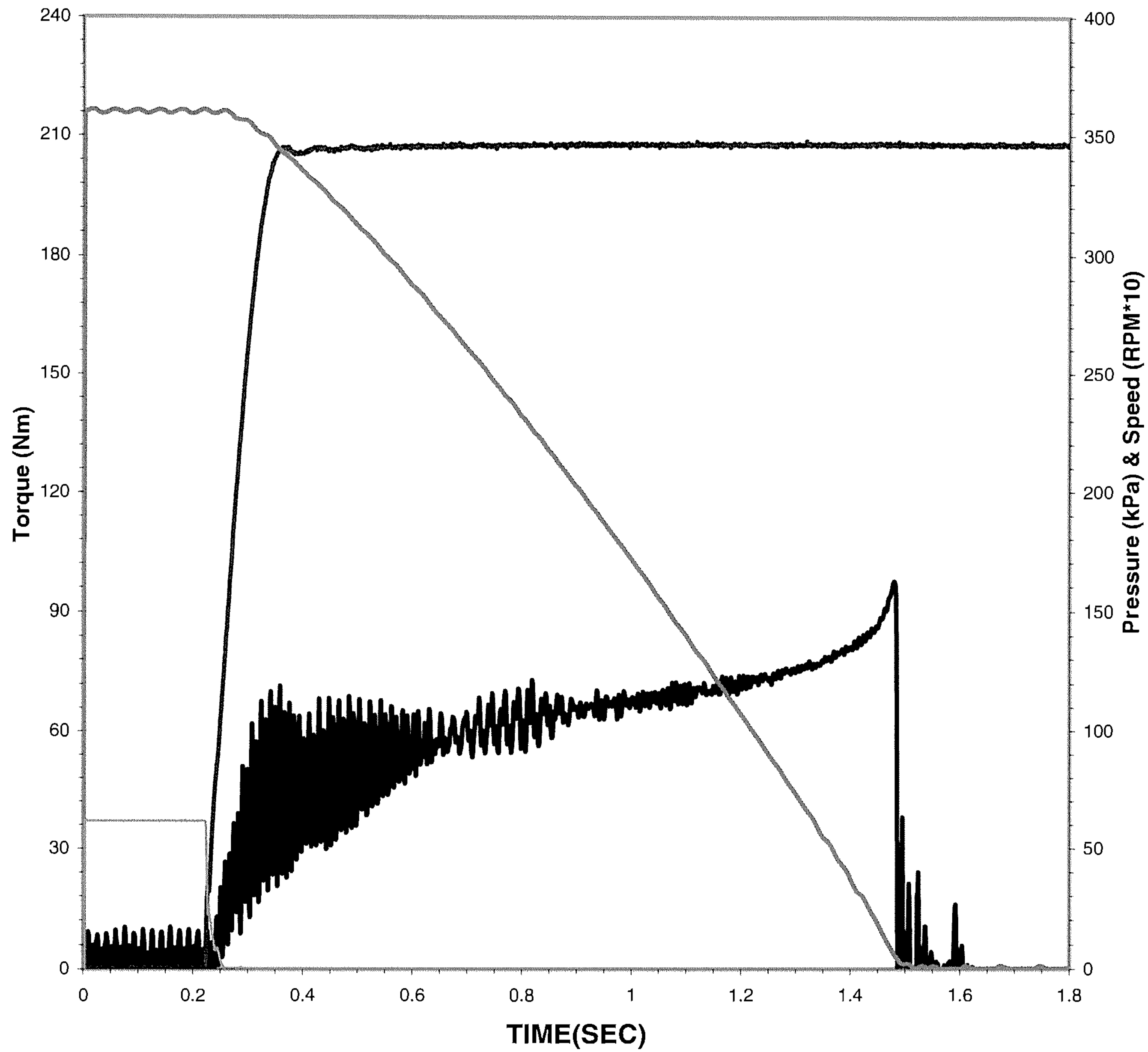
| | |
|---|---|
| 0.2 Sec Dyn: | 52 N*m |
| Midpoint Dyn: | 67 N*m |
| LwSpd Dynamic: | 98 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.087 |
| Midpoint Dyn: | 0.111 |
| LwSpd Dynamic: | 0.163 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE A




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 20:34:24 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 998 |
| Temperature: | 93.0 °C<br>(93.3 ± 3.0 °C) |
| Apply Pressure: | 346 kPa<br>(345 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 14.3 KJ<br>(14.50 ± 0.40 KJ) |
| Engage Time: | 1.26 Sec |

**Torque**

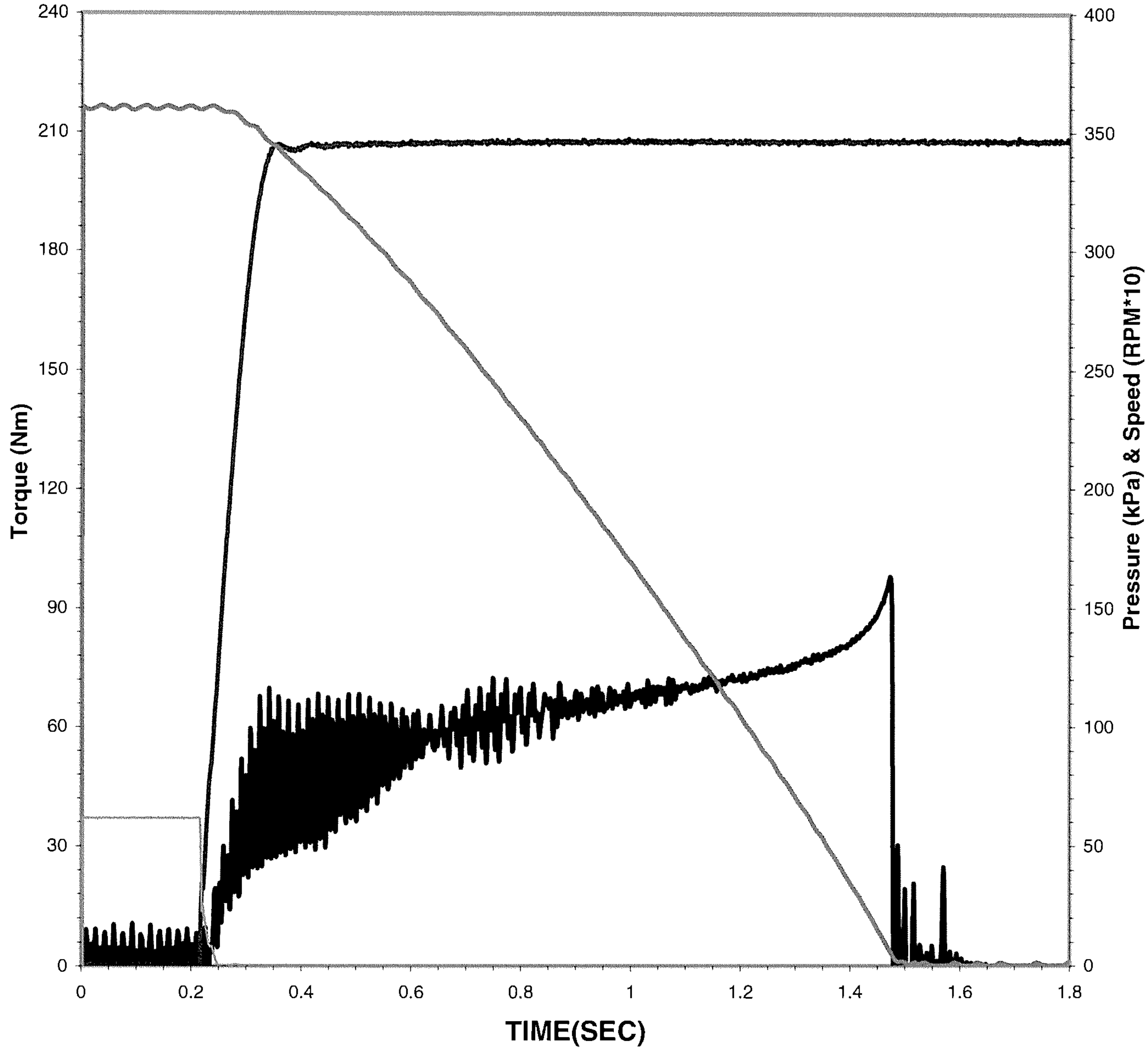
| | |
|---|---|
| 0.2 Sec Dyn: | 47 N*m |
| Midpoint Dyn: | 65 N*m |
| LwSpd Dynamic: | 95 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.078 |
| Midpoint Dyn: | 0.108 |
| LwSpd Dynamic: | 0.158 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE A




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 20:34:39 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 999 |
| Temperature: | 93.0 °C<br>(93.3 ± 3.0 °C) |
| Apply Pressure: | 346 kPa<br>(345 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 14.3 KJ<br>(14.50 ± 0.40 KJ) |
| Engage Time: | 1.261 Sec |

**Torque**

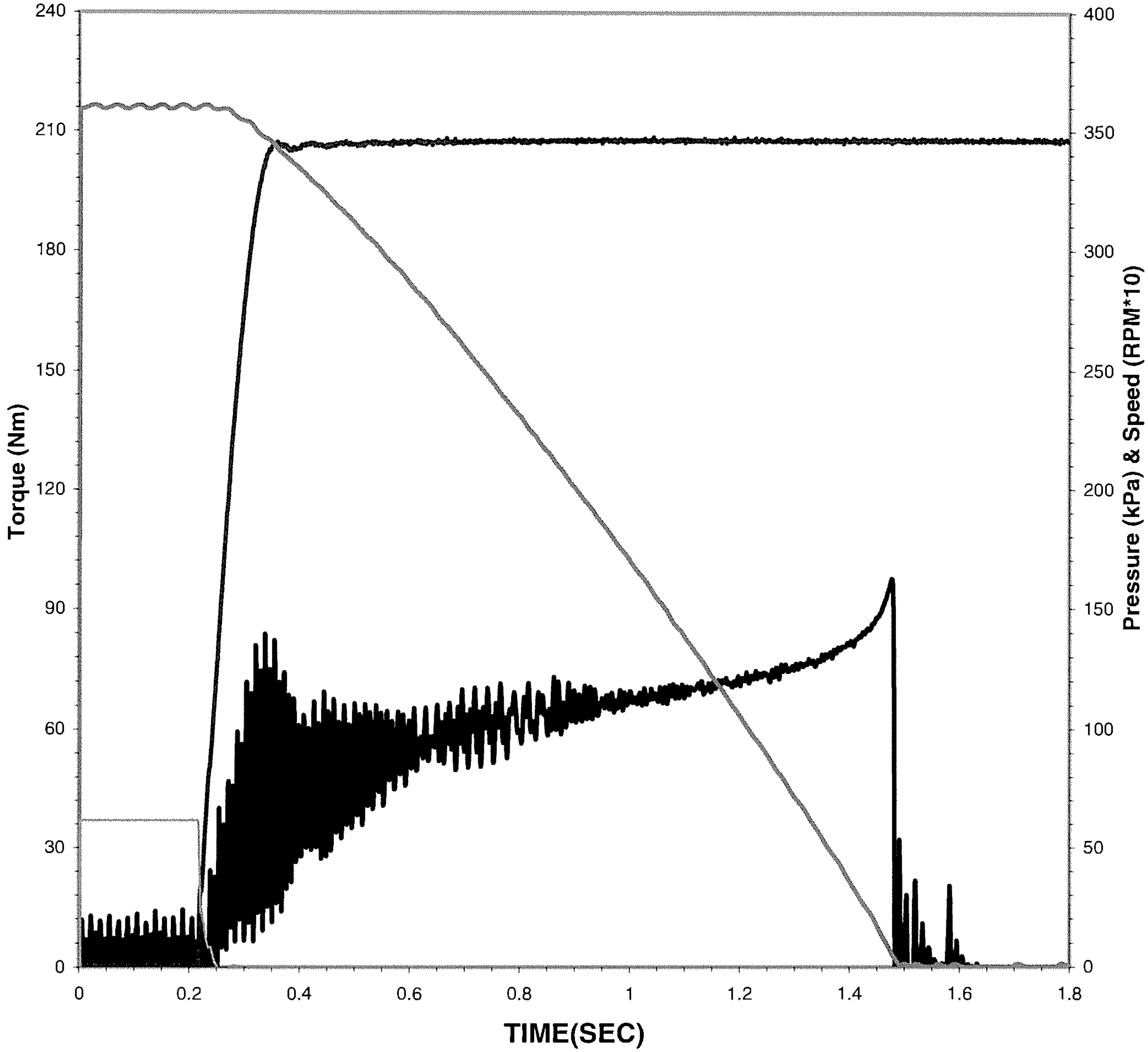
| | |
|---|---|
| 0.2 Sec Dyn: | 47 N*m |
| Midpoint Dyn: | 65 N*m |
| LwSpd Dynamic: | 97 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.078 |
| Midpoint Dyn: | 0.107 |
| LwSpd Dynamic: | 0.161 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE A




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 20:34:54 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 1000 |
| Temperature: | 93.0 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 346 kPa (345 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 14.3 KJ (14.50 ± 0.40 KJ) |
| Engage Time: | 1.264 Sec |

**Torque**

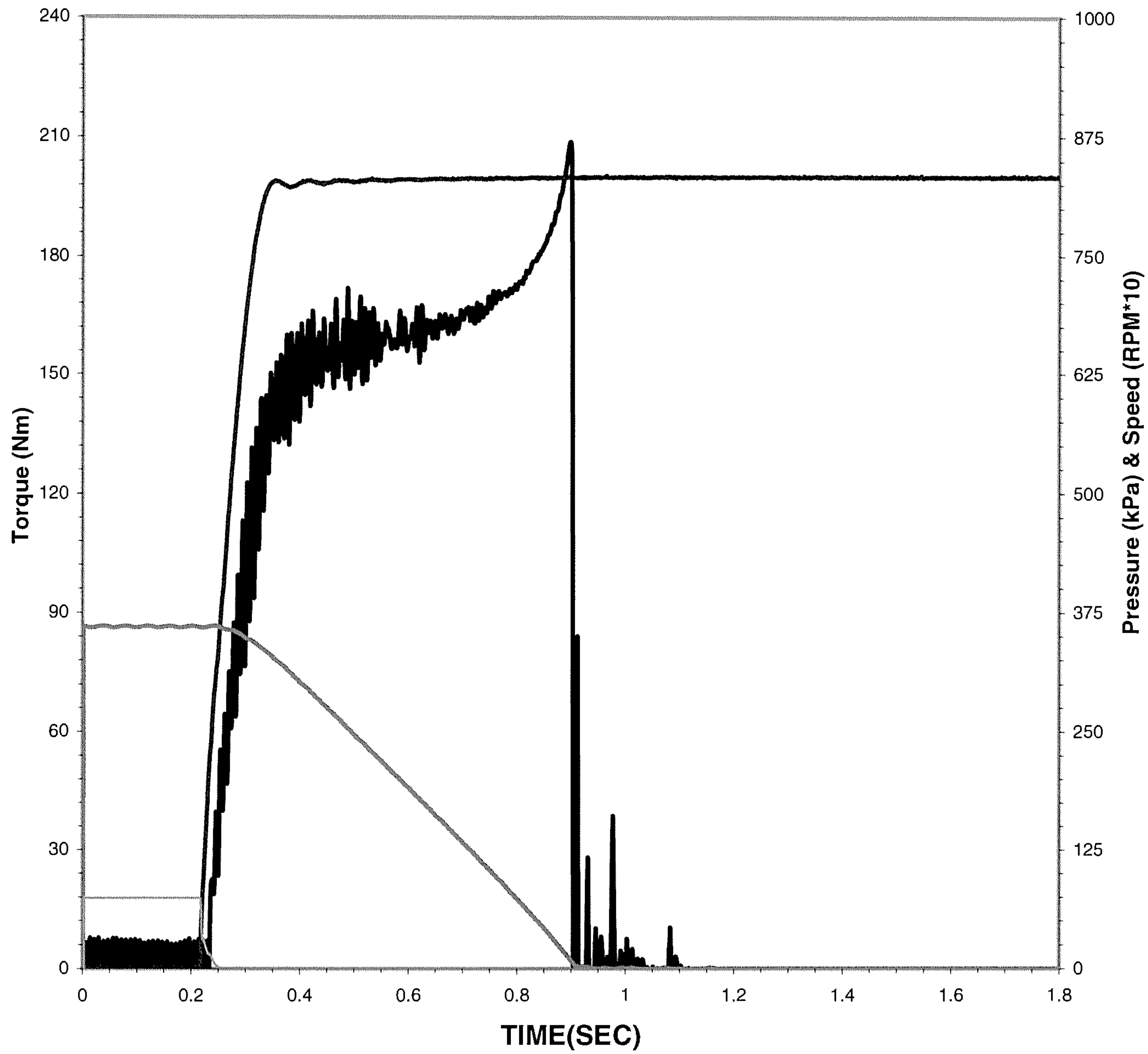
| | |
|---|---|
| 0.2 Sec Dyn: | 47 N*m |
| Midpoint Dyn: | 65 N*m |
| LwSpd Dynamic: | 96 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.078 |
| Midpoint Dyn: | 0.108 |
| LwSpd Dynamic: | 0.160 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 21:26:54 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 1010 |
| Temperature: | 90.4 °C<br>(112.7 ± 3.0 °C) |
| Apply Pressure: | 829 kPa<br>827 ± 7 KPa) |
| Apply Rate: | 0.14 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ<br>(18.71 ± 0.40 KJ) |
| Engage Time: | 0.688 Sec |

**Torque**

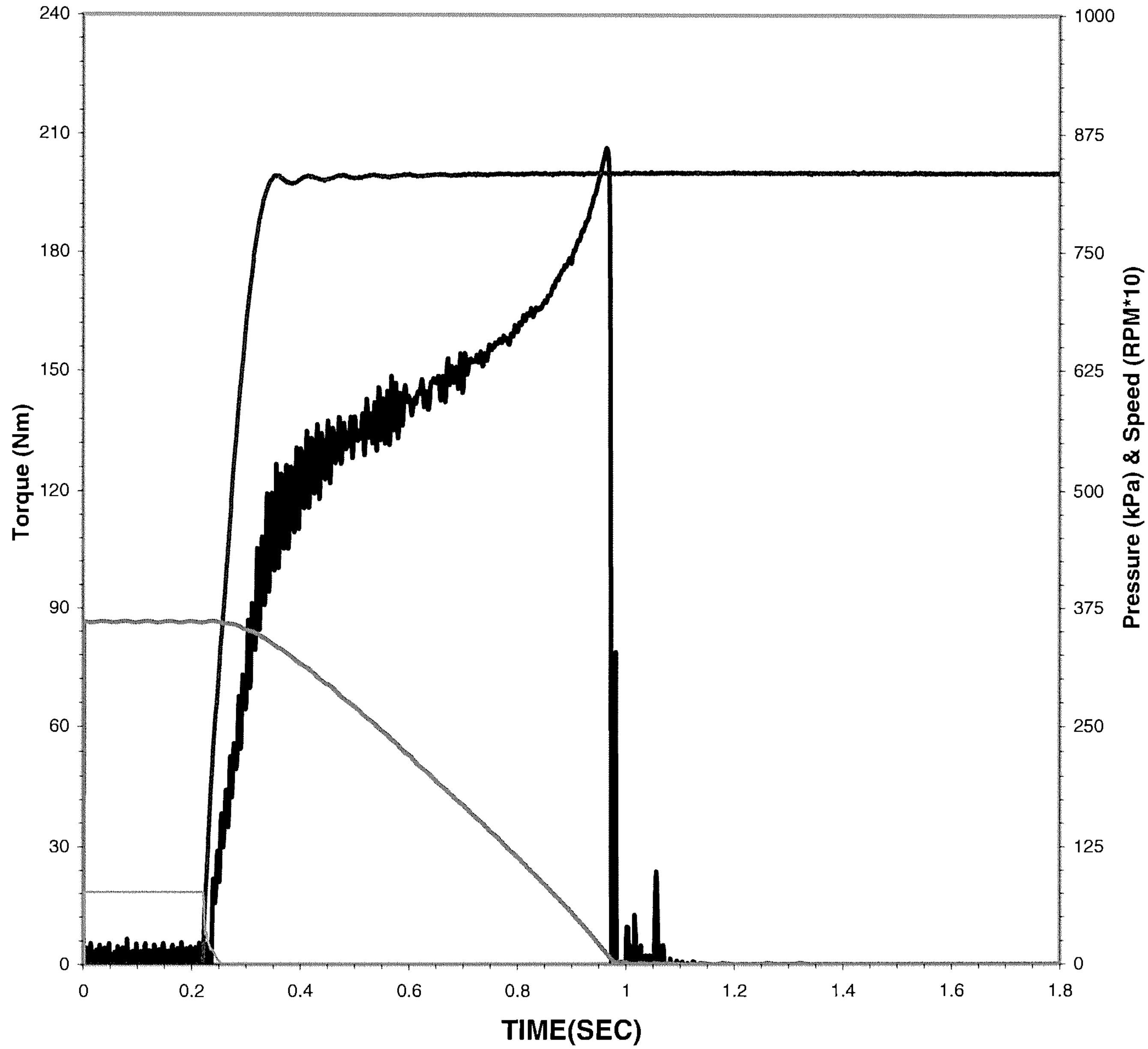
| | |
|---|---|
| 0.2 Sec Dyn: | 155 N*m |
| Midpoint Dyn: | 159 N*m |
| LwSpd Dynamic: | 206 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.107 |
| Midpoint Dyn: | 0.110 |
| LwSpd Dynamic: | 0.142 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 23:29:09 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 1499 |
| Temperature: | 110.5 °C<br>(112.7 ± 3.0 °C) |
| Apply Pressure: | 831 kPa<br>827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ<br>(18.71 ± 0.40 KJ) |
| Engage Time: | 0.752 Sec |

**Torque**

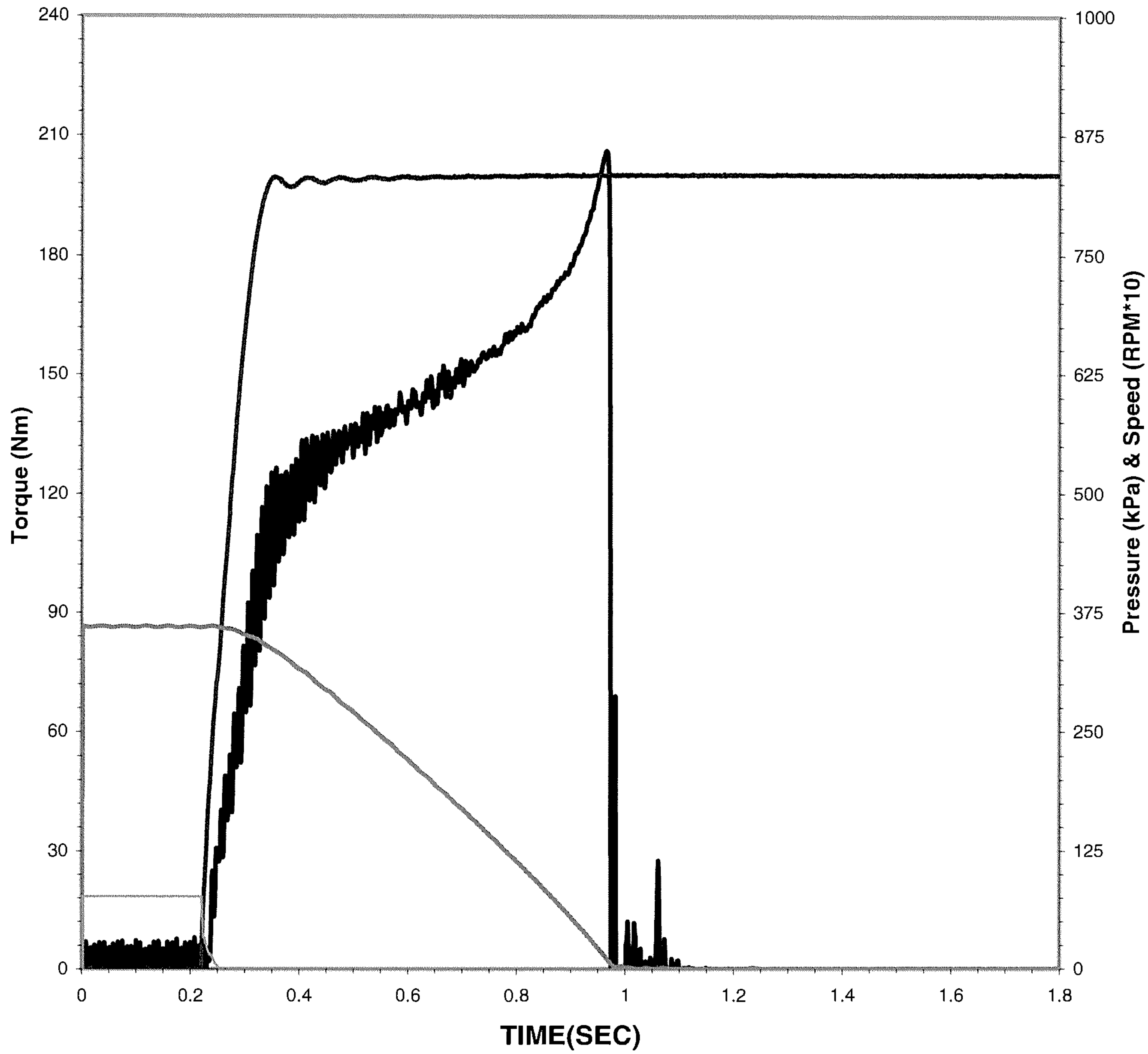
| | |
|---|---|
| 0.2 Sec Dyn: | 125 N*m |
| Midpoint Dyn: | 142 N*m |
| LwSpd Dynamic: | 198 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.087 |
| Midpoint Dyn: | 0.098 |
| LwSpd Dynamic: | 0.137 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 23:29:24 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 1500 |
| Temperature: | 110.4 °C<br>(112.7 ± 3.0 °C) |
| Apply Pressure: | 831 kPa<br>827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.5 KJ<br>(18.71 ± 0.40 KJ) |
| Engage Time: | 0.754 Sec |

**Torque**

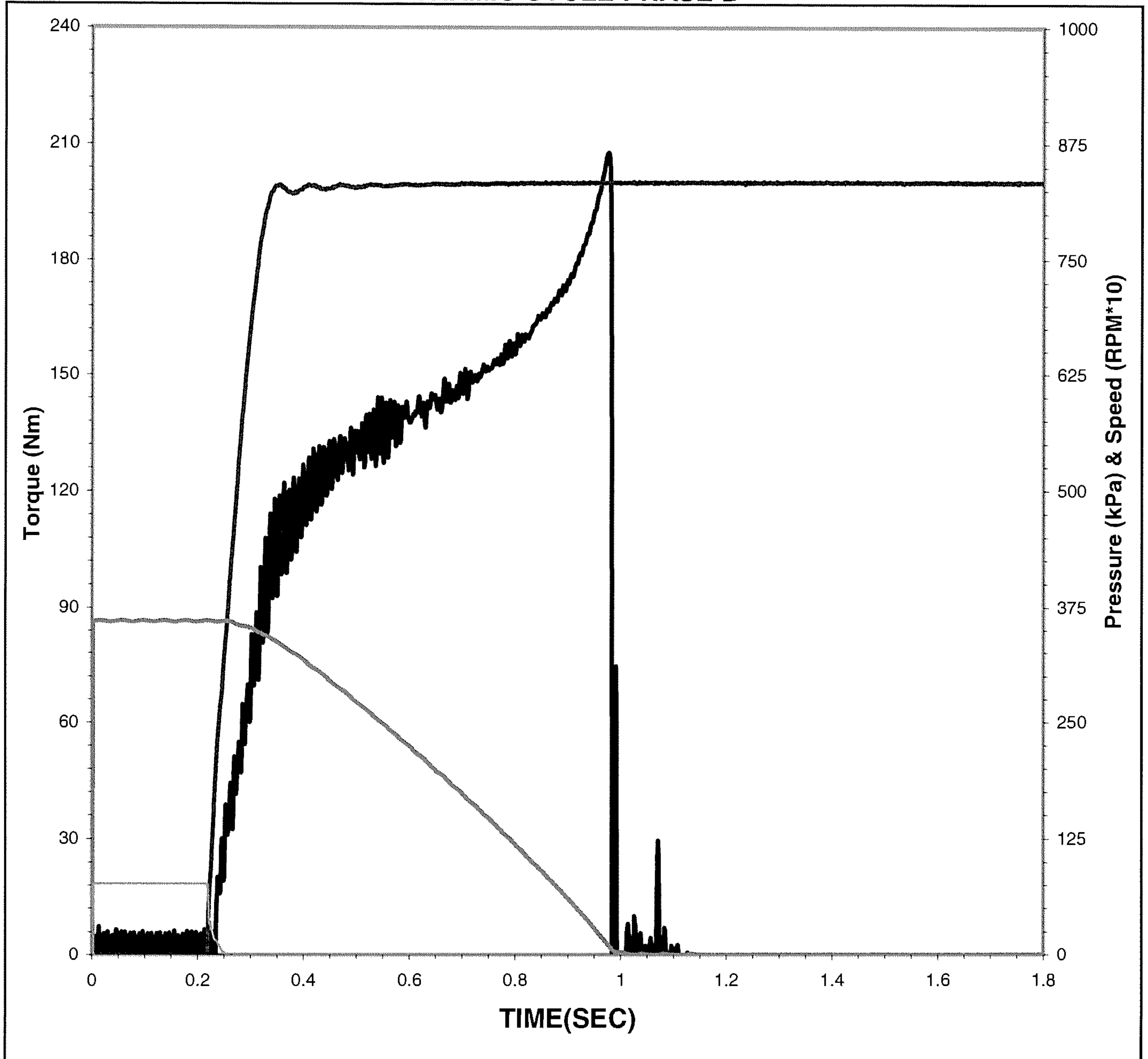
| | |
|---|---|
| 0.2 Sec Dyn: | 126 N*m |
| Midpoint Dyn: | 142 N*m |
| LwSpd Dynamic: | 202 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.087 |
| Midpoint Dyn: | 0.098 |
| LwSpd Dynamic: | 0.139 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/14/2011 |
| Time of Test: | 23:29:51 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 1501 |
| Temperature: | 106.1 °C (112.7 ± 3.0 °C) |
| Apply Pressure: | 831 kPa 827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.5 KJ (18.71 ± 0.40 KJ) |
| Engage Time: | 0.765 Sec |

**Torque**

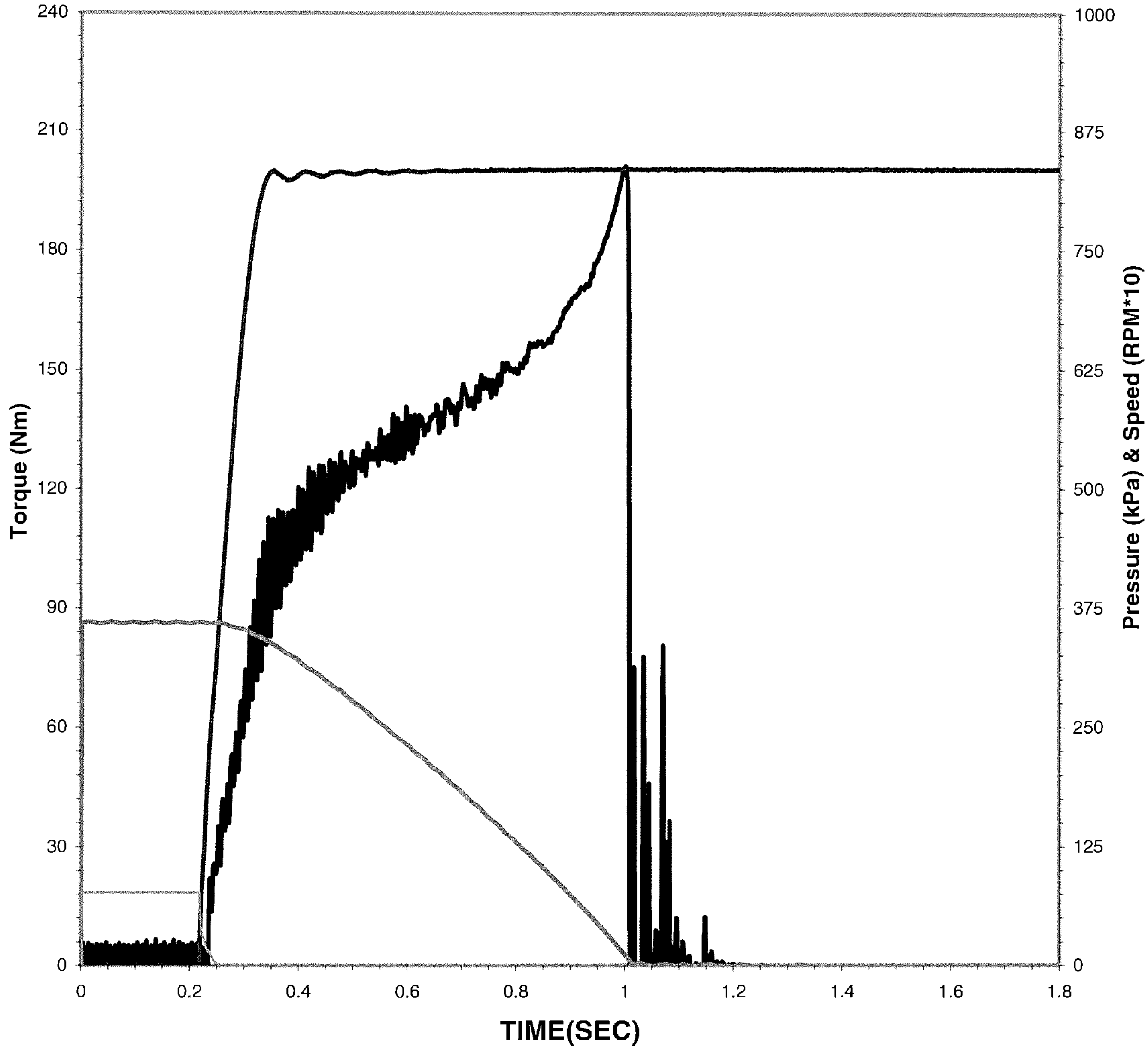
| | |
|---|---|
| 0.2 Sec Dyn: | 122 N*m |
| Midpoint Dyn: | 140 N*m |
| LwSpd Dynamic: | 205 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.084 |
| Midpoint Dyn: | 0.097 |
| LwSpd Dynamic: | 0.141 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 1:34:21 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 1999 |
| Temperature: | 110.6 °C (112.7 ± 3.0 °C) |
| Apply Pressure: | 832 kPa 827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ (18.71 ± 0.40 KJ) |
| Engage Time: | 0.792 Sec |

**Torque**

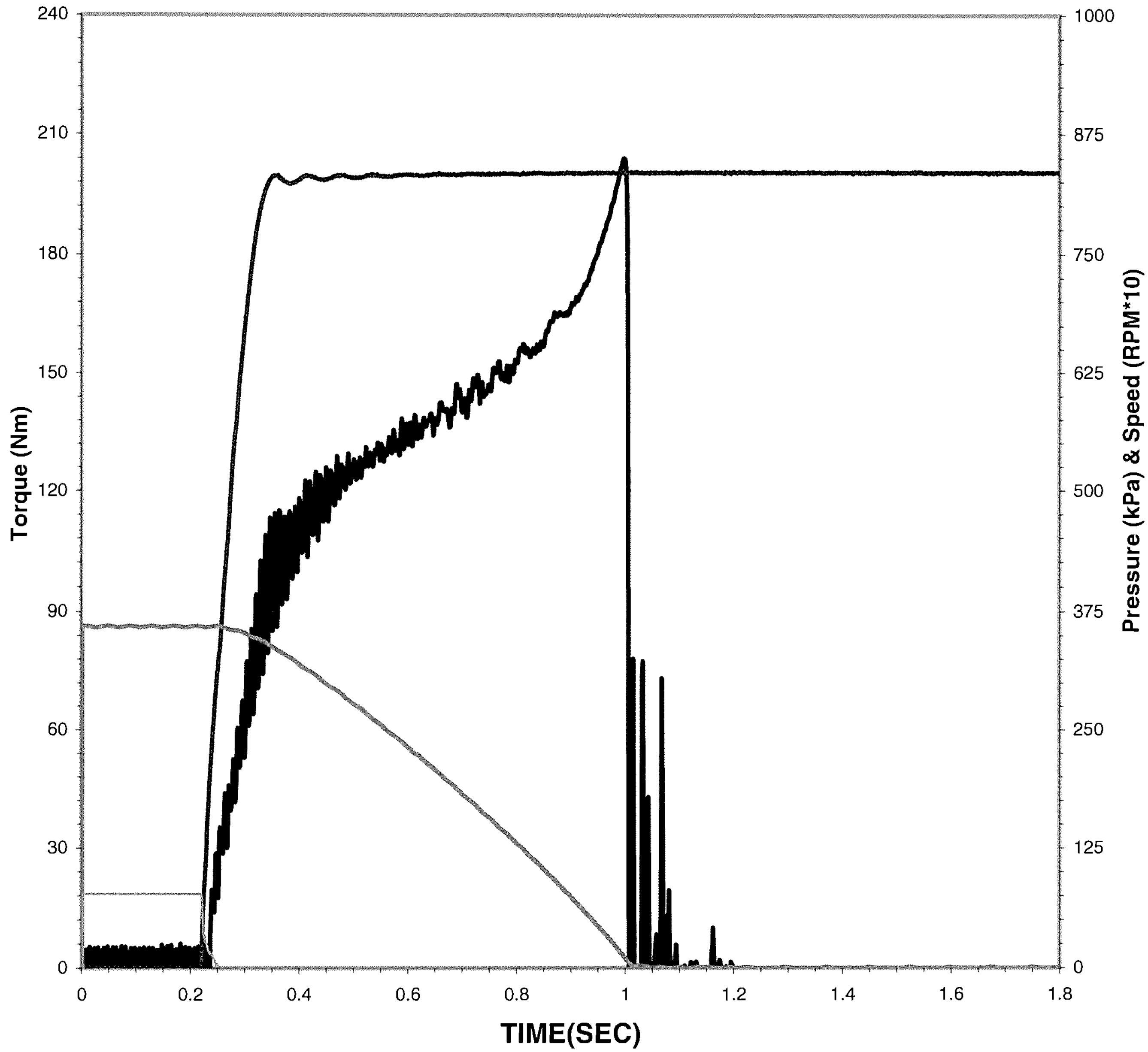
| | |
|---|---|
| 0.2 Sec Dyn: | 114 N*m |
| Midpoint Dyn: | 136 N*m |
| LwSpd Dynamic: | 194 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.079 |
| Midpoint Dyn: | 0.094 |
| LwSpd Dynamic: | 0.134 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 1:34:36 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 2000 |
| Temperature: | 110.5 °C<br>(112.7 ± 3.0 °C) |
| Apply Pressure: | 832 kPa<br>827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ<br>(18.71 ± 0.40 KJ) |
| Engage Time: | 0.786 Sec |

**Torque**

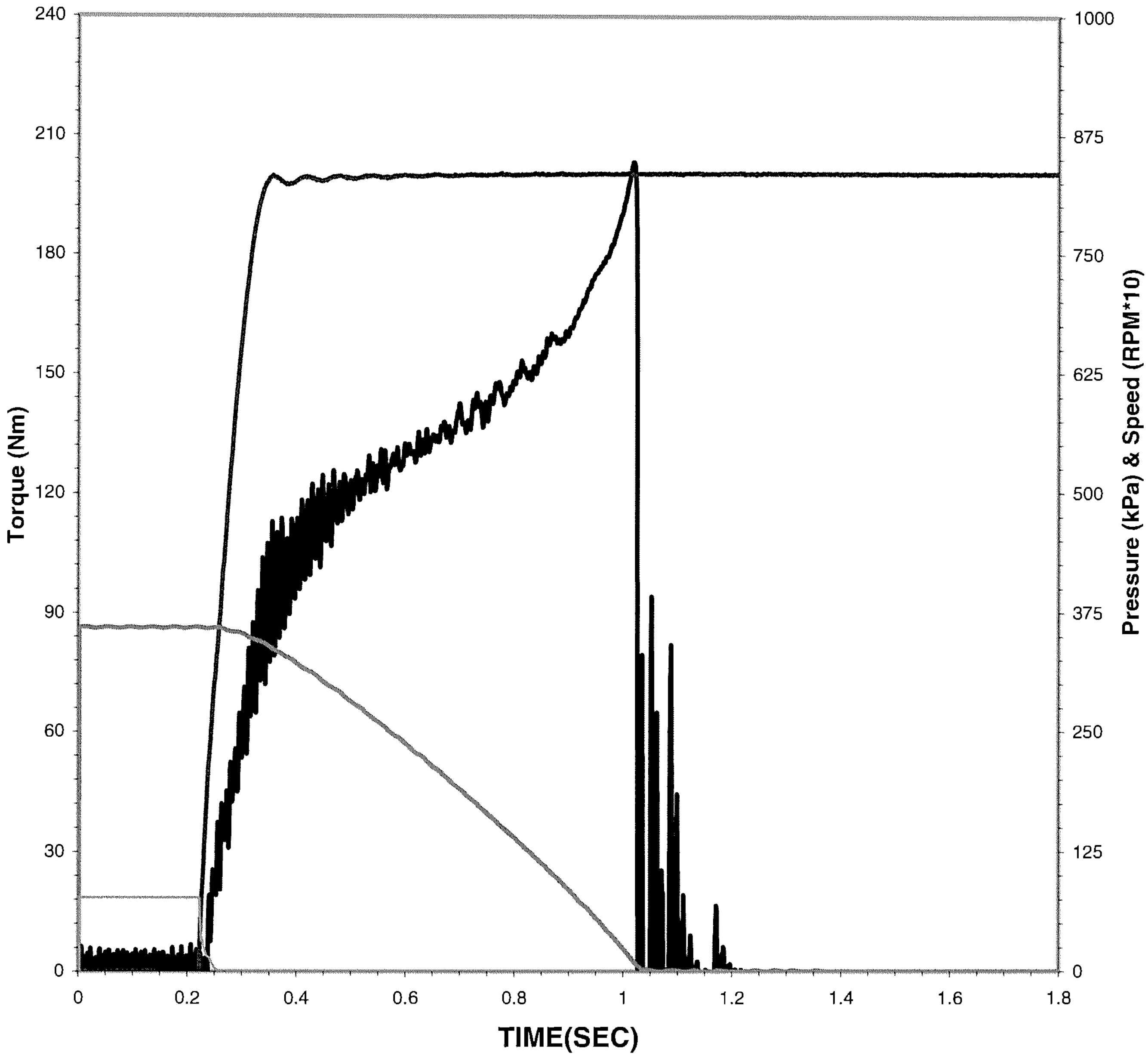
| | |
|---|---|
| 0.2 Sec Dyn: | 114 N*m |
| Midpoint Dyn: | 136 N*m |
| LwSpd Dynamic: | 196 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.079 |
| Midpoint Dyn: | 0.094 |
| LwSpd Dynamic: | 0.135 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 1:35:02 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 2001 |
| Temperature: | 106.1 °C<br>(112.7 ± 3.0 °C) |
| Apply Pressure: | 832 kPa<br>827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ<br>(18.71 ± 0.40 KJ) |
| Engage Time: | 0.805 Sec |

**Torque**

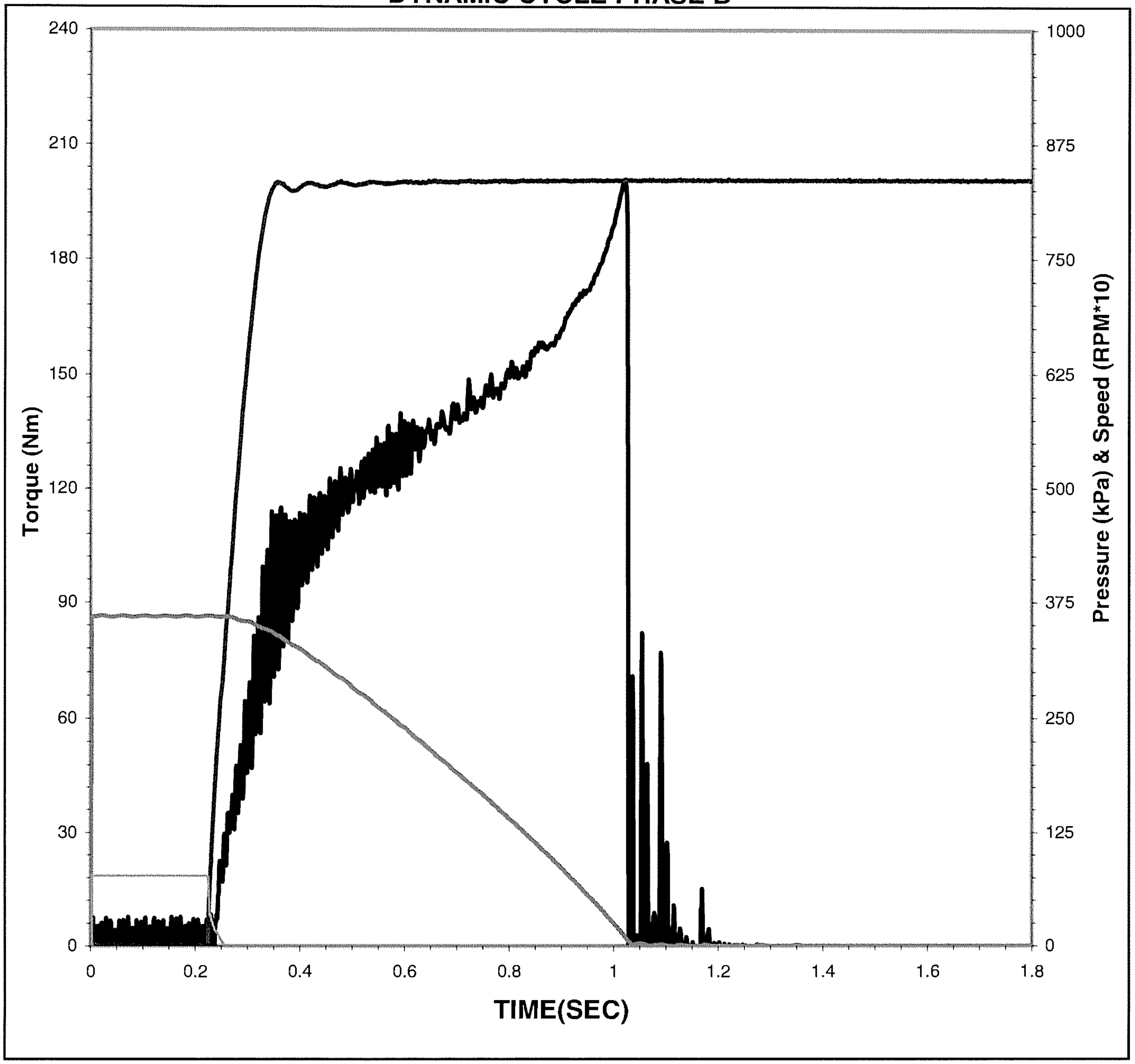
| | |
|---|---|
| 0.2 Sec Dyn: | 110 N*m |
| Midpoint Dyn: | 132 N*m |
| LwSpd Dynamic: | 198 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.076 |
| Midpoint Dyn: | 0.091 |
| LwSpd Dynamic: | 0.136 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 3:39:33 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 2499 |
| Temperature: | 110.4 °C<br>(112.7 ± 3.0 °C) |
| Apply Pressure: | 833 kPa<br>827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ<br>(18.71 ± 0.40 KJ) |
| Engage Time: | 0.805 Sec |

**Torque**

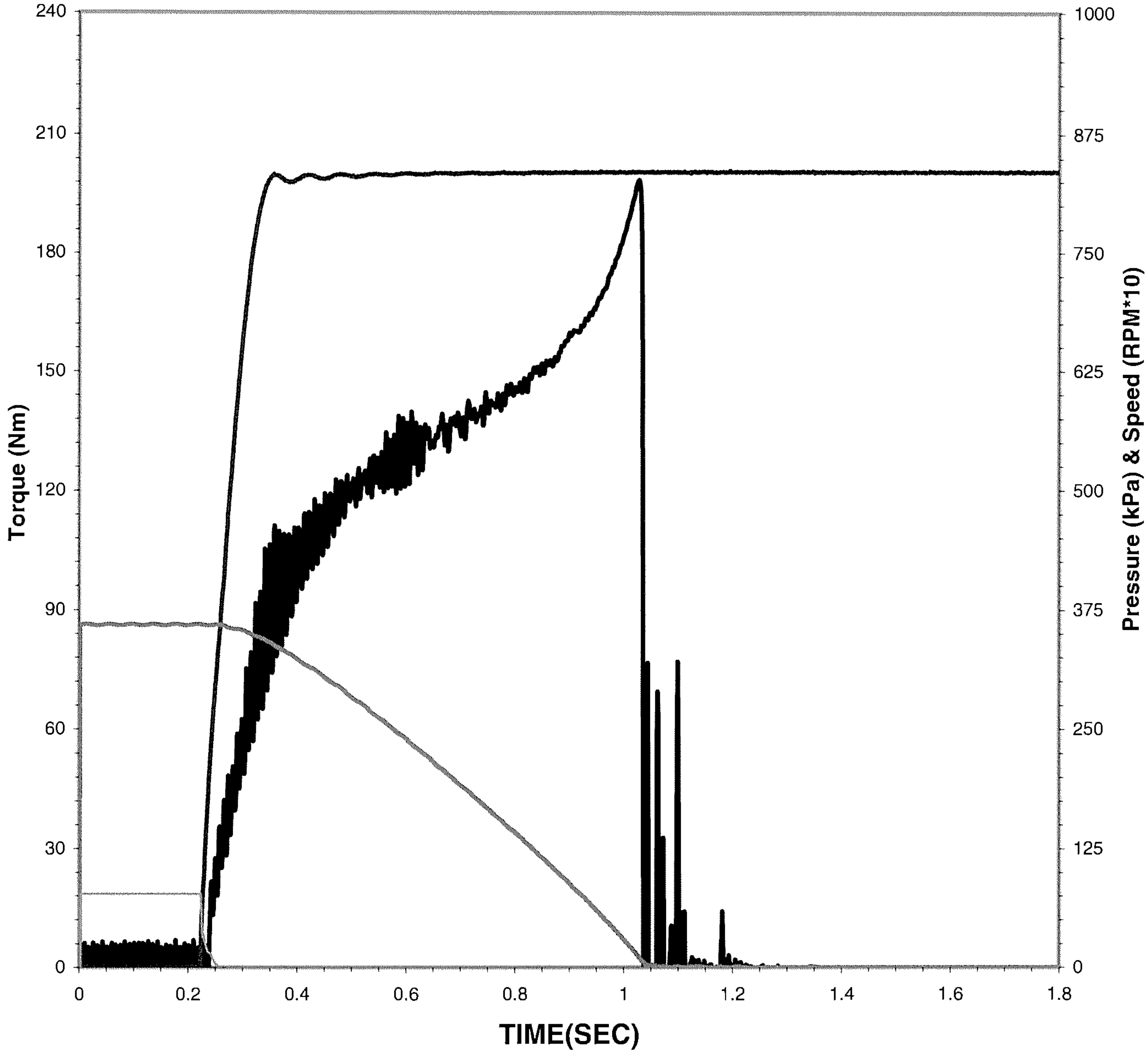
| | |
|---|---|
| 0.2 Sec Dyn: | 110 N*m |
| Midpoint Dyn: | 133 N*m |
| LwSpd Dynamic: | 196 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.076 |
| Midpoint Dyn: | 0.092 |
| LwSpd Dynamic: | 0.135 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 3:39:48 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 2500 |
| Temperature: | 110.5 °C (112.7 ± 3.0 °C) |
| Apply Pressure: | 833 kPa 827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ (18.71 ± 0.40 KJ) |
| Engage Time: | 0.814 Sec |

**Torque**

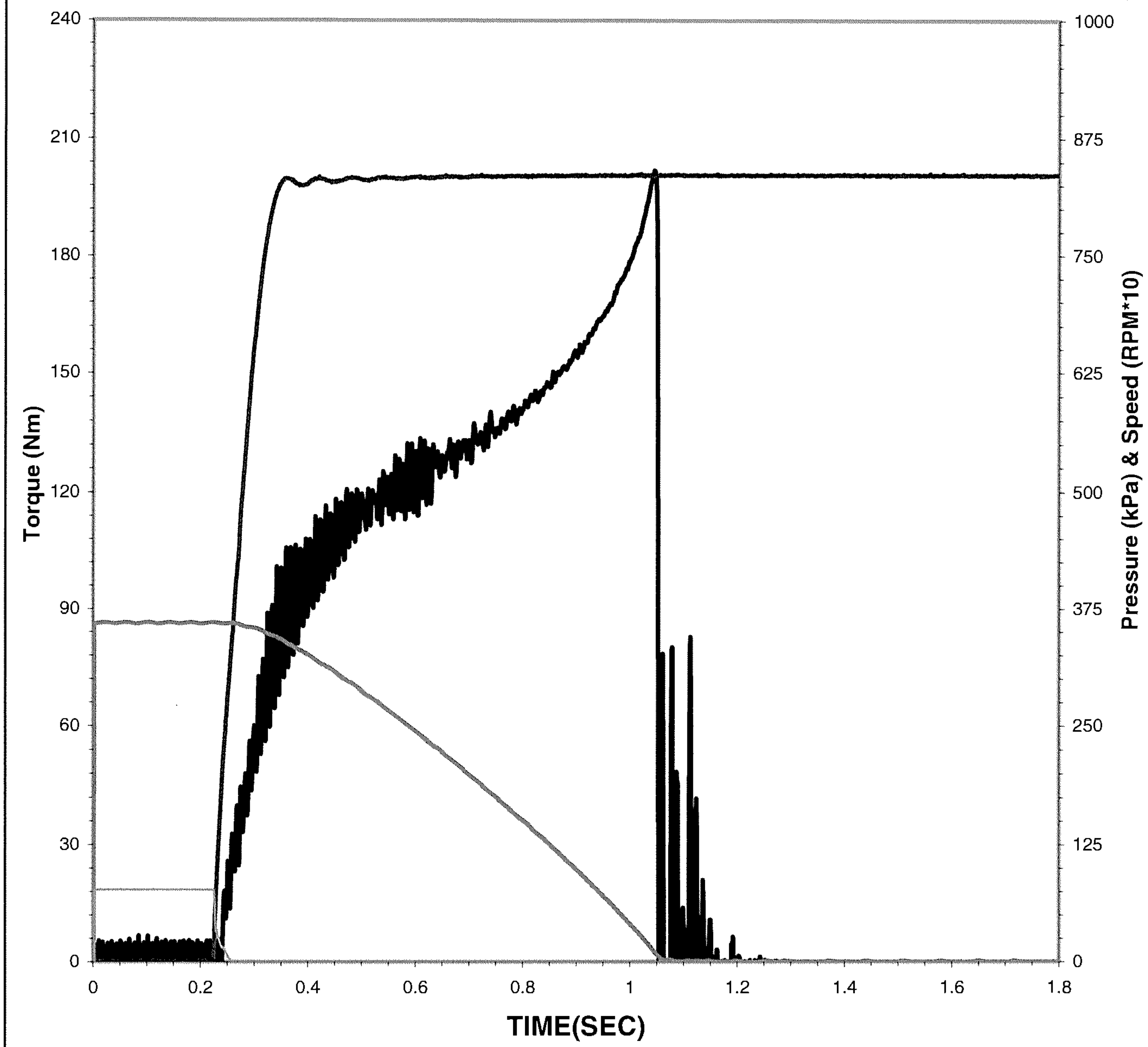
| | |
|---|---|
| 0.2 Sec Dyn: | 107 N*m |
| Midpoint Dyn: | 132 N*m |
| LwSpd Dynamic: | 191 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.074 |
| Midpoint Dyn: | 0.091 |
| LwSpd Dynamic: | 0.132 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 3:40:14 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 2501 |
| Temperature: | 106.0 °C<br>(112.7 ± 3.0 °C) |
| Apply Pressure: | 833 kPa<br>827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ<br>(18.71 ± 0.40 KJ) |
| Engage Time: | 0.829 Sec |

**Torque**

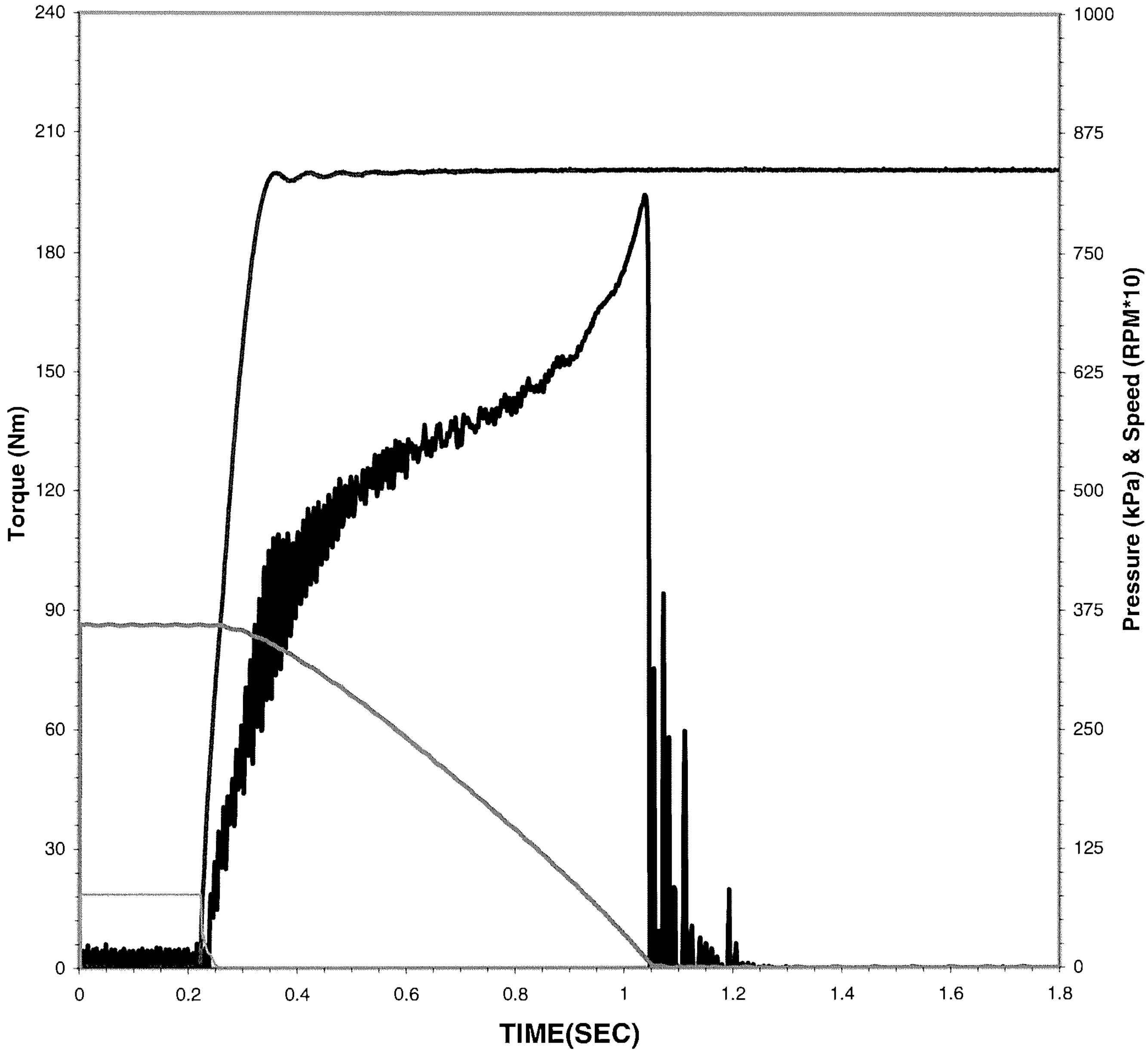
| | |
|---|---|
| 0.2 Sec Dyn: | 105 N*m |
| Midpoint Dyn: | 127 N*m |
| LwSpd Dynamic: | 198 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.073 |
| Midpoint Dyn: | 0.088 |
| LwSpd Dynamic: | 0.137 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 5:44:44 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 2999 |
| Temperature: | 110.6 °C<br>(112.7 ± 3.0 °C) |
| Apply Pressure: | 833 kPa<br>827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ<br>(18.71 ± 0.40 KJ) |
| Engage Time: | 0.825 Sec |

**Torque**

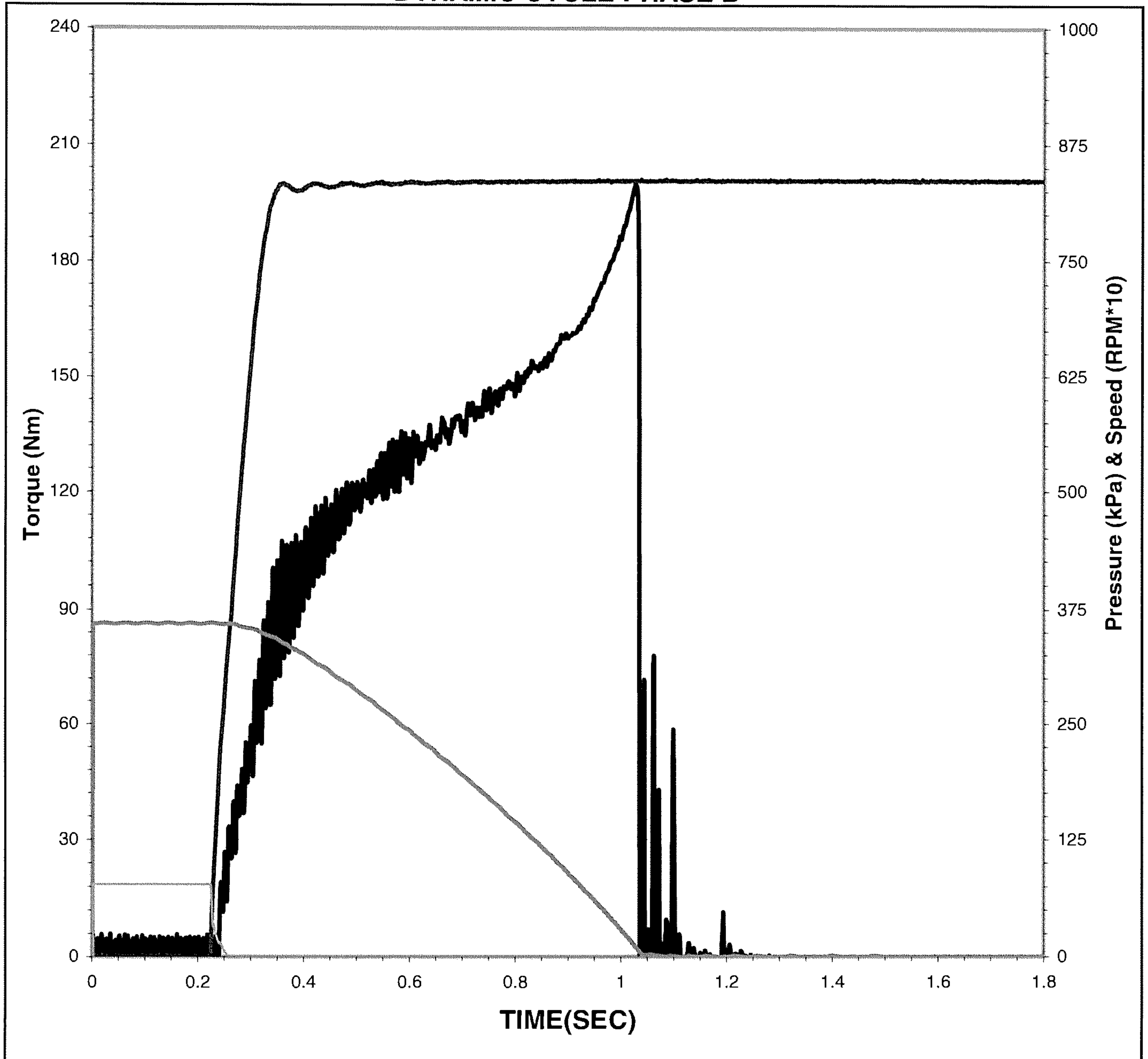
| | |
|---|---|
| 0.2 Sec Dyn: | 106 N*m |
| Midpoint Dyn: | 132 N*m |
| LwSpd Dynamic: | 188 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.073 |
| Midpoint Dyn: | 0.091 |
| LwSpd Dynamic: | 0.130 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 5:44:59 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 3000 |
| Temperature: | 110.5 °C<br>(112.7 ± 3.0 °C) |
| Apply Pressure: | 833 kPa<br>827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ<br>(18.71 ± 0.40 KJ) |
| Engage Time: | 0.811 Sec |

**Torque**

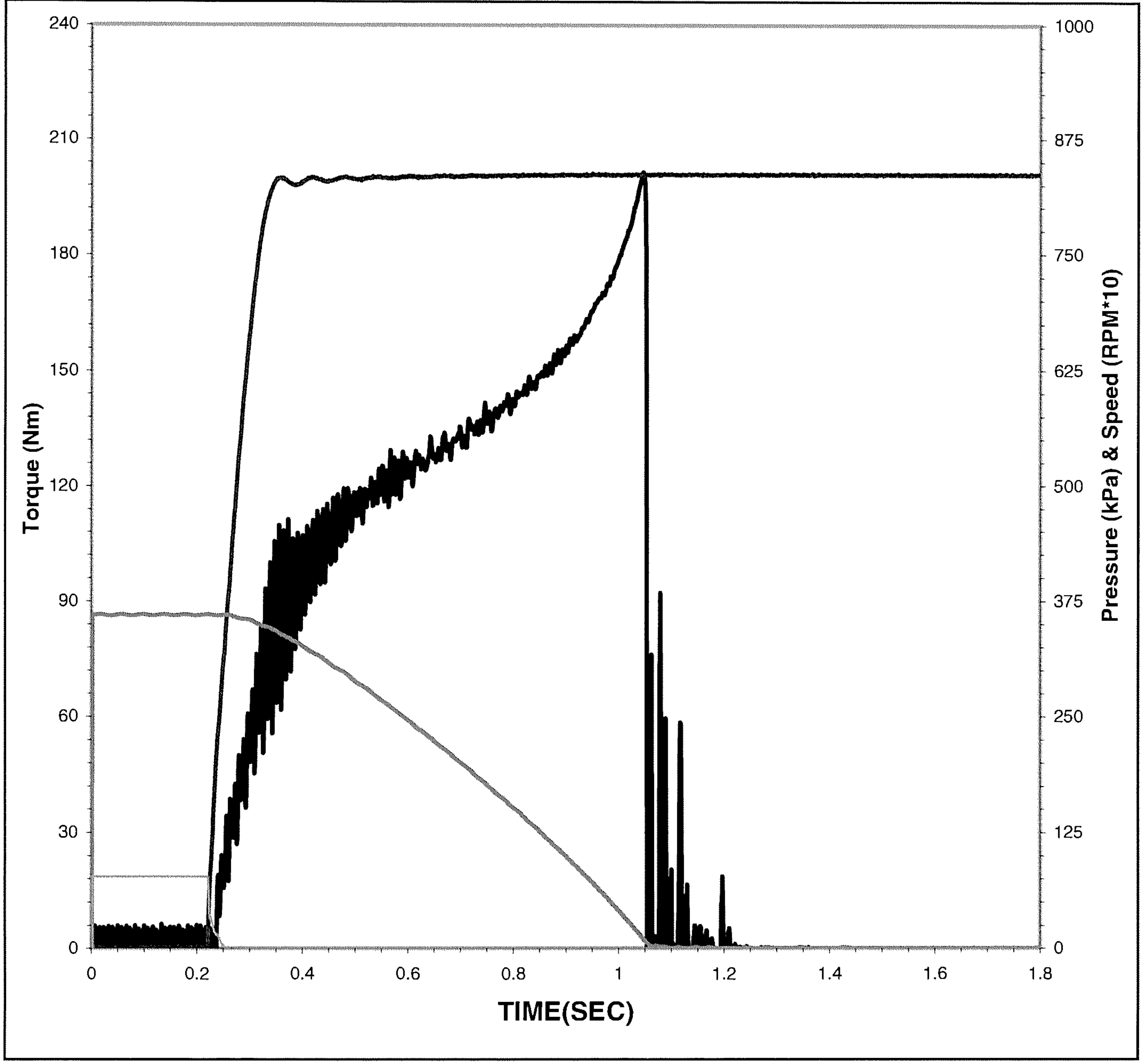
| | |
|---|---|
| 0.2 Sec Dyn: | 107 N*m |
| Midpoint Dyn: | 133 N*m |
| LwSpd Dynamic: | 196 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.074 |
| Midpoint Dyn: | 0.092 |
| LwSpd Dynamic: | 0.136 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 5:45:26 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 3001 |
| Temperature: | 106.1 °C<br>(112.7 ± 3.0 °C) |
| Apply Pressure: | 833 kPa<br>827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.5 KJ<br>(18.71 ± 0.40 KJ) |
| Engage Time: | 0.833 Sec |

**Torque**

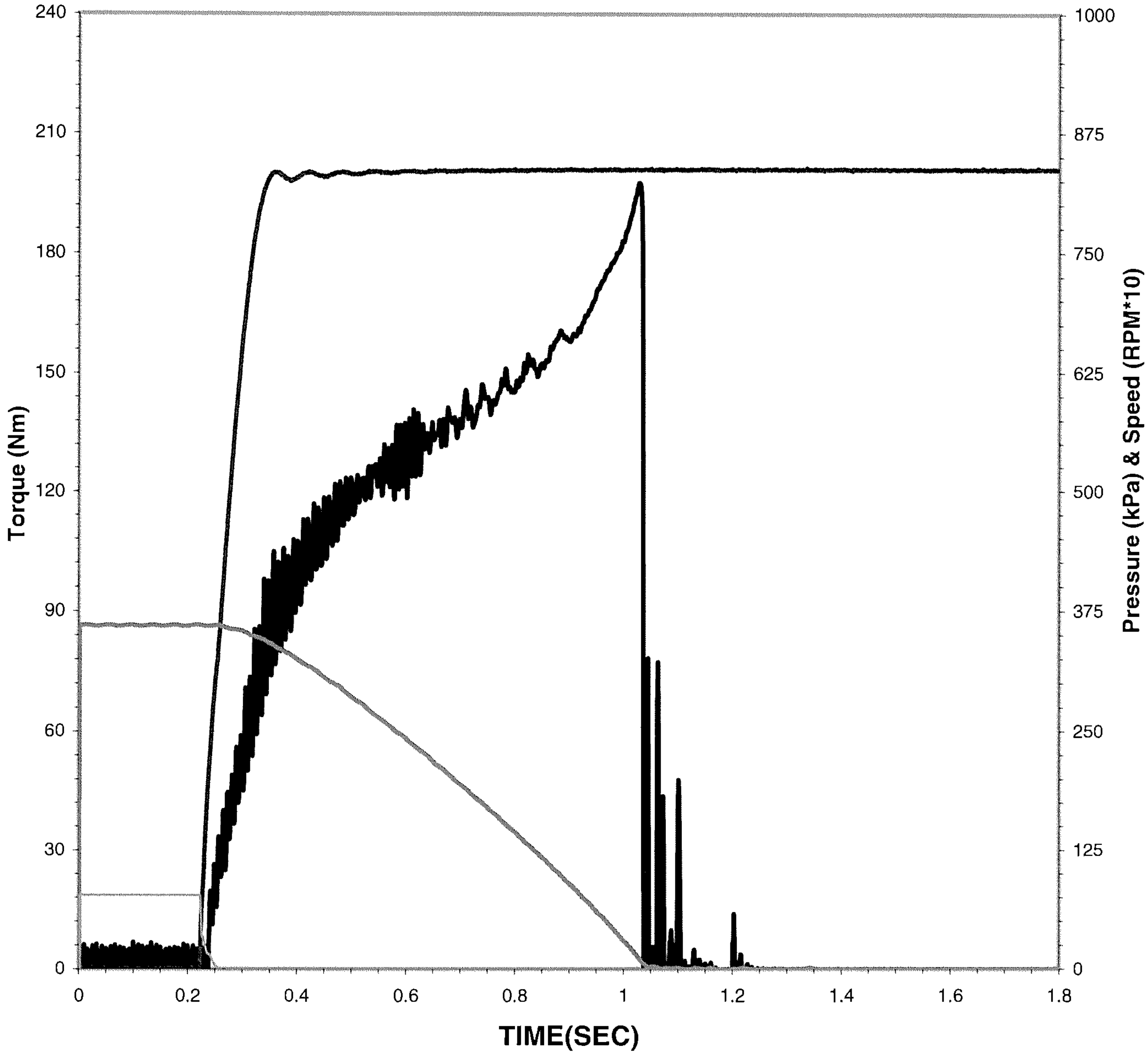
| | |
|---|---|
| 0.2 Sec Dyn: | 102 N*m |
| Midpoint Dyn: | 128 N*m |
| LwSpd Dynamic: | 195 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.071 |
| Midpoint Dyn: | 0.089 |
| LwSpd Dynamic: | 0.135 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| **Date of Test:** | **10/15/2011** |
| **Time of Test:** | **7:49:56** |
| **Test Number:** | **C4-4-1342** |
| **Fluid Code:** | **LO271510** |
| **Cycle Number:** | **3499** |
| **Temperature:** | **110.8 °C** |
| | (112.7 ± 3.0 °C) |
| **Apply Pressure:** | **833 kPa** |
| | 827 ± 7 KPa) |
| **Apply Rate:** | **0.13 Sec** |
| | (0.15 ± 0.02 Sec) |
| **Energy:** | **18.4 KJ** |
| | (18.71 ± 0.40 KJ) |
| **Engage Time:** | **0.815 Sec** |

**Torque**

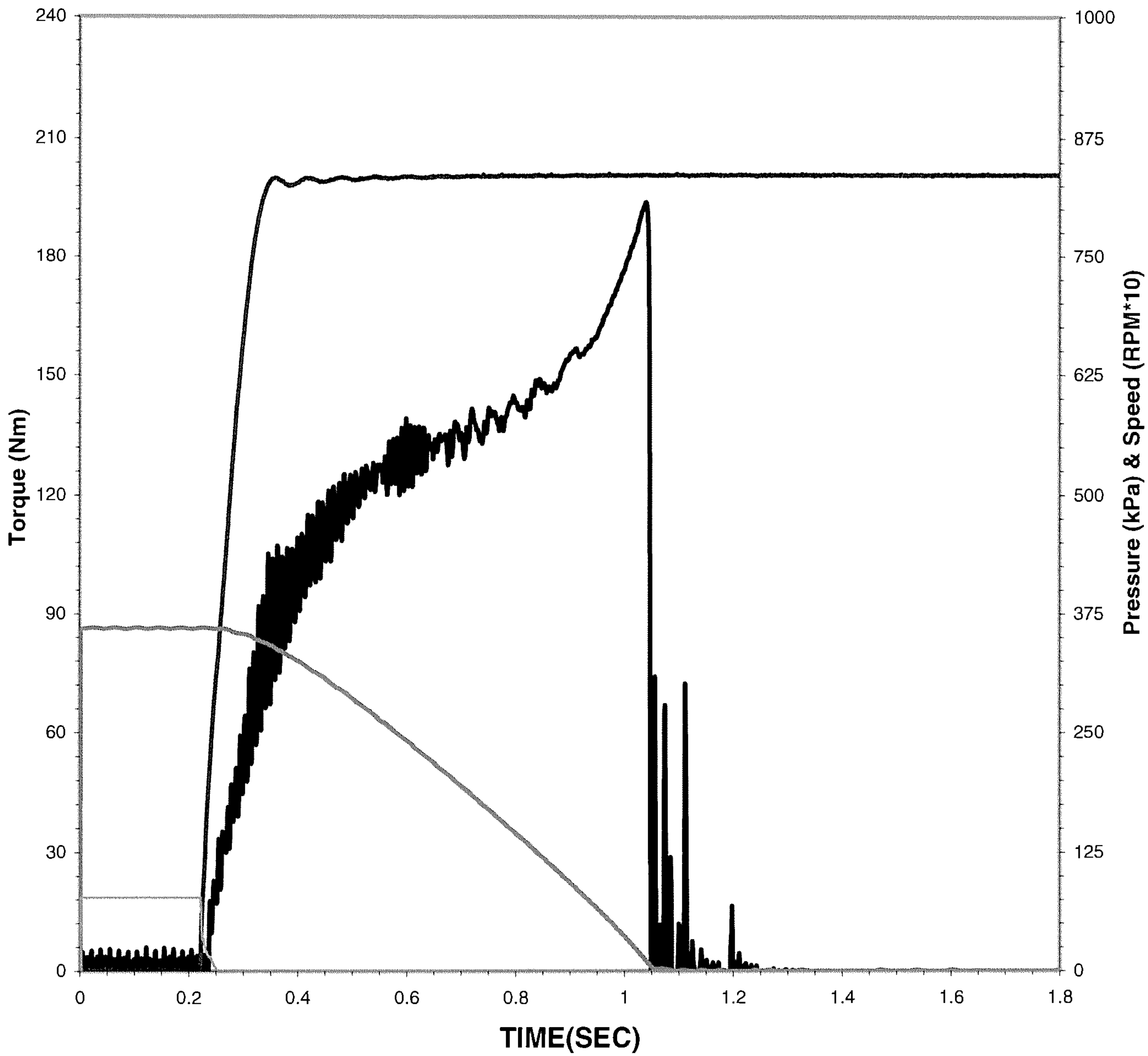
| | |
|---|---|
| **0.2 Sec Dyn:** | **106 N*m** |
| **Midpoint Dyn:** | **133 N*m** |
| **LwSpd Dynamic:** | **192 N*m** |

**Coefficient of Friction**

| | |
|---|---|
| **.2 Sec Dyn:** | **0.073** |
| **Midpoint Dyn:** | **0.092** |
| **LwSpd Dynamic:** | **0.133** |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 7:50:11 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 3500 |
| Temperature: | 110.9 °C (112.7 ± 3.0 °C) |
| Apply Pressure: | 833 kPa 827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ (18.71 ± 0.40 KJ) |
| Engage Time: | 0.828 Sec |

**Torque**

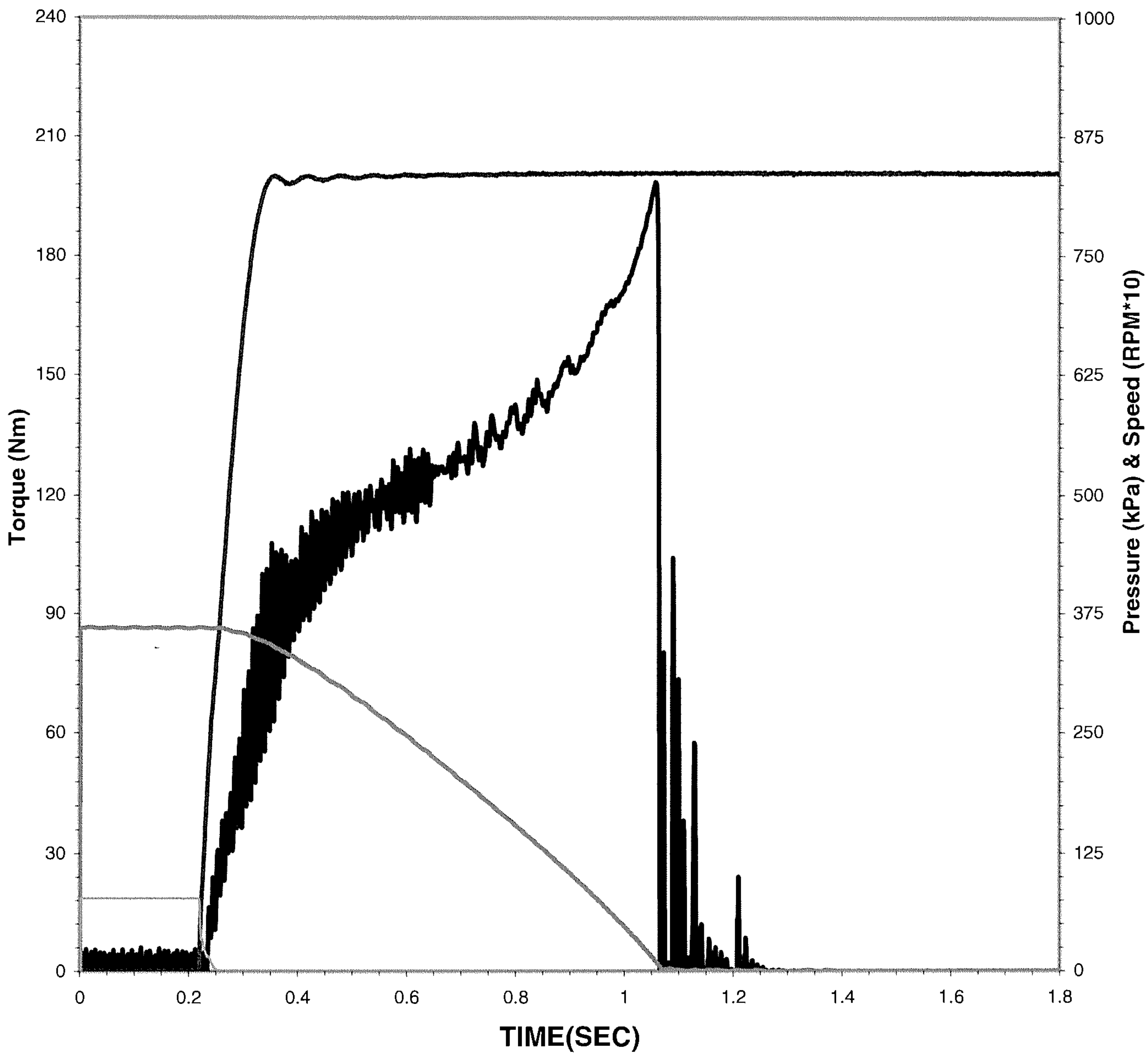
| | |
|---|---|
| 0.2 Sec Dyn: | 106 N*m |
| Midpoint Dyn: | 132 N*m |
| LwSpd Dynamic: | 188 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.073 |
| Midpoint Dyn: | 0.091 |
| LwSpd Dynamic: | 0.130 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 7:50:38 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 3501 |
| Temperature: | 106.2 °C (112.7 ± 3.0 °C) |
| Apply Pressure: | 834 kPa 827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ (18.71 ± 0.40 KJ) |
| Engage Time: | 0.846 Sec |

**Torque**

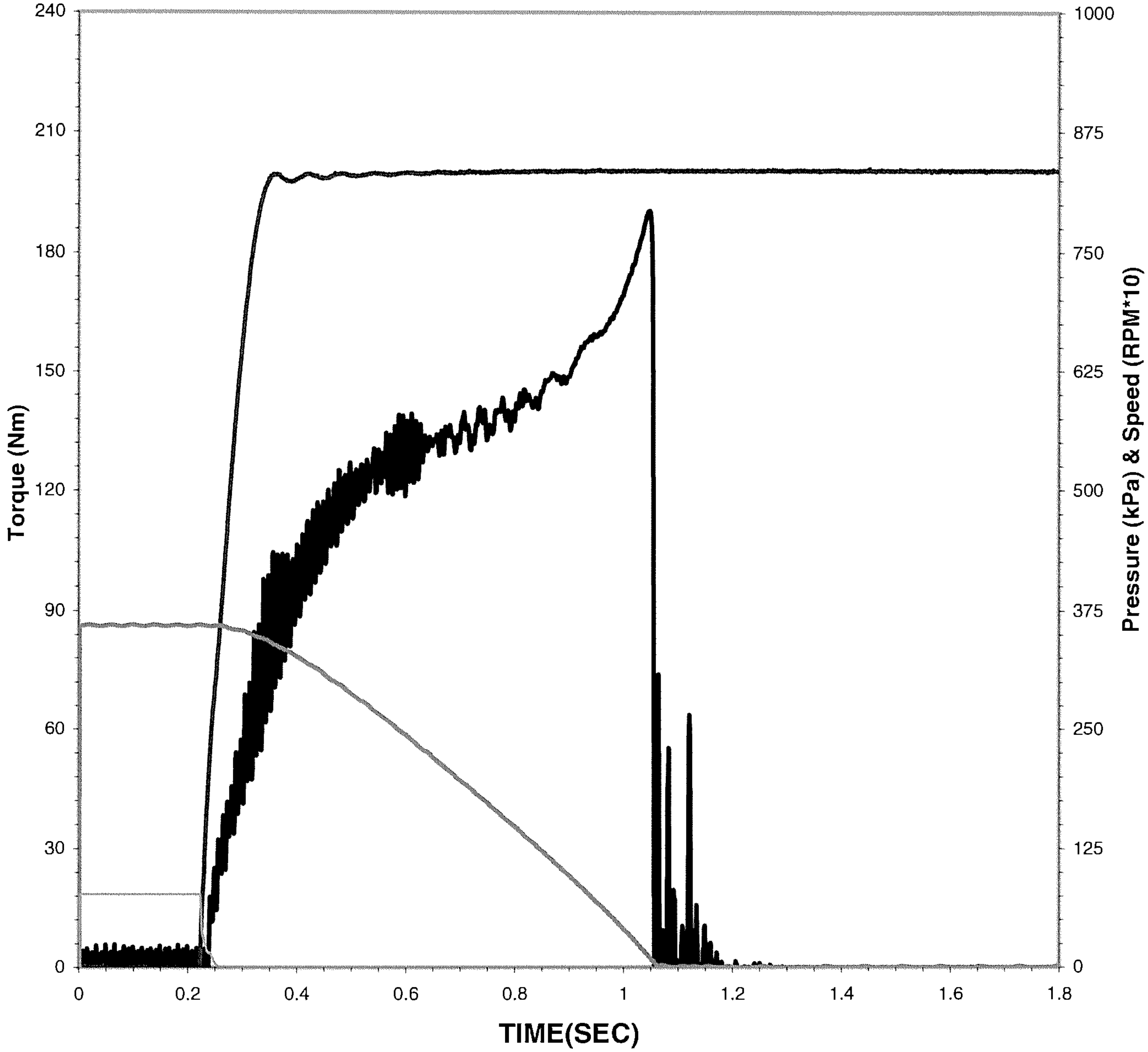
| | |
|---|---|
| 0.2 Sec Dyn: | 102 N*m |
| Midpoint Dyn: | 125 N*m |
| LwSpd Dynamic: | 193 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.070 |
| Midpoint Dyn: | 0.086 |
| LwSpd Dynamic: | 0.133 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 9:55:08 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 3999 |
| Temperature: | 110.7 °C<br>(112.7 ± 3.0 °C) |
| Apply Pressure: | 832 kPa<br>827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ<br>(18.71 ± 0.40 KJ) |
| Engage Time: | 0.833 Sec |

**Torque**

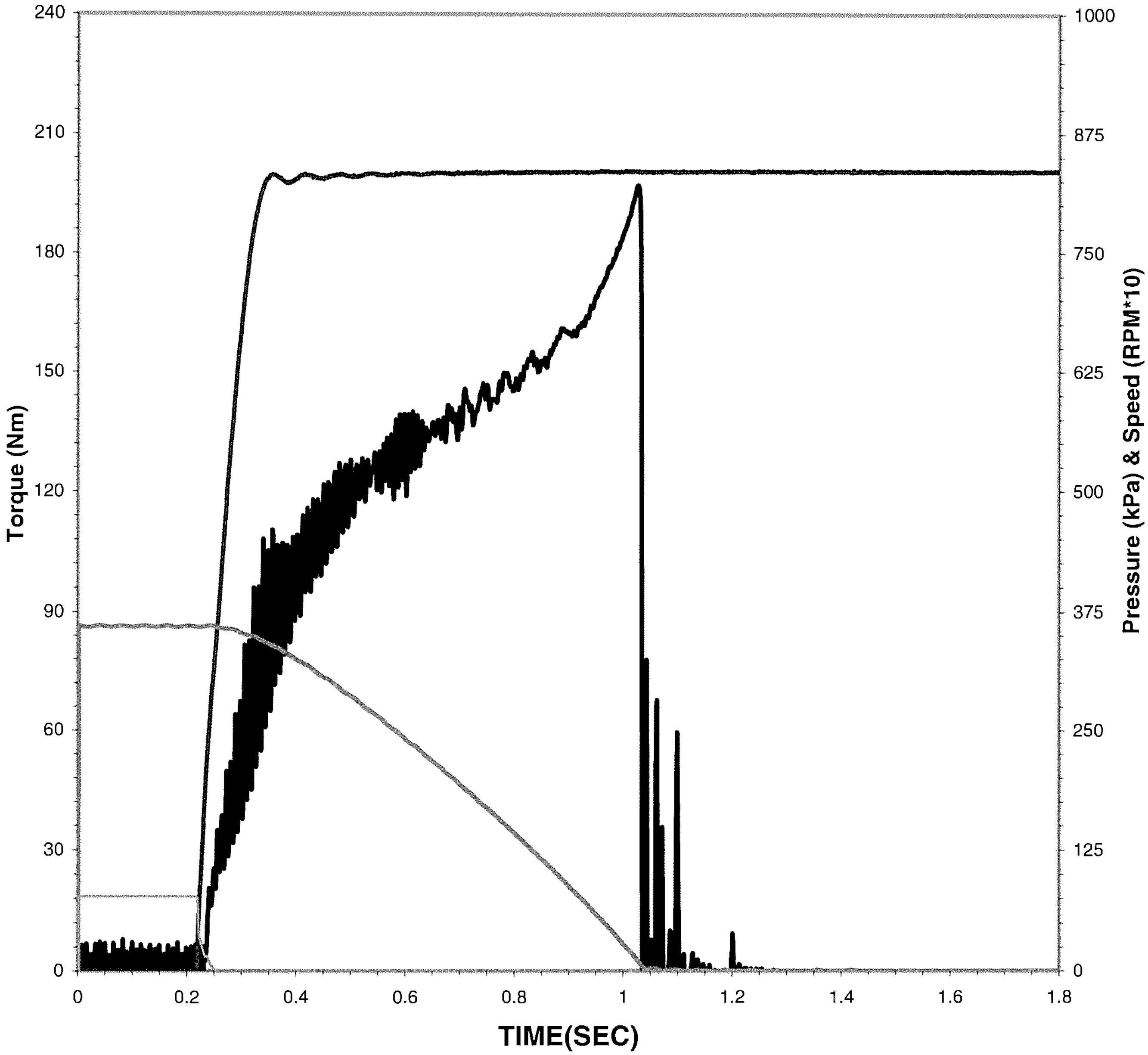
| | |
|---|---|
| 0.2 Sec Dyn: | 105 N*m |
| Midpoint Dyn: | 132 N*m |
| LwSpd Dynamic: | 183 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.073 |
| Midpoint Dyn: | 0.091 |
| LwSpd Dynamic: | 0.127 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 9:55:23 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 4000 |
| Temperature: | 110.4 °C<br>(112.7 ± 3.0 °C) |
| Apply Pressure: | 832 kPa<br>827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ<br>(18.71 ± 0.40 KJ) |
| Engage Time: | 0.817 Sec |

**Torque**

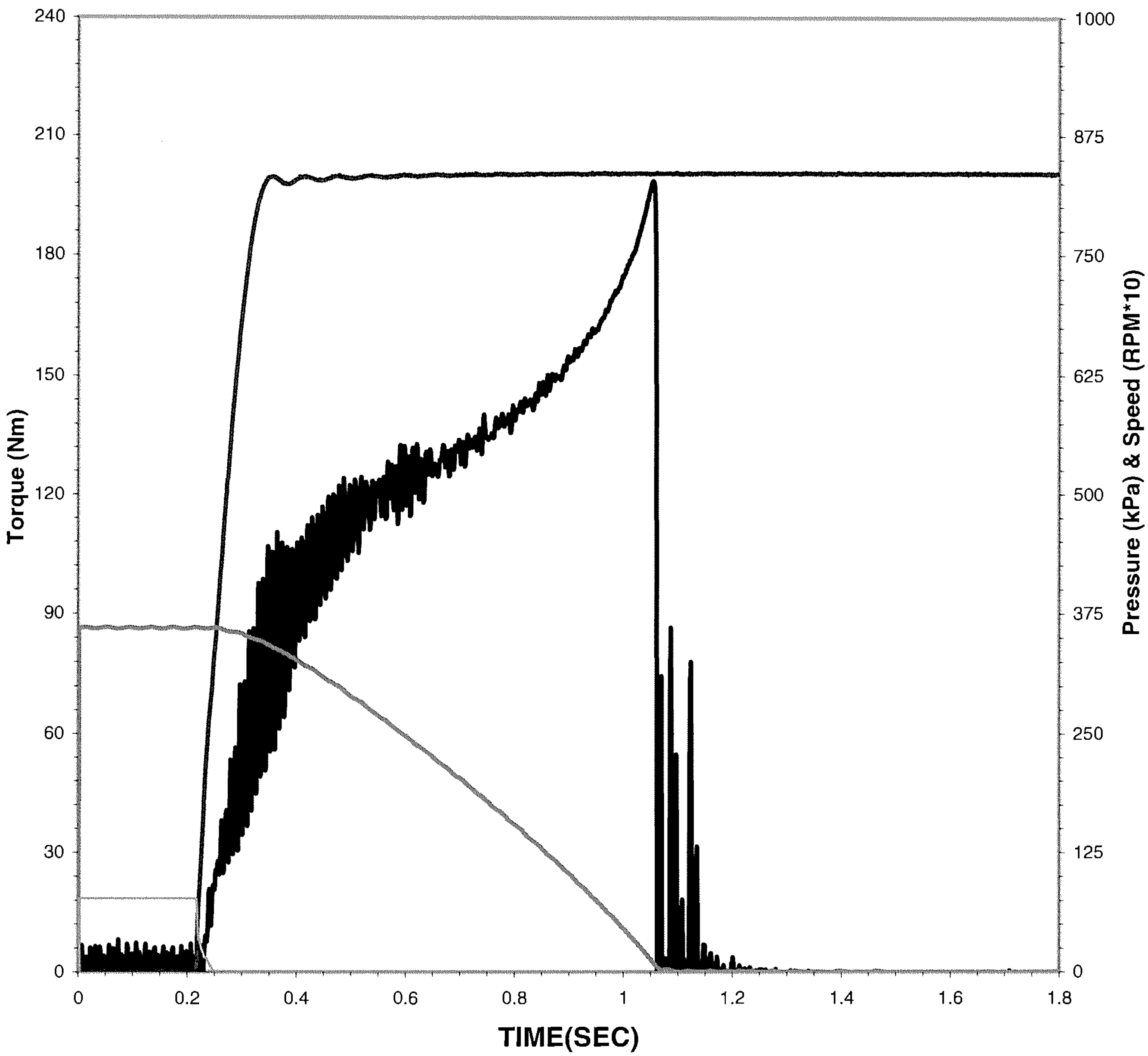
| | |
|---|---|
| 0.2 Sec Dyn: | 104 N*m |
| Midpoint Dyn: | 133 N*m |
| LwSpd Dynamic: | 191 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.072 |
| Midpoint Dyn: | 0.092 |
| LwSpd Dynamic: | 0.132 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 9:55:50 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 4001 |
| Temperature: | 106.0 °C (112.7 ± 3.0 °C) |
| Apply Pressure: | 833 kPa 827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ (18.71 ± 0.40 KJ) |
| Engage Time: | 0.845 Sec |

**Torque**

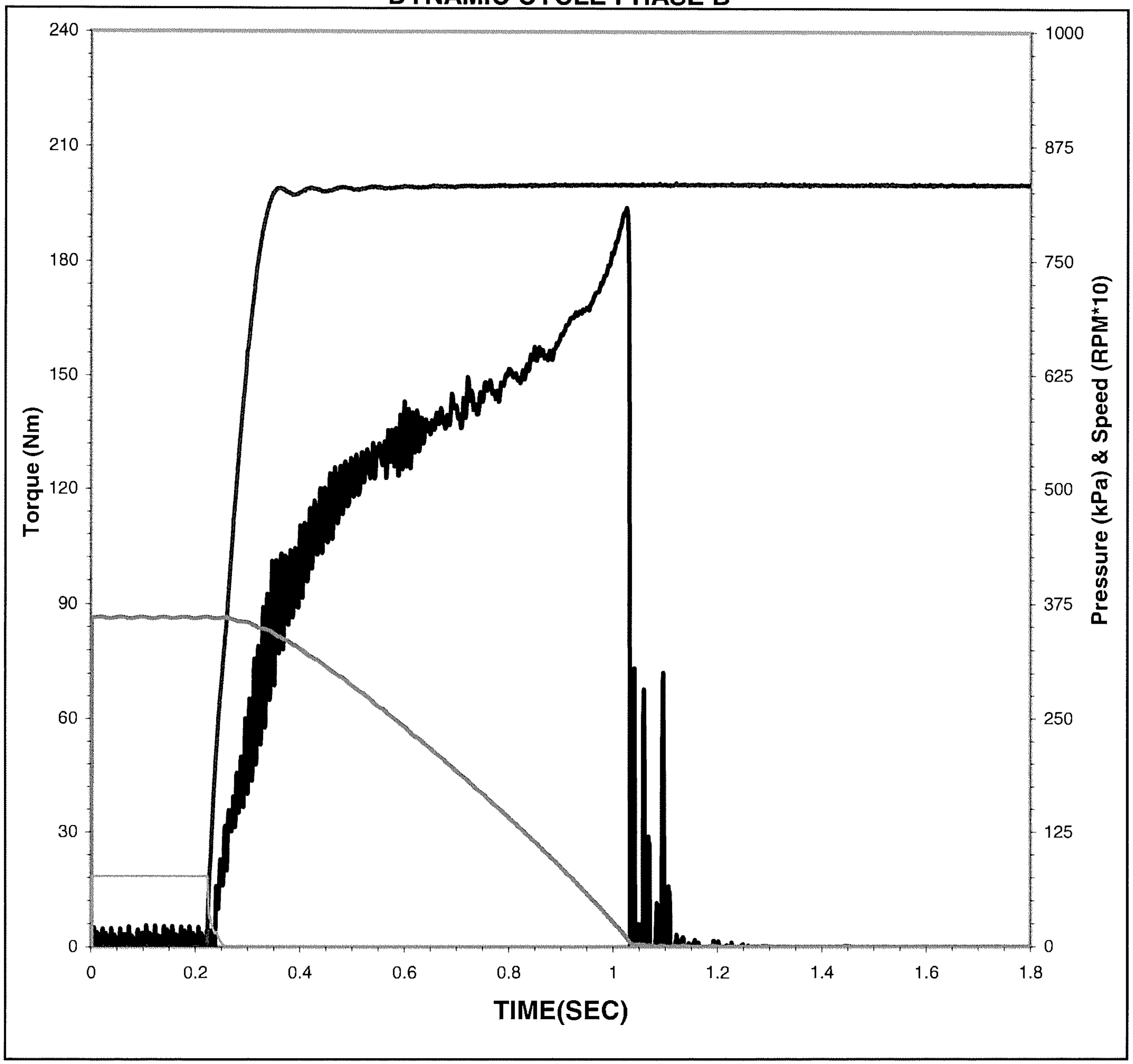
| | |
|---|---|
| 0.2 Sec Dyn: | 98 N*m |
| Midpoint Dyn: | 127 N*m |
| LwSpd Dynamic: | 192 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.068 |
| Midpoint Dyn: | 0.088 |
| LwSpd Dynamic: | 0.133 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 12:00:20 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 4499 |
| Temperature: | 110.4 °C<br>(112.7 ± 3.0 °C) |
| Apply Pressure: | 831 kPa<br>827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ<br>(18.71 ± 0.40 KJ) |
| Engage Time: | 0.81 Sec |

**Torque**

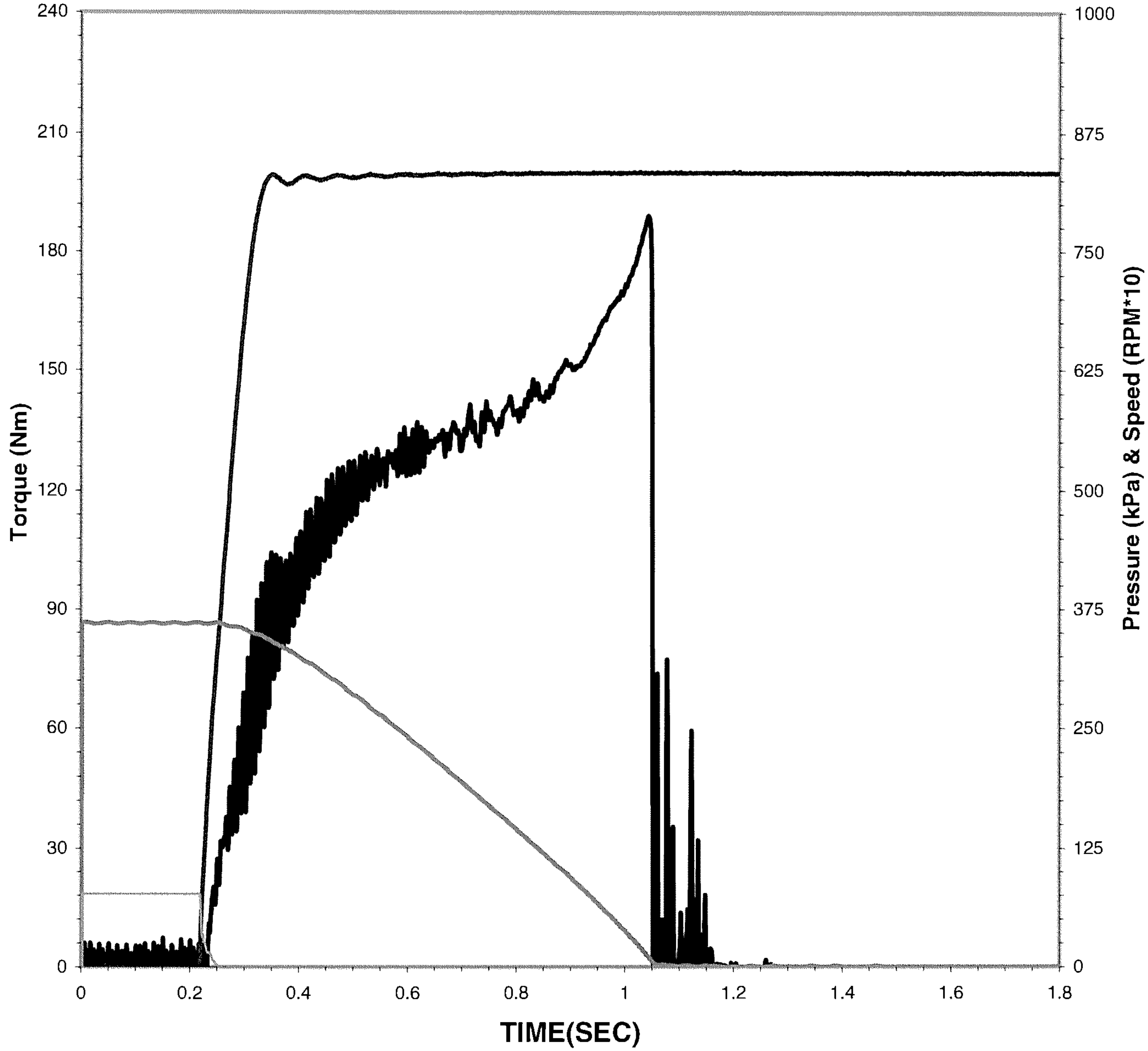
| | |
|---|---|
| 0.2 Sec Dyn: | 109 N*m |
| Midpoint Dyn: | 135 N*m |
| LwSpd Dynamic: | 186 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.075 |
| Midpoint Dyn: | 0.093 |
| LwSpd Dynamic: | 0.129 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 12:00:35 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 4500 |
| Temperature: | 110.5 °C<br>(112.7 ± 3.0 °C) |
| Apply Pressure: | 831 kPa<br>827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.5 KJ<br>(18.71 ± 0.40 KJ) |
| Engage Time: | 0.833 Sec |

**Torque**

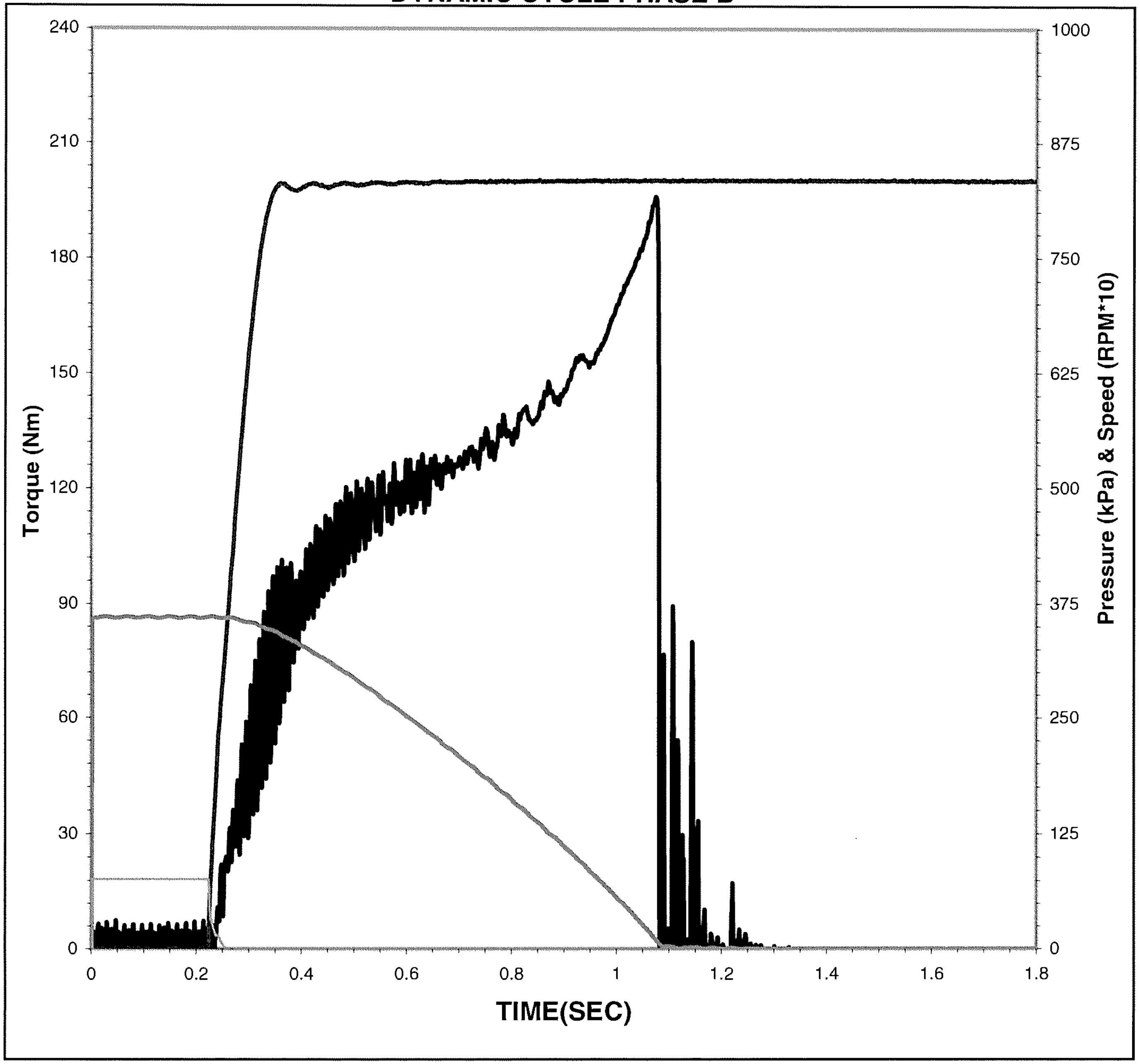
| | |
|---|---|
| 0.2 Sec Dyn: | 106 N*m |
| Midpoint Dyn: | 132 N*m |
| LwSpd Dynamic: | 182 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.073 |
| Midpoint Dyn: | 0.091 |
| LwSpd Dynamic: | 0.126 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 12:01:01 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 4501 |
| Temperature: | 105.9 °C<br>(112.7 ± 3.0 °C) |
| Apply Pressure: | 831 kPa<br>827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ<br>(18.71 ± 0.40 KJ) |
| Engage Time: | 0.859 Sec |

**Torque**

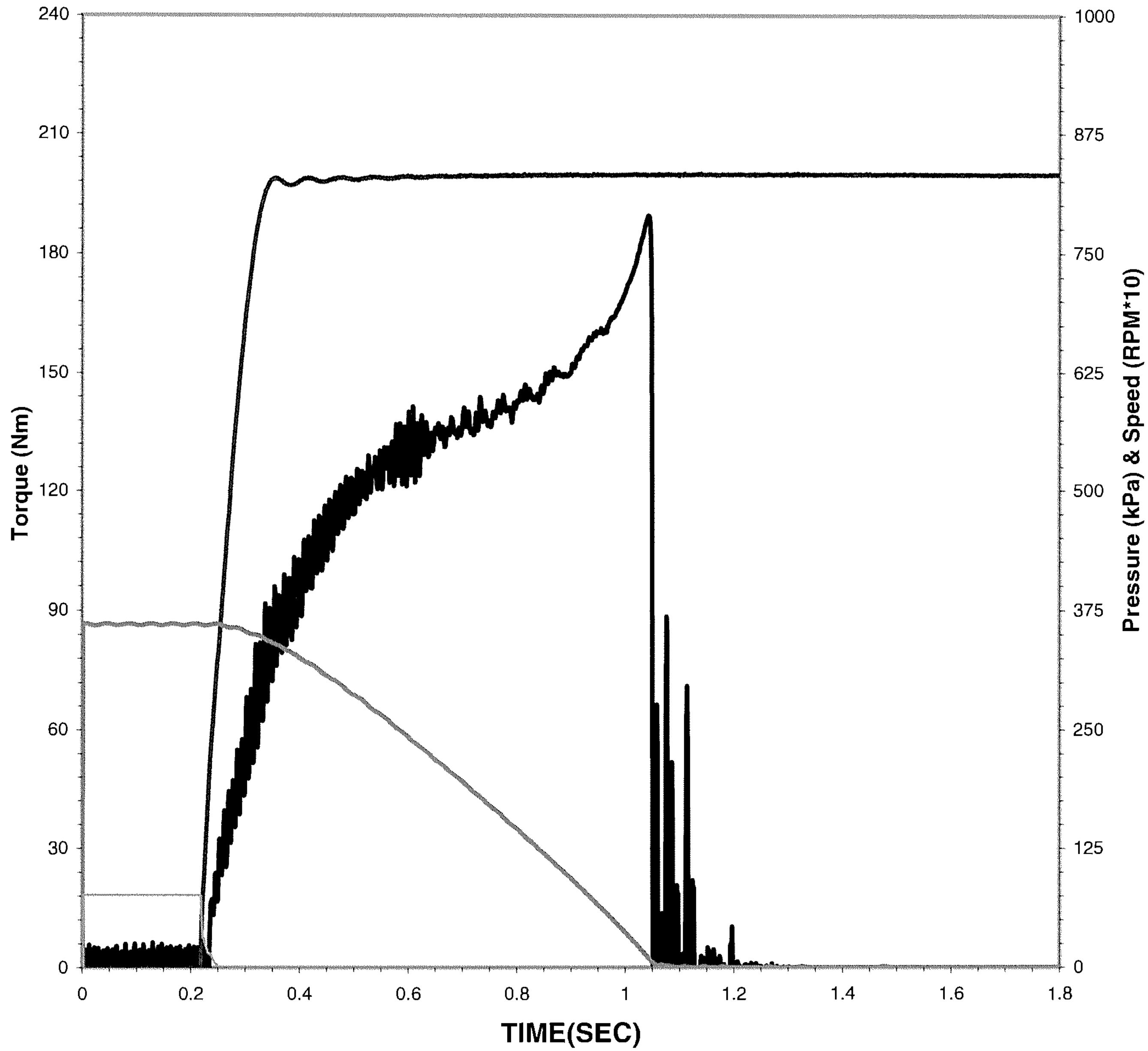
| | |
|---|---|
| 0.2 Sec Dyn: | 98 N*m |
| Midpoint Dyn: | 124 N*m |
| LwSpd Dynamic: | 190 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.068 |
| Midpoint Dyn: | 0.086 |
| LwSpd Dynamic: | 0.131 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 14:05:32 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 4999 |
| Temperature: | 110.5 °C |
| | (112.7 ± 3.0 °C) |
| Apply Pressure: | 830 kPa |
| | 827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec |
| | (0.15 ± 0.02 Sec) |
| Energy: | 18.5 KJ |
| | (18.71 ± 0.40 KJ) |
| Engage Time: | 0.833 Sec |

**Torque**

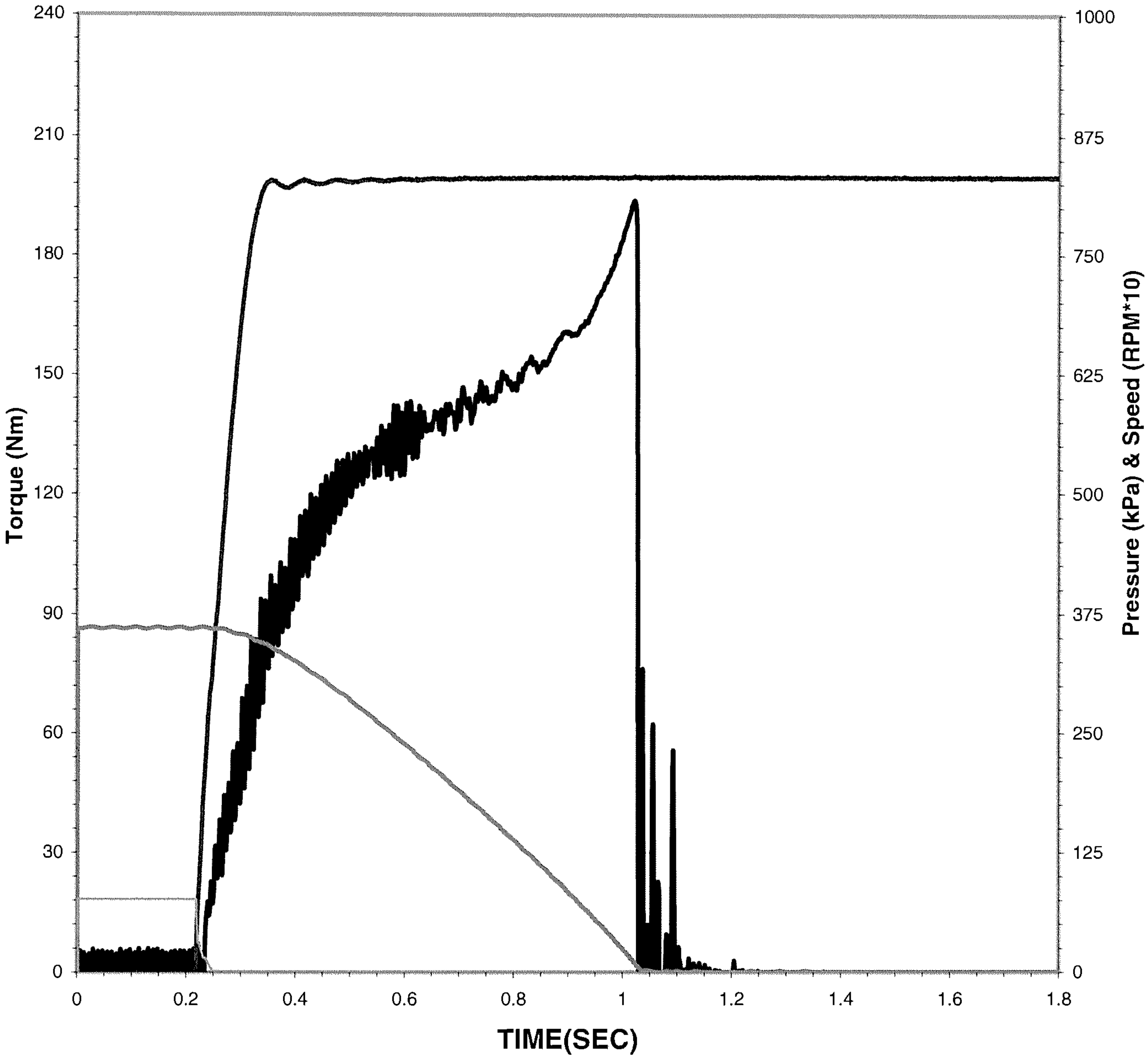
| | |
|---|---|
| 0.2 Sec Dyn: | 102 N*m |
| Midpoint Dyn: | 134 N*m |
| LwSpd Dynamic: | 186 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.071 |
| Midpoint Dyn: | 0.092 |
| LwSpd Dynamic: | 0.128 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 14:05:47 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 5000 |
| Temperature: | 110.3 °C (112.7 ± 3.0 °C) |
| Apply Pressure: | 830 kPa 827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.5 KJ (18.71 ± 0.40 KJ) |
| Engage Time: | 0.812 Sec |

**Torque**

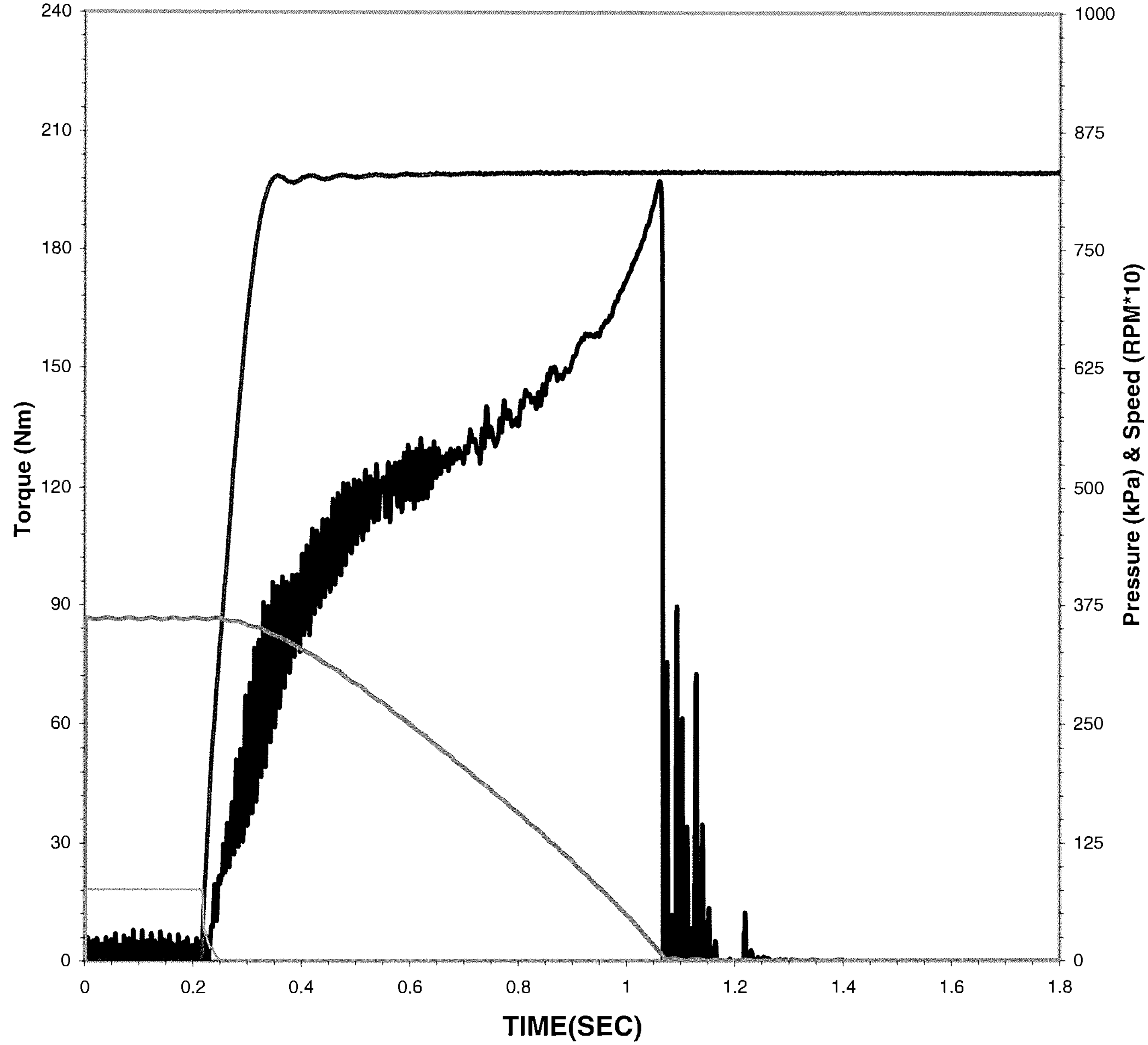
| | |
|---|---|
| 0.2 Sec Dyn: | 107 N*m |
| Midpoint Dyn: | 137 N*m |
| LwSpd Dynamic: | 188 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.074 |
| Midpoint Dyn: | 0.094 |
| LwSpd Dynamic: | 0.130 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 14:06:13 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 5001 |
| Temperature: | 106.0 °C<br>(112.7 ± 3.0 °C) |
| Apply Pressure: | 830 kPa<br>827 ± 7 KPa) |
| Apply Rate: | 0.14 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.5 KJ<br>(18.71 ± 0.40 KJ) |
| Engage Time: | 0.851 Sec |

**Torque**

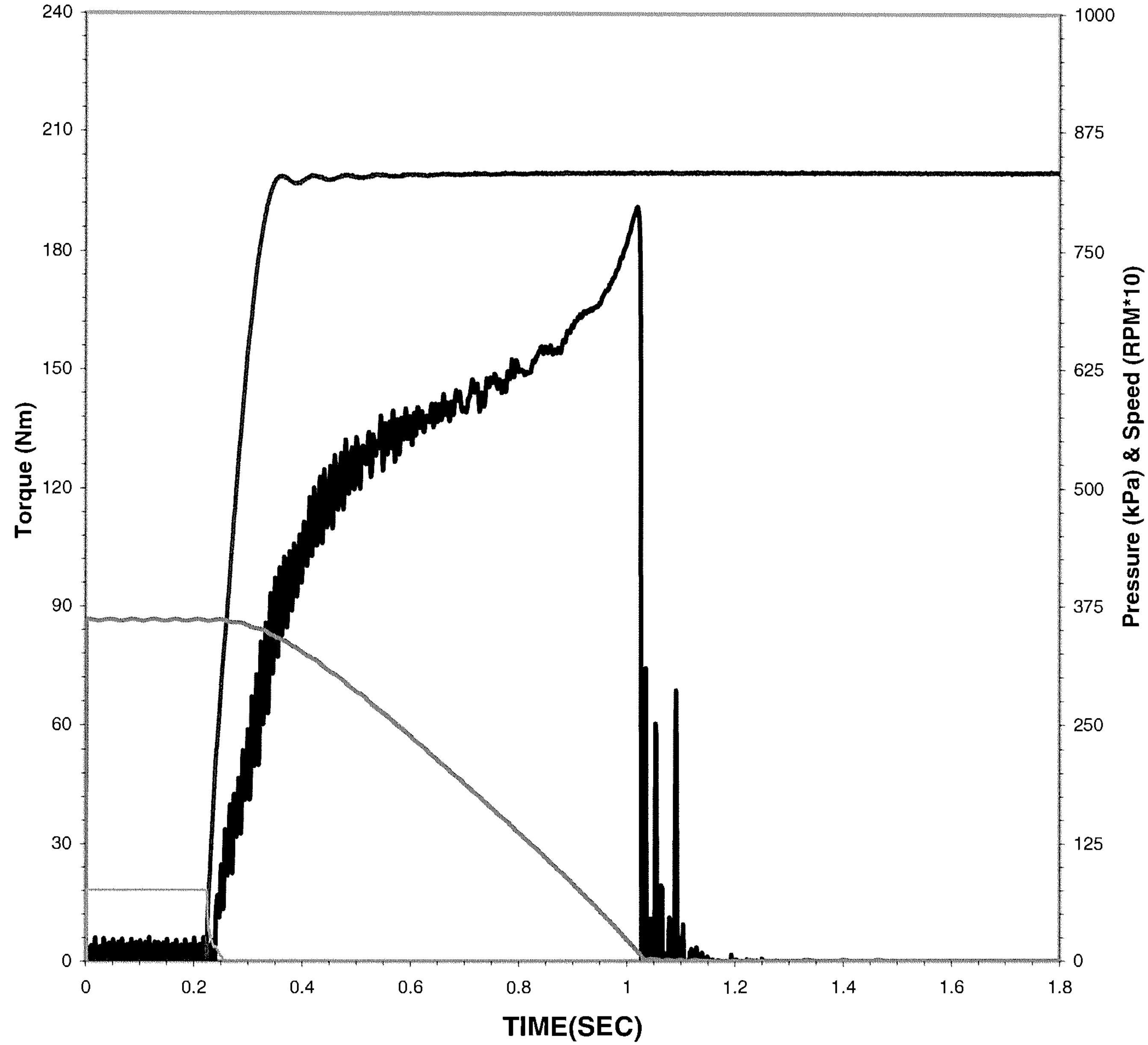
| | |
|---|---|
| 0.2 Sec Dyn: | 96 N*m |
| Midpoint Dyn: | 126 N*m |
| LwSpd Dynamic: | 194 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.066 |
| Midpoint Dyn: | 0.087 |
| LwSpd Dynamic: | 0.134 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 16:10:28 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 5498 |
| Temperature: | 110.5 °C (112.7 ± 3.0 °C) |
| Apply Pressure: | 829 kPa 827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ (18.71 ± 0.40 KJ) |
| Engage Time: | 0.804 Sec |

**Torque**

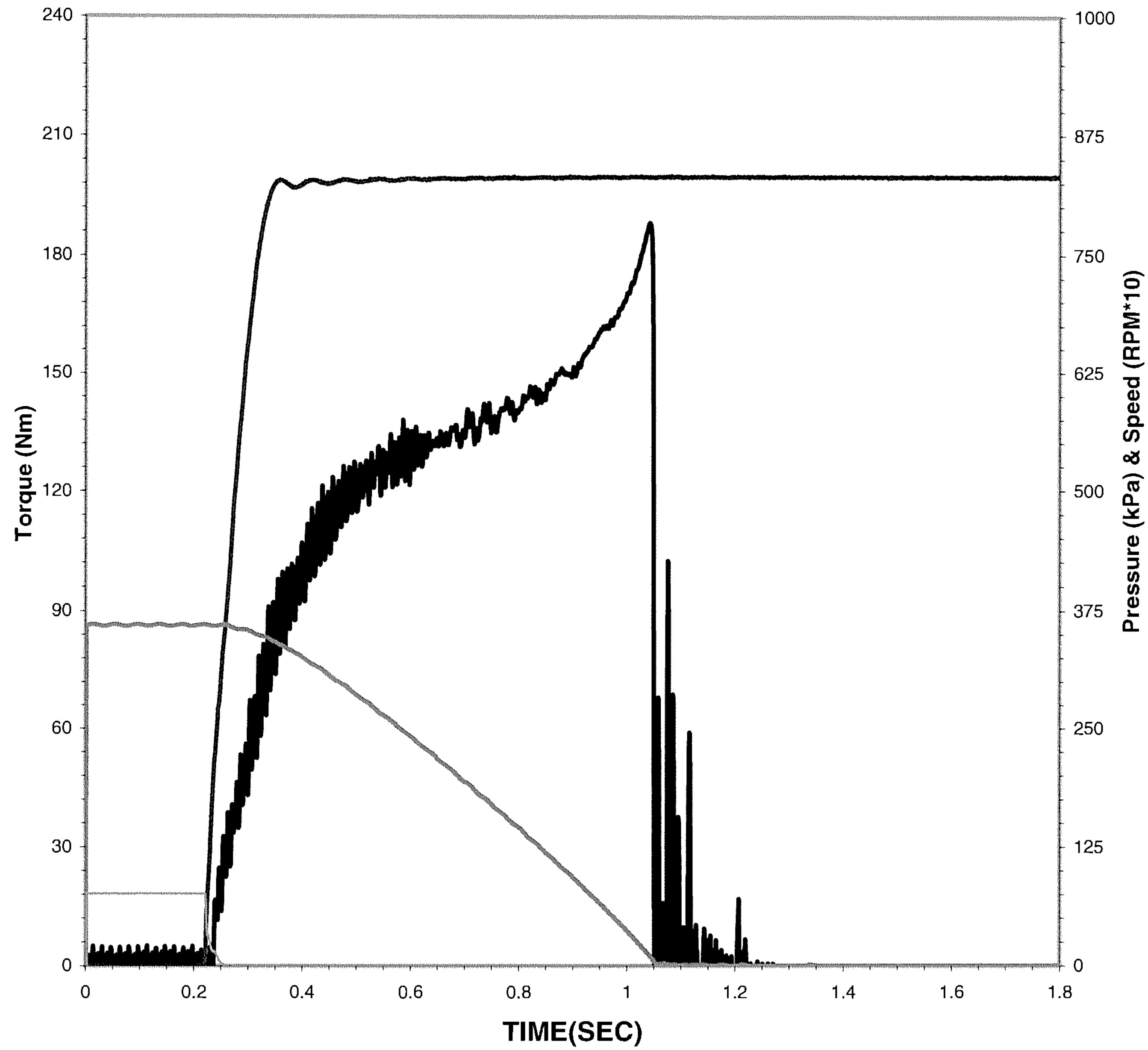
| | |
|---|---|
| 0.2 Sec Dyn: | 112 N*m |
| Midpoint Dyn: | 138 N*m |
| LwSpd Dynamic: | 185 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.078 |
| Midpoint Dyn: | 0.095 |
| LwSpd Dynamic: | 0.128 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 16:10:43 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 5499 |
| Temperature: | 110.6 °C (112.7 ± 3.0 °C) |
| Apply Pressure: | 829 kPa 827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.5 KJ (18.71 ± 0.40 KJ) |
| Engage Time: | 0.83 Sec |

**Torque**

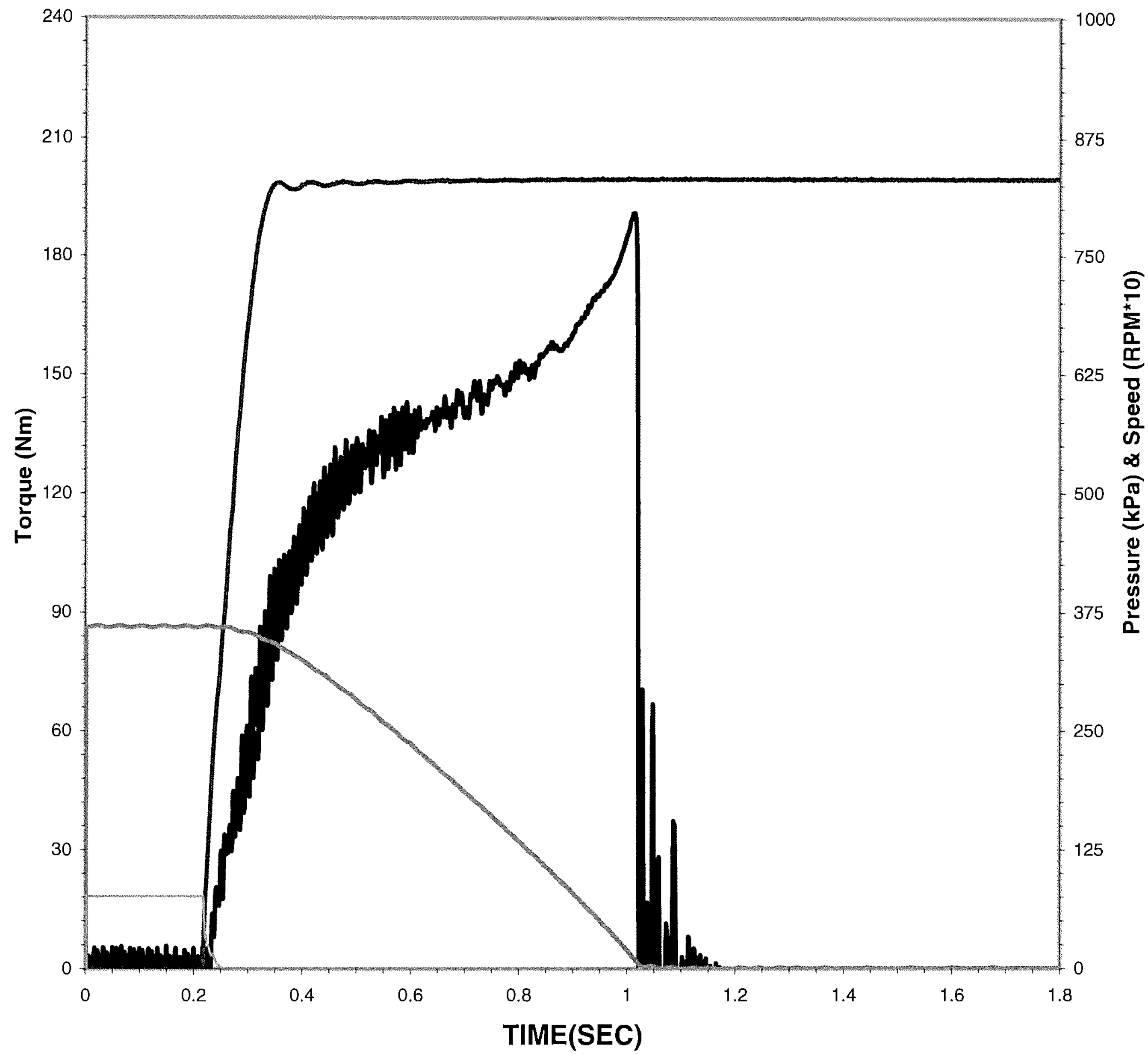
| | |
|---|---|
| 0.2 Sec Dyn: | 108 N*m |
| Midpoint Dyn: | 132 N*m |
| LwSpd Dynamic: | 184 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.074 |
| Midpoint Dyn: | 0.091 |
| LwSpd Dynamic: | 0.127 |

# ALLISON C-4 GRAPHITE DATA

## DYNAMIC CYCLE PHASE B




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 16:10:59 |
| Test Number: | C4-4-1342 |
| Fluid Code: | LO271510 |
| Cycle Number: | 5500 |
| Temperature: | 110.6 °C (112.7 ± 3.0 °C) |
| Apply Pressure: | 829 kPa 827 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.5 KJ (18.71 ± 0.40 KJ) |
| Engage Time: | 0.804 Sec |

**Torque**

| | |
|---|---|
| 0.2 Sec Dyn: | 113 N*m |
| Midpoint Dyn: | 138 N*m |
| LwSpd Dynamic: | 187 N*m |

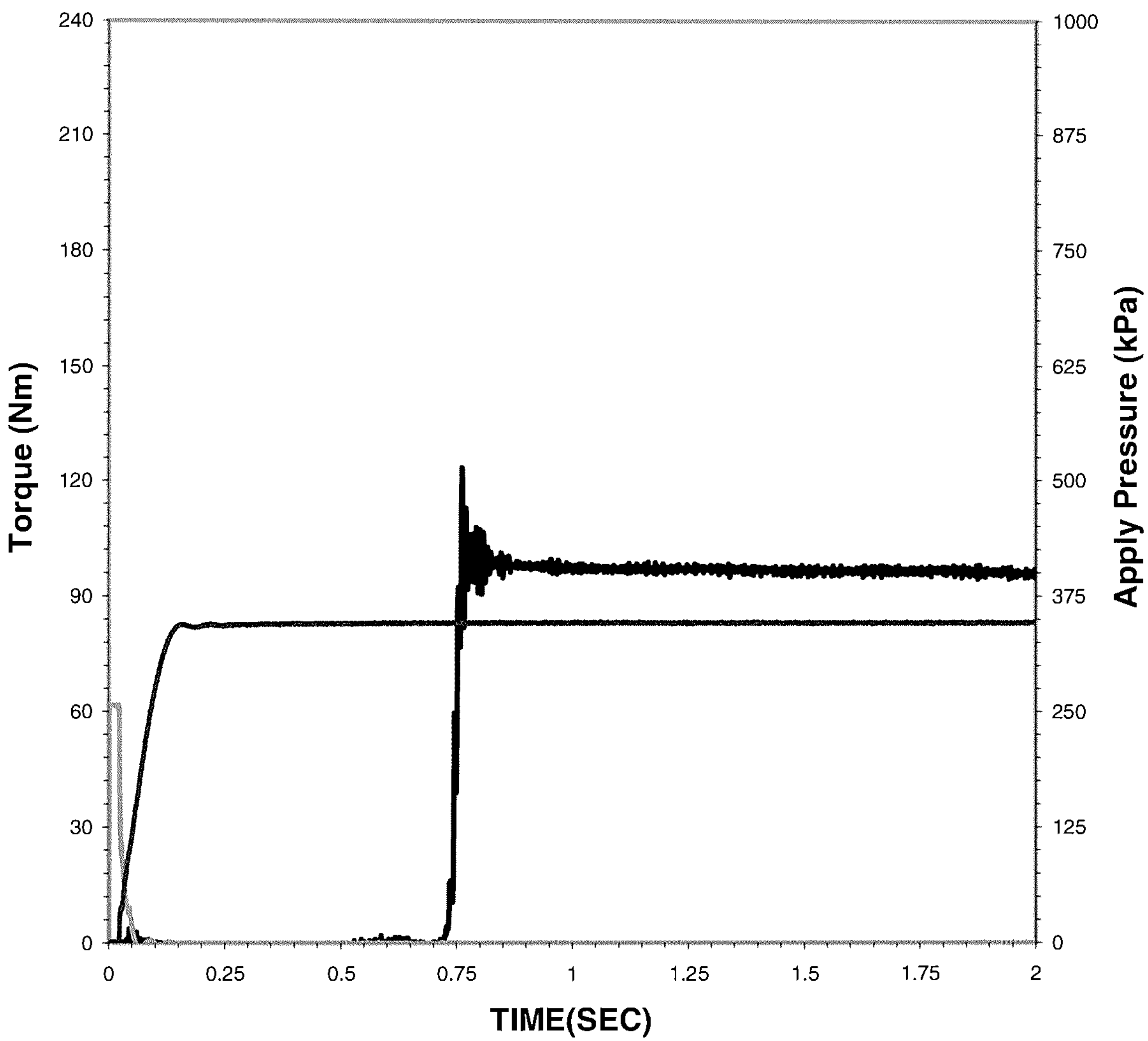
**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.078 |
| Midpoint Dyn: | 0.095 |
| LwSpd Dynamic: | 0.129 |

**STATIC TRACES**

# ALLISON C-4 GRAPHITE DATA

## STATIC CYCLE




Date of Test: 10/14/2011

Time of Test: 16:27:12

Test Number: C4-4-1342

Fluid Code: LO271510

Cycle Number: 10

**PHASE A**

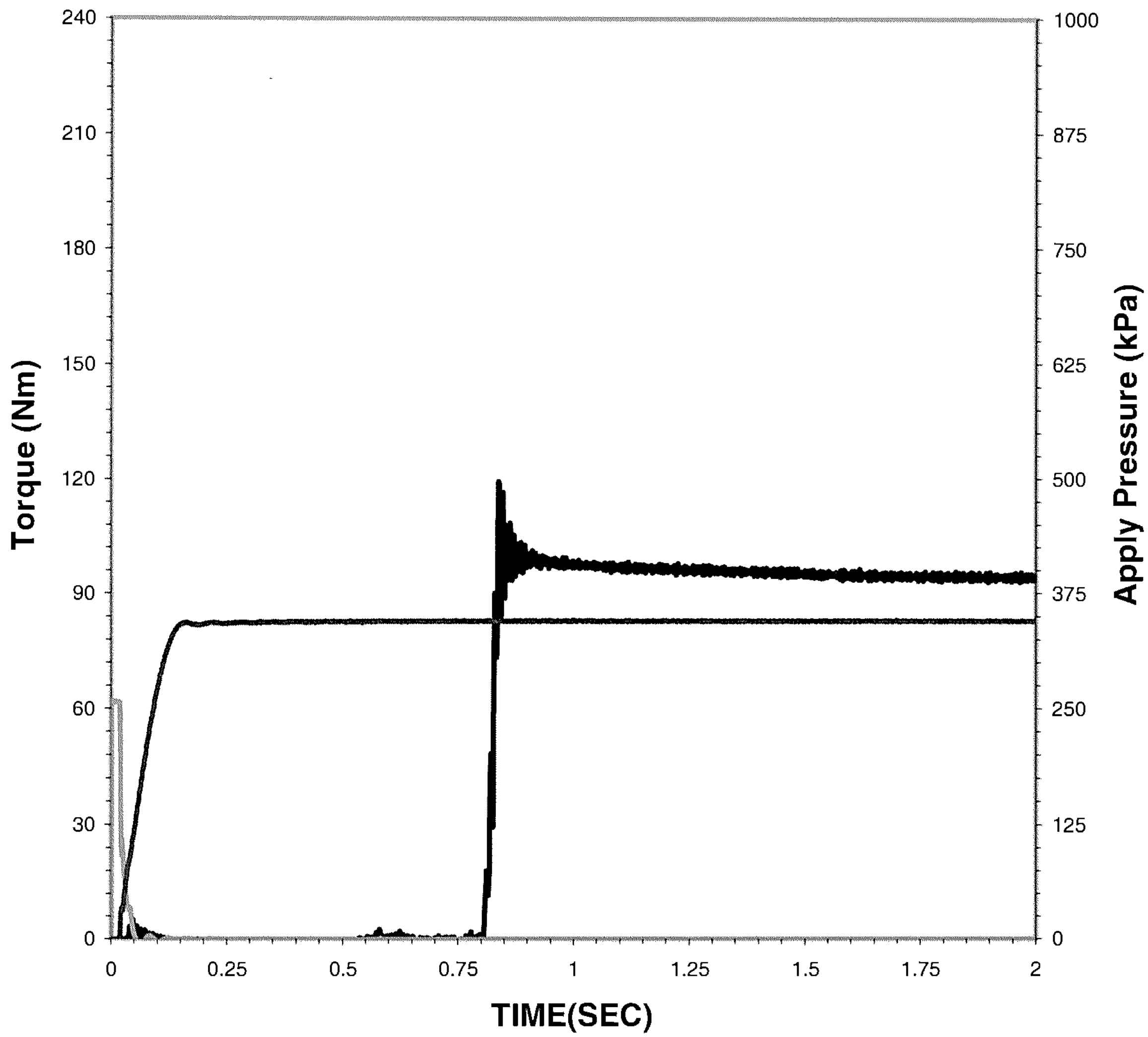
Apply Pressure:
At .25 Second: 345 kPa

**Torque**
Static Peak: 124 Nm
.25 Second: 98 Nm

**Coefficient of Friction**
Static Peak: 0.205
.25 Second: 0.163

# ALLISON C-4 GRAPHITE DATA

## STATIC CYCLE




Date of Test: 10/14/2011

Time of Test: 18:29:54

Test Number: C4-4-1342

Fluid Code: LO271510

Cycle Number: 500

**PHASE A**

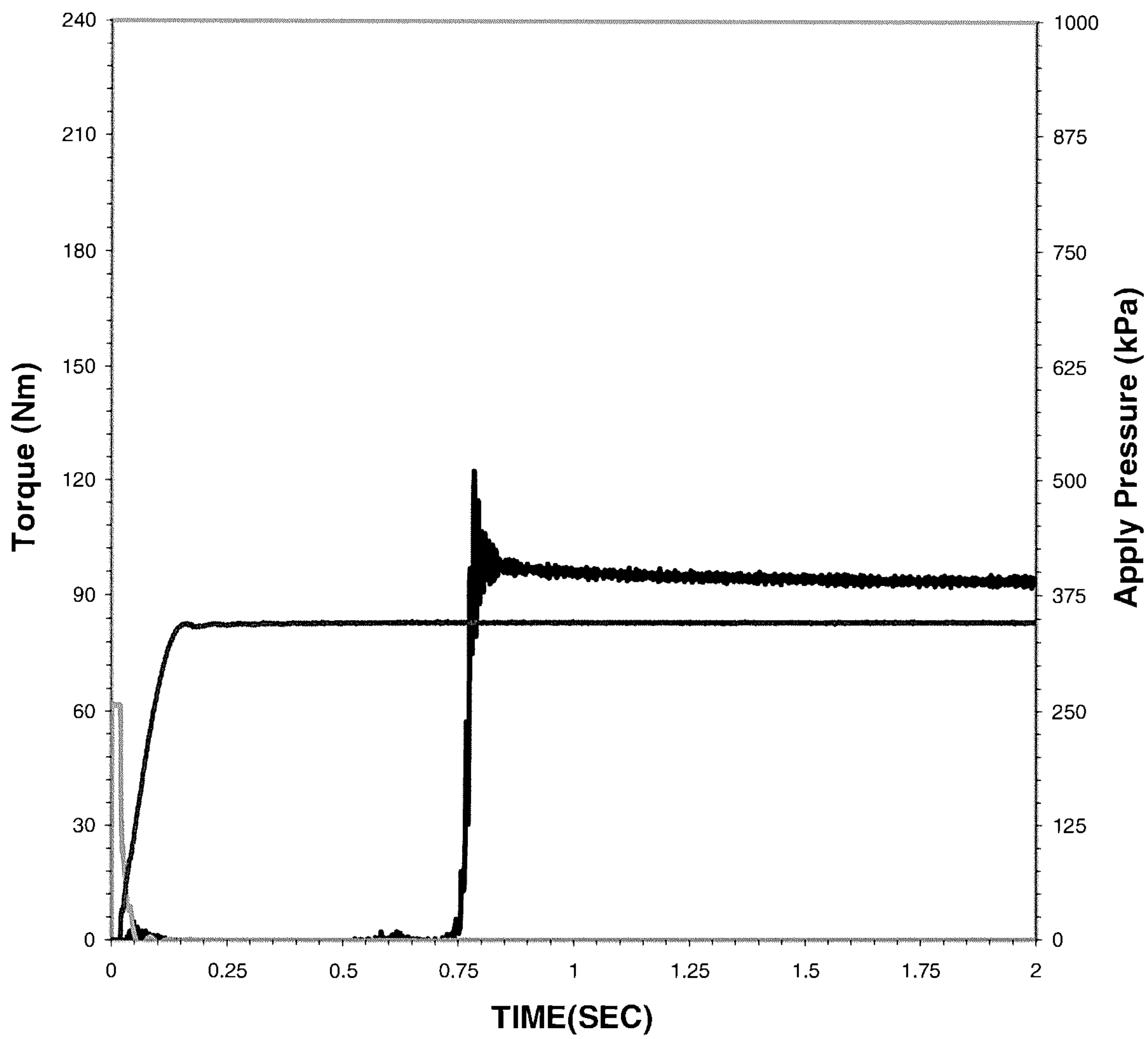
Apply Pressure:
At .25 Second: 346 kPa

**Torque**
Static Peak: 120 Nm
.25 Second: 98 Nm

**Coefficient of Friction**
Static Peak: 0.199
.25 Second: 0.163

# ALLISON C-4 GRAPHITE DATA

## STATIC CYCLE




Date of Test: 10/14/2011

Time of Test: 20:35:06

Test Number: C4-4-1342

Fluid Code: LO271510

Cycle Number: 1000

**PHASE A**

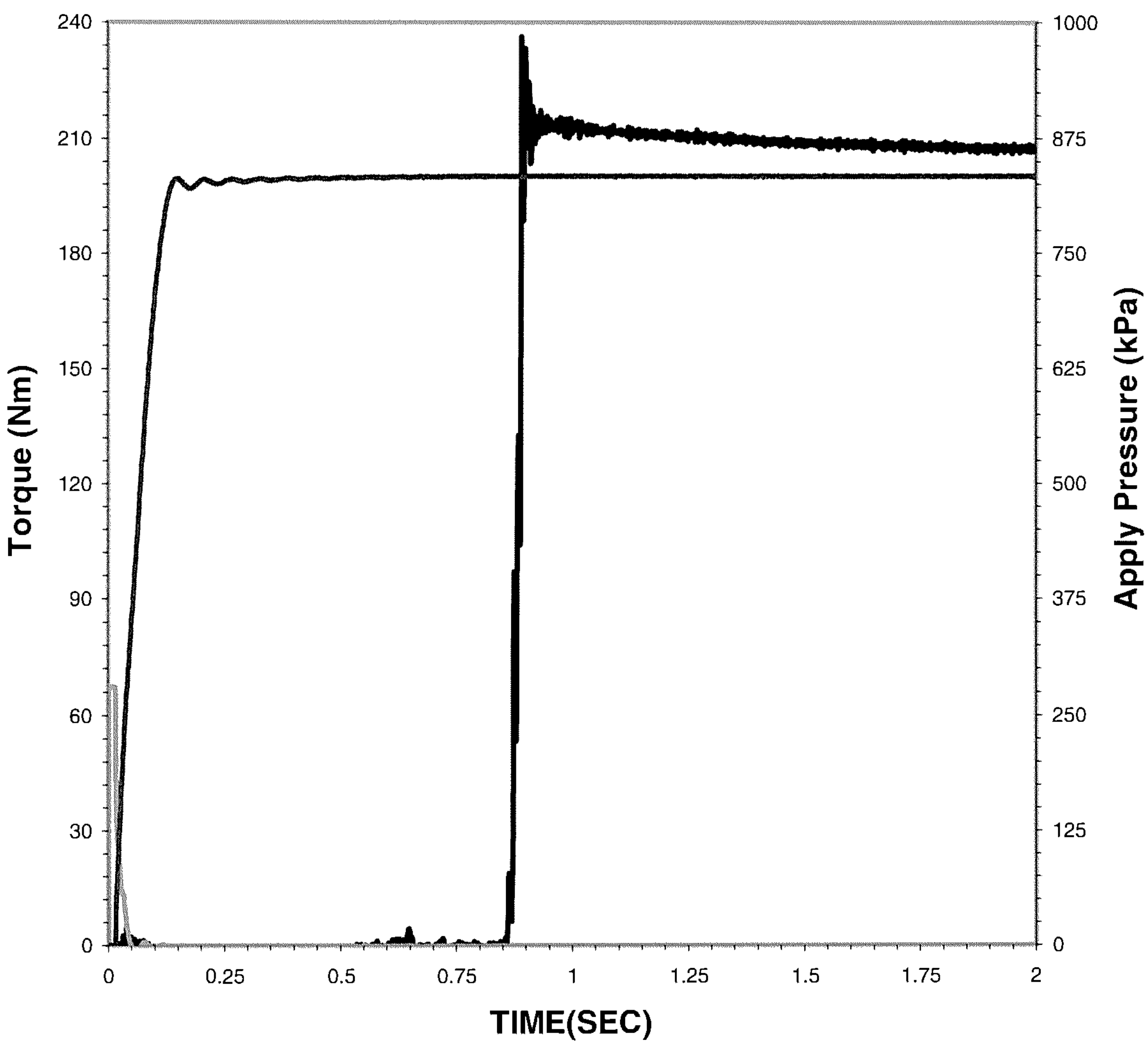
Apply Pressure:
At .25 Second: 346 kPa

**Torque**
Static Peak: 123 Nm
.25 Second: 96 Nm

**Coefficient of Friction**
Static Peak: 0.204
.25 Second: 0.160

# ALLISON C-4 GRAPHITE DATA

## STATIC CYCLE




Date of Test: 10/14/2011

Time of Test: 23:29:36

Test Number: C4-4-1342

Fluid Code: LO271510

Cycle Number: 1500

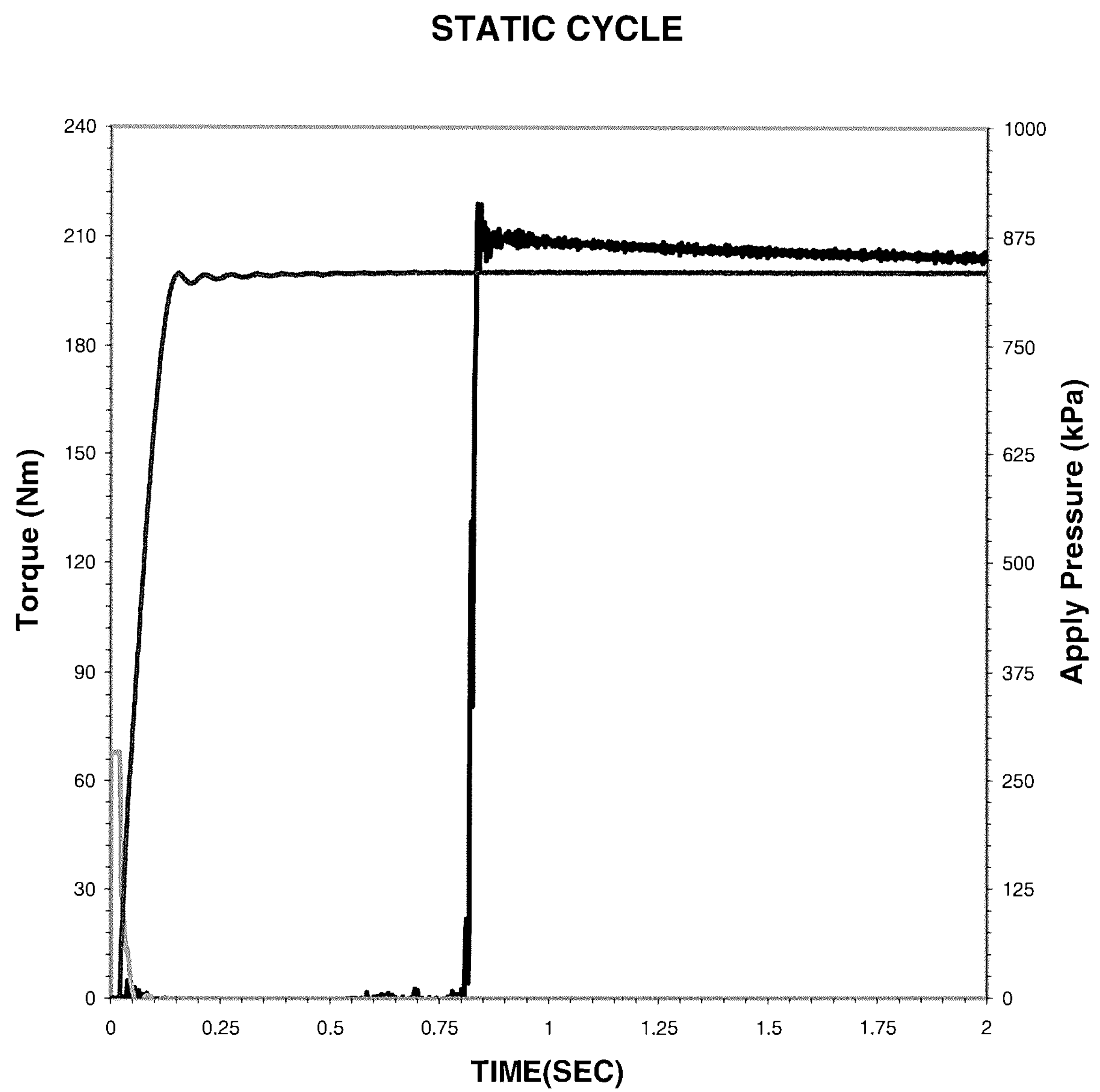
**PHASE B**

Apply Pressure:
At .25 Second: 831 kPa

**Torque**
Static Peak: 237 Nm
.25 Second: 213 Nm

**Coefficient of Friction**
Static Peak: 0.164
.25 Second: 0.147

# ALLISON C-4 GRAPHITE DATA




Date of Test: 10/15/2011

Time of Test: 1:34:47

Test Number: C4-4-1342

Fluid Code: LO271510

Cycle Number: 2000

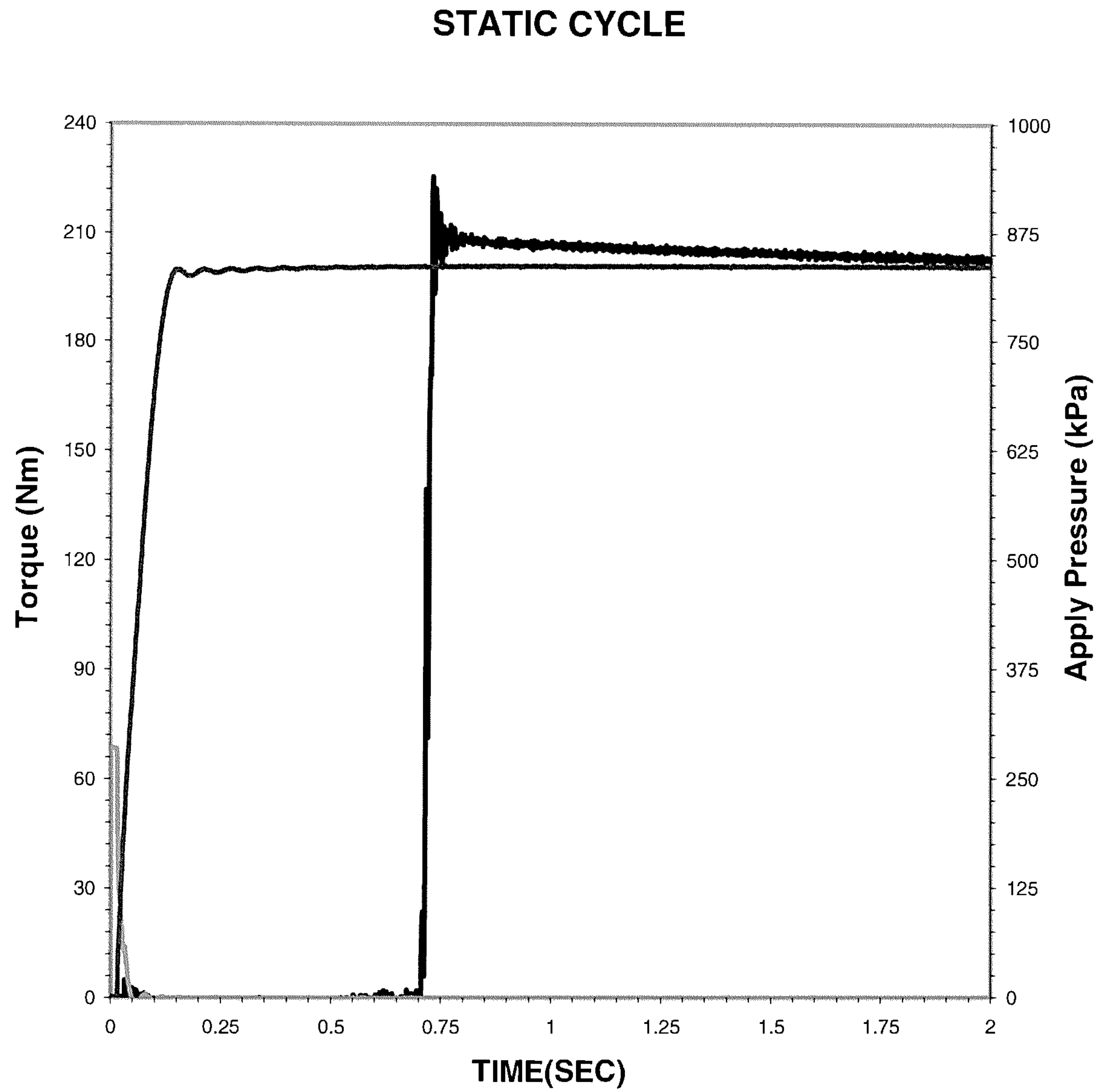
**PHASE B**

Apply Pressure:
At .25 Second: 832 kPa

**Torque**
Static Peak: 219 Nm
.25 Second: 208 Nm

**Coefficient of Friction**
Static Peak: 0.152
.25 Second: 0.144

# ALLISON C-4 GRAPHITE DATA




Date of Test: 10/15/2011

Time of Test: 3:39:59

Test Number: C4-4-1342

Fluid Code: LO271510

Cycle Number: 2500

**PHASE B**

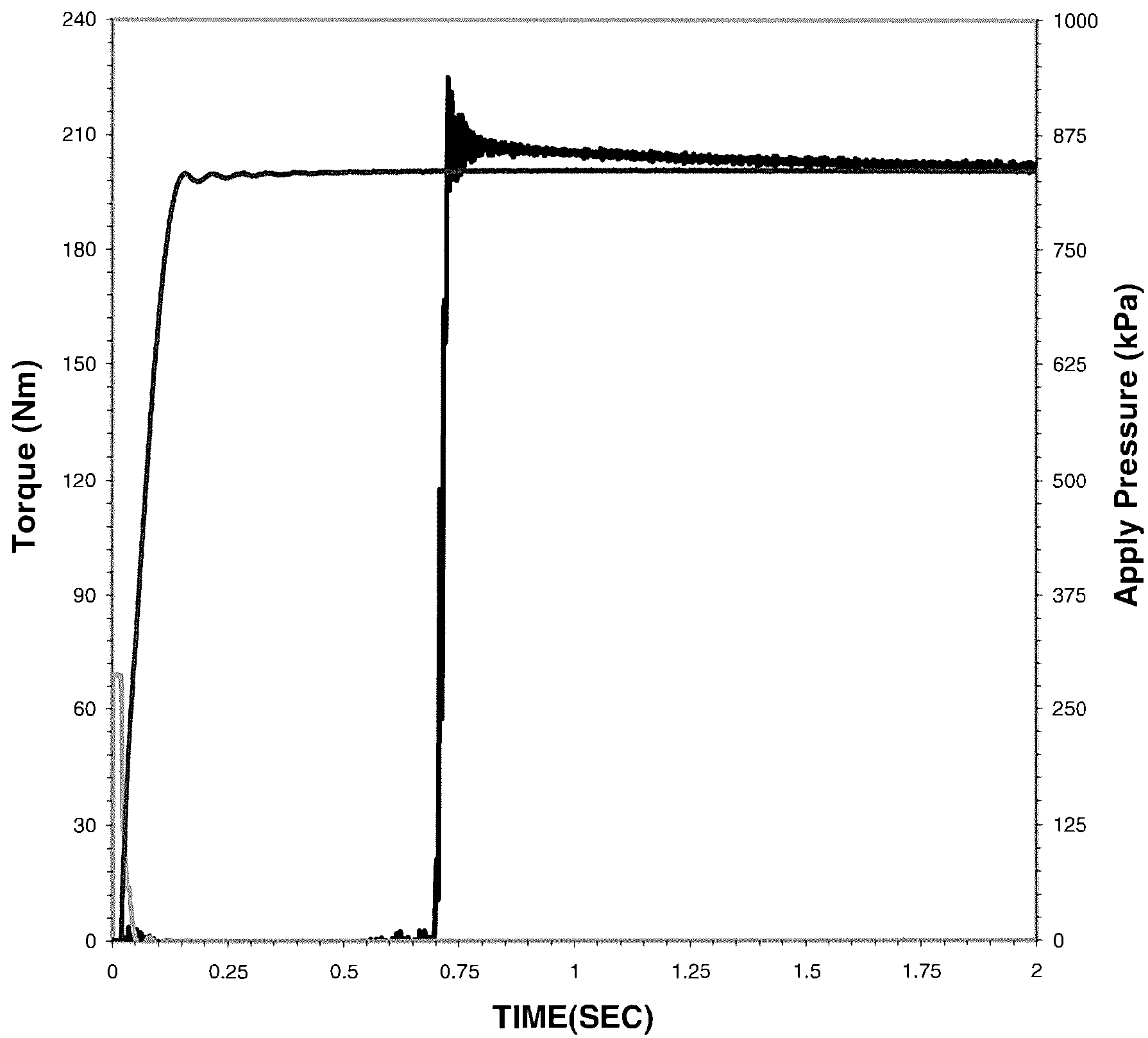
Apply Pressure:
At .25 Second: 833 kPa

**Torque**
Static Peak: 226 Nm
.25 Second: 208 Nm

**Coefficient of Friction**
Static Peak: 0.156
.25 Second: 0.144

# ALLISON C-4 GRAPHITE DATA

## STATIC CYCLE




Date of Test: 10/15/2011

Time of Test: 5:45:11

Test Number: C4-4-1342

Fluid Code: LO271510

Cycle Number: 3000

**PHASE B**

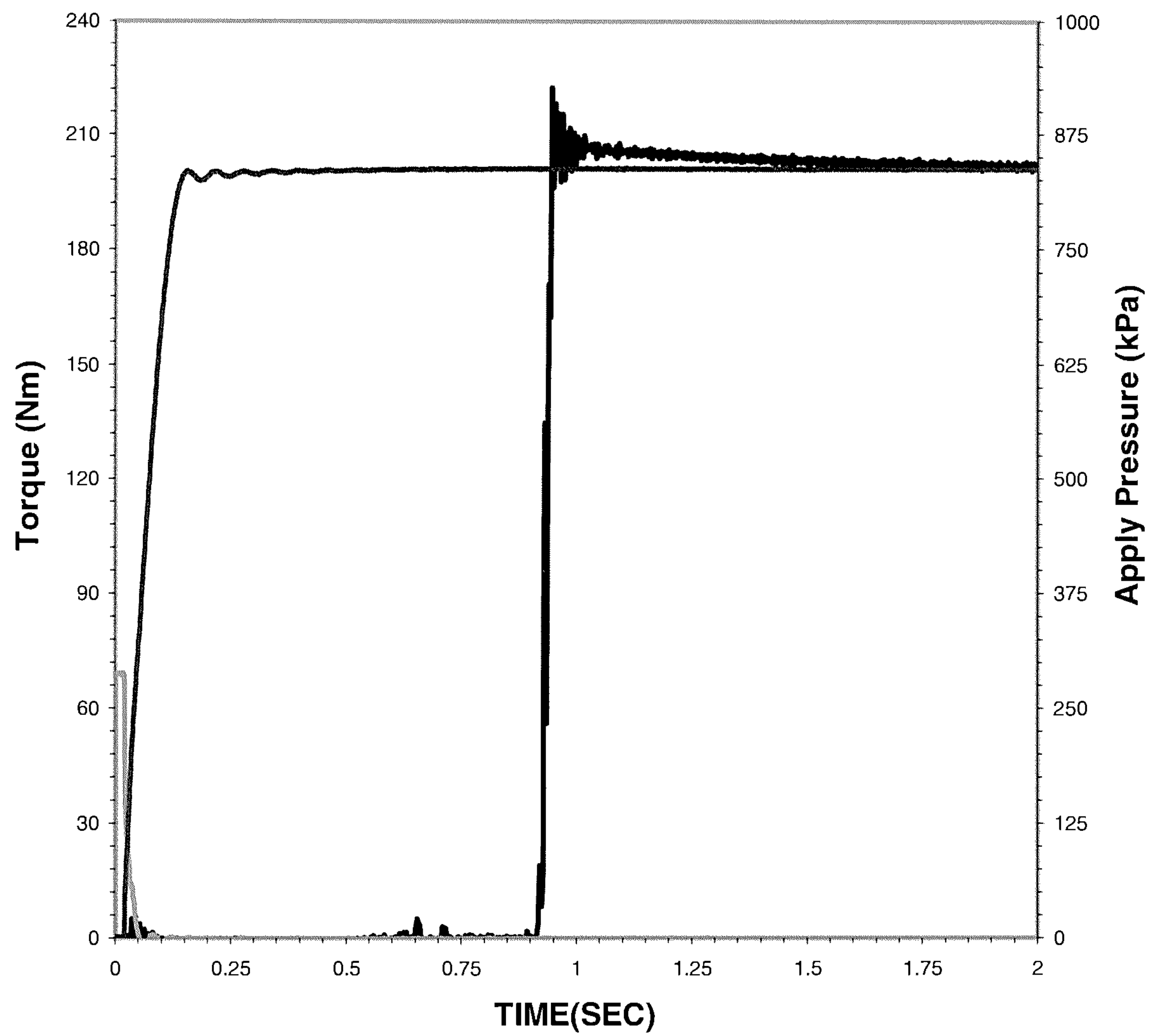
Apply Pressure:
At .25 Second: 833 kPa

**Torque**
Static Peak: 226 Nm
.25 Second: 206 Nm

**Coefficient of Friction**
Static Peak: 0.156
.25 Second: 0.142

# ALLISON C-4 GRAPHITE DATA

## STATIC CYCLE




Date of Test: 10/15/2011

Time of Test: 7:50:23

Test Number: C4-4-1342

Fluid Code: LO271510

Cycle Number: 3500

**PHASE B**

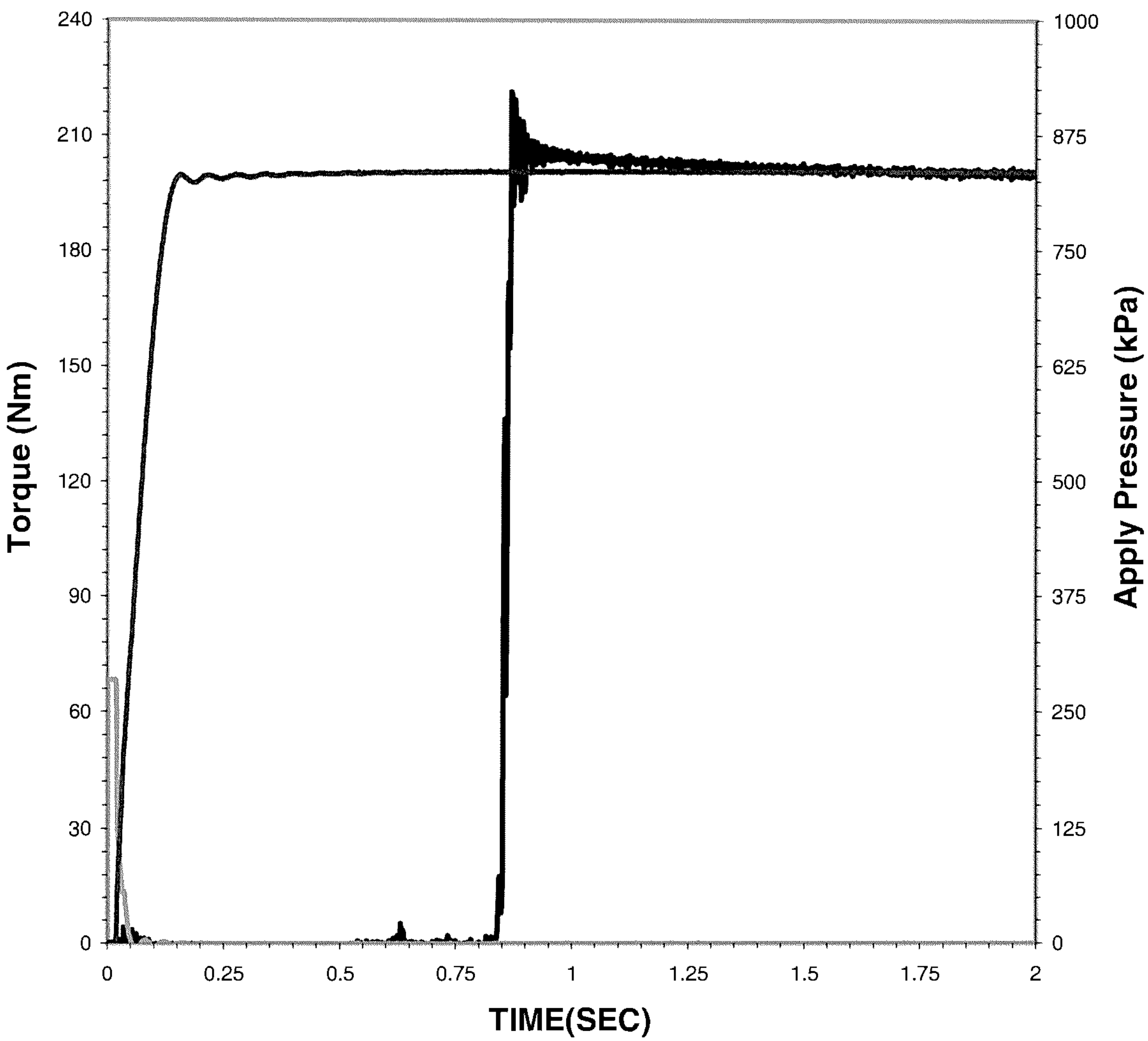
Apply Pressure:
At .25 Second: 833 kPa

**Torque**
Static Peak: 223 Nm
.25 Second: 206 Nm

**Coefficient of Friction**
Static Peak: 0.154
.25 Second: 0.143

# ALLISON C-4 GRAPHITE DATA

## STATIC CYCLE




Date of Test: 10/15/2011

Time of Test: 9:55:35

Test Number: C4-4-1342

Fluid Code: LO271510

Cycle Number: 4000

**PHASE B**

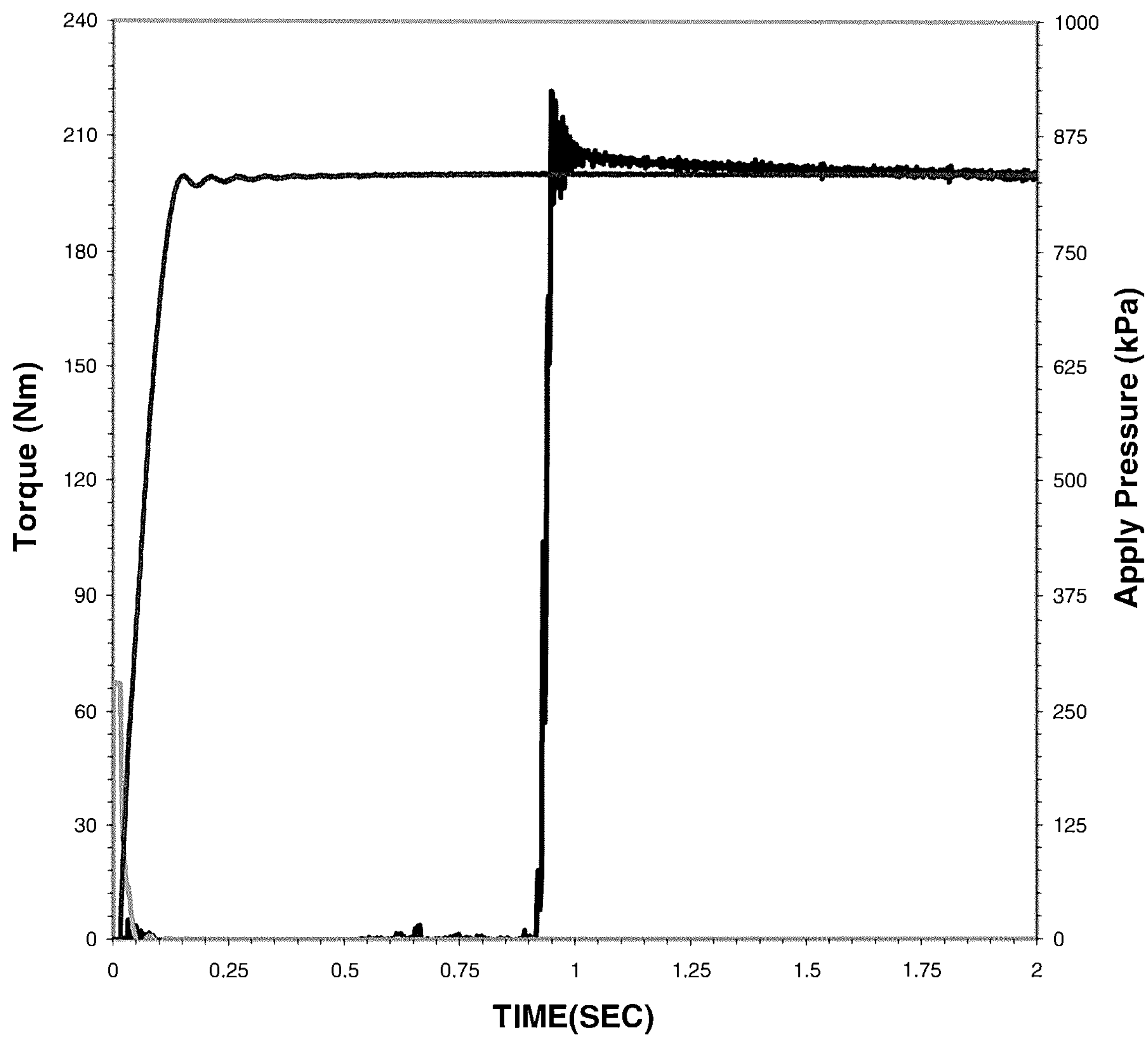
Apply Pressure:
At .25 Second: 832 kPa

**Torque**
Static Peak: 222 Nm
.25 Second: 204 Nm

**Coefficient of Friction**
Static Peak: 0.153
.25 Second: 0.141

# ALLISON C-4 GRAPHITE DATA

## STATIC CYCLE




Date of Test: 10/15/2011

Time of Test: 12:00:46

Test Number: C4-4-1342

Fluid Code: LO271510

Cycle Number: 4500

**PHASE B**

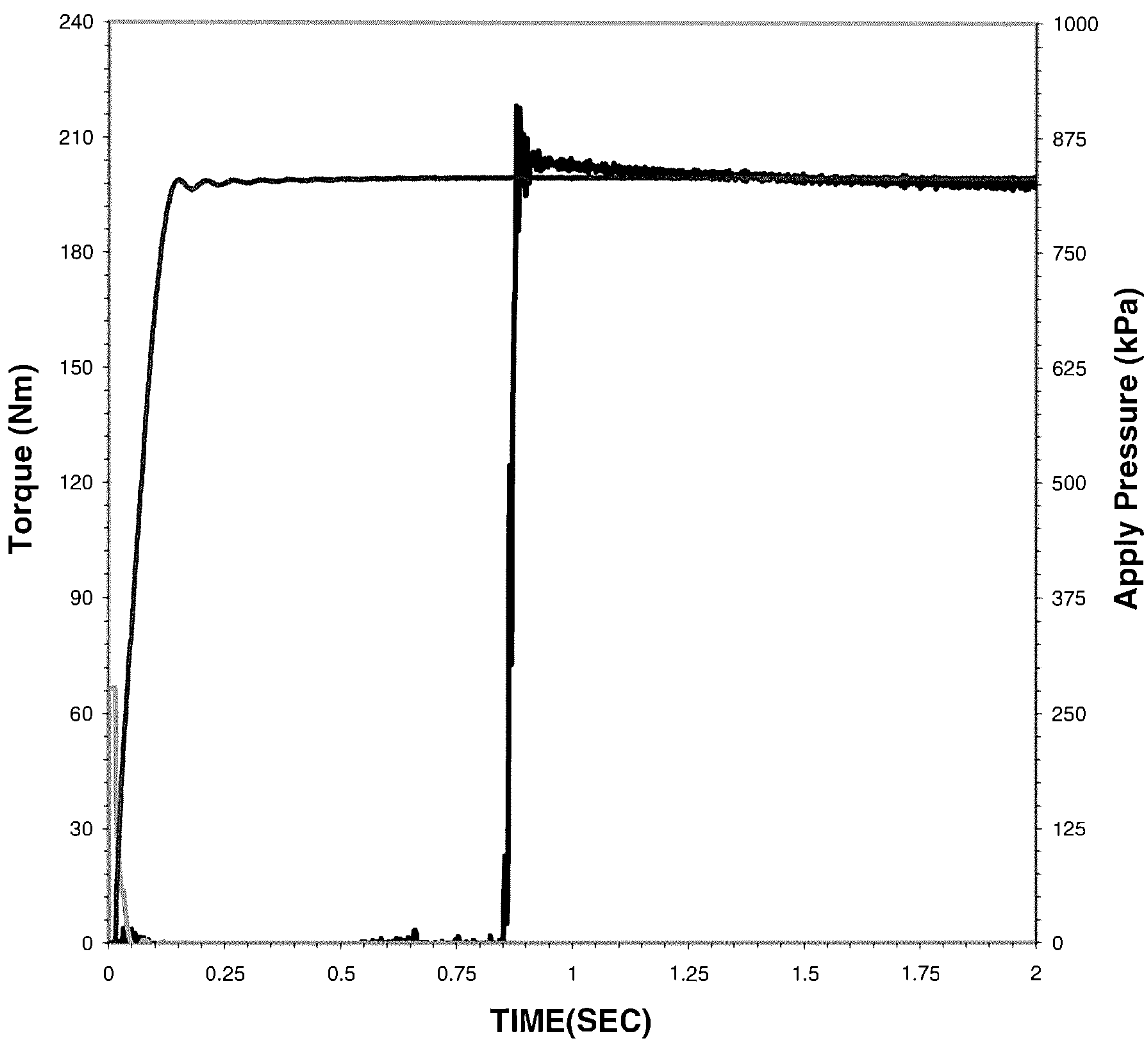
Apply Pressure:
At .25 Second: 831 kPa

**Torque**
Static Peak: 222 Nm
.25 Second: 204 Nm

**Coefficient of Friction**
Static Peak: 0.154
.25 Second: 0.141

# ALLISON C-4 GRAPHITE DATA

## STATIC CYCLE




Date of Test: 10/15/2011

Time of Test: 14:05:58

Test Number: C4-4-1342

Fluid Code: LO271510

Cycle Number: 5000

**PHASE B**

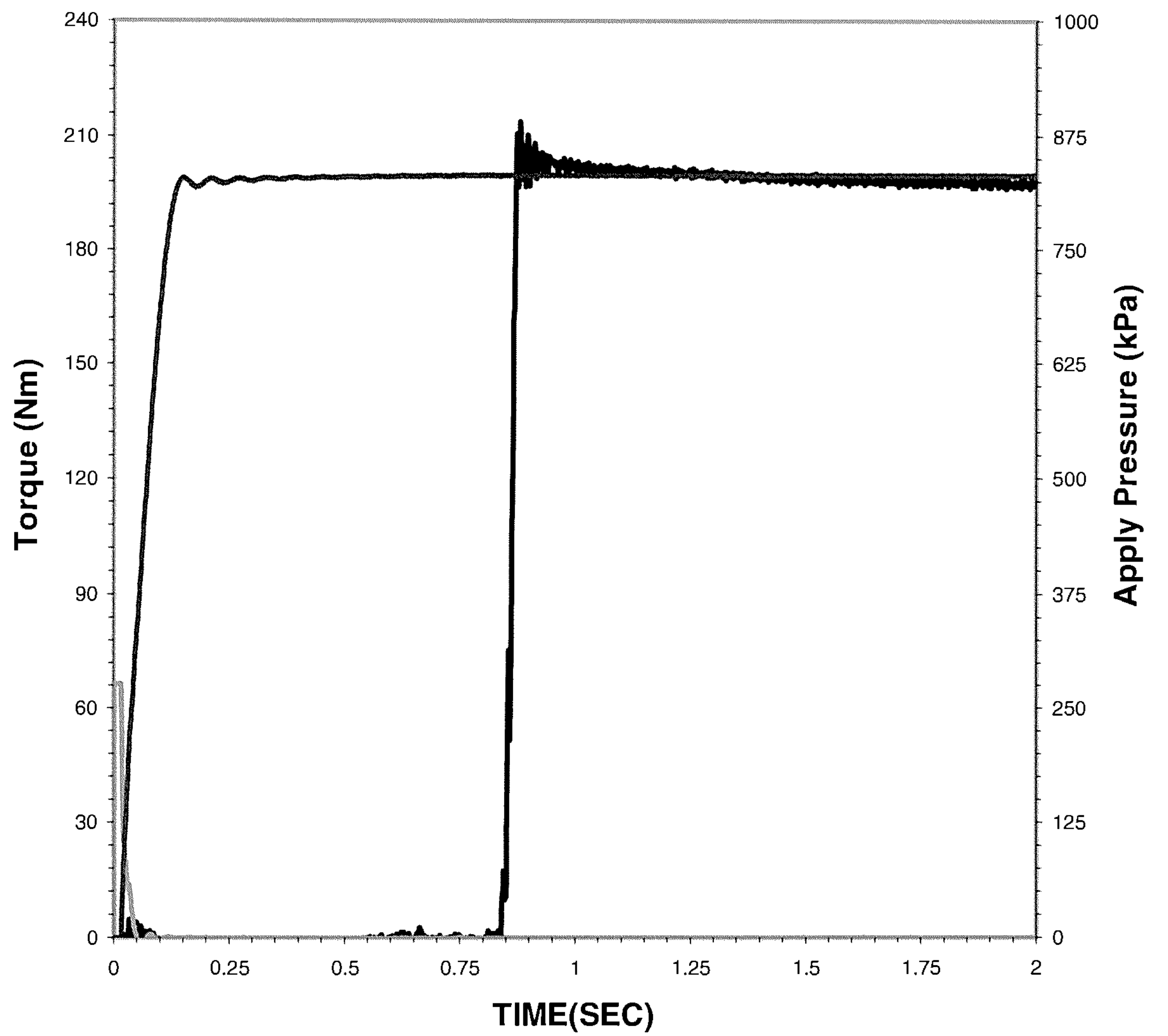
Apply Pressure:
At .25 Second: 830 kPa

**Torque**
Static Peak: 219 Nm
.25 Second: 201 Nm

**Coefficient of Friction**
Static Peak: 0.151
.25 Second: 0.139

# ALLISON C-4 GRAPHITE DATA

## STATIC CYCLE




Date of Test: 10/15/2011

Time of Test: 16:11:10

Test Number: C4-4-1342

Fluid Code: LO271510

Cycle Number: 5500

**PHASE B**

Apply Pressure:
At .25 Second: 829 kPa

**Torque**
Static Peak: 214 Nm
.25 Second: 202 Nm

**Coefficient of Friction**
Static Peak: 0.148
.25 Second: 0.140

# APPENDIX – D2 (PART 2)
# TYPE C-4 PAPER CLUTCH FRICTION TEST
# LO271510

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

**Report on**

**ALLISON HEAVY-DUTY TRANSMISSION FLUID**
# TYPE C-4 PAPER CLUTCH FRICTION TEST

Conducted for

**ARMY LAB**

Oil Code:
**LO271510**

Test Number:
**C2-4-1574**

**October 17, 2011**

Submitted by:

Matthew Jackson
Manager
Specialty & Driveline Fluids Evaluation

The results of this report relate only to the fluid tested.
This report shall not be reproduced, except in full, without the written approval of Southwest Research Institute®.

## IX. Paper Clutch Friction Test

| | | | |
|---|---|---|---|
| Test Laboratory: | SWRI | Lab Fluid Code: | LO-271510 |
| Test Number: | C2-4-1574 | Sponsor Fluid Code: | LO271510 |
| Friction Plate Batch: | LOT 6 | Completion Date: | 10/17/11 |
| Steel Plate Batch: | 10/9/2008 | | |

Clutch Wear Data
(units in mm)

| | Maximum | Average |
|---|---|---|
| Steel Plates | 0.0010 | 0.0004 |
| Clutch Plate | 0.1310 | 0.1174 |

| | Before | After |
|---|---|---|
| Pack Clearance | 0.8890 | 1.1176 |

Reference Tests

| Test Number | Test Date | Test Fluid |
|---|---|---|
| C2-0-1557 | 08/12/10 | RDL-2746 08-05 |
| C2-0-1568 | 12/10/10 | RDL-2746 08-05 |
| C2-0-1570 | 01/13/11 | RDL-2746 08-05 |

| | New | EOT |
|---|---|---|
| Viscosity at 40°C, cSt | 45.39 | 40.01 |
| Viscosity at 100°C, cSt | 8.48 | 7.80 |
| Iron Content, ppm | 1 | 181 |

| D5185 | New Fluid (ppm) |
|---|---|
| Ba | <1 |
| B | 18 |
| Ca | 896 |
| Mg | 1255 |
| P | 1055 |
| Si | 6 |
| Na | <5 |
| Zn | 1272 |

Name: Matthew Jackson
Signature:
Title: Manager
Date: 10/25/11

# ALLISON C- 4 PAPER FRICTION TEST

(Torque in N*m)

| | | | |
|---|---|---|---|
| Sponsor Fluid Code: | **LO271510** | Test Number: | **C2-4-1574** |
| Lab Fluid Code: | **LO-271510** | Fric. Plate Batch: | **Lot 6** |
| Completion Date: | **10/17/2011** | Steel Plate Batch: | **10/9/2008** |

## TORQUE

| CYCLE | SLIP TIME | TORQUE (MIDPOINT) | TORQUE STATIC PEAK | STATIC PEAK - MIDPOINT | LOW SPEED STATIC PEAK | LOWSPEED STATIC TORQUE |
|---|---|---|---|---|---|---|
| 100 | 0.50 | 196 | 356 | 160 | 383 | 371 |
| 500 | 0.47 | 209 | 359 | 150 | 383 | 368 |
| 1000 | 0.45 | 221 | 349 | 128 | 365 | 359 |
| 2500 | 0.43 | 238 | 336 | 98 | 352 | 343 |
| 5000 | 0.42 | 244 | 333 | 89 | 353 | 340 |
| 7500 | 0.43 | 241 | 325 | 84 | 345 | 334 |
| 10000 | 0.43 | 241 | 325 | 84 | 341 | 335 |

## COEFFICIENT OF FRICTION

| CYCLE | SLIP TIME | TORQUE (MIDPOINT) | TORQUE STATIC PEAK | STATIC PEAK - MIDPOINT | LOW SPEED STATIC PEAK | LOWSPEED STATIC TORQUE |
|---|---|---|---|---|---|---|
| 100 | 0.50 | 0.095 | 0.173 | 0.078 | 0.187 | 0.181 |
| 500 | 0.47 | 0.102 | 0.175 | 0.073 | 0.187 | 0.179 |
| 1000 | 0.45 | 0.108 | 0.170 | 0.062 | 0.178 | 0.175 |
| 2500 | 0.43 | 0.116 | 0.164 | 0.048 | 0.171 | 0.167 |
| 5000 | 0.42 | 0.119 | 0.162 | 0.043 | 0.172 | 0.166 |
| 7500 | 0.43 | 0.117 | 0.158 | 0.041 | 0.168 | 0.163 |
| 10000 | 0.43 | 0.117 | 0.158 | 0.041 | 0.166 | 0.163 |

| | Limits | | Results | | | |
|---|---|---|---|---|---|---|
| | Value | % Change | 100 N | 10,000 N | % Change | P/F |
| Slip Time Max. | 0.600 | N/A | 0.500 | 0.430 | -14.00 | P |
| Mid-Point Fric. Coeff. Min. | 0.085 | N/A | 0.095 | 0.117 | 23.16 | P |
| Static Friction Coeff. | N/A | N/A | 0.173 | 0.158 | -8.67 | |
| Low Speed Peak Fric. Coeff. | N/A | N/A | 0.187 | 0.166 | -11.23 | |
| 0.25 Second Low Speed Coeff. | N/A | N/A | 0.181 | 0.163 | -9.94 | |

SOUTHWEST RESEARCH INSTITUTE®

# ALLISON C4-PAPER FRICTION TEST

**(all units in mm)**

**Candidate Fluid: LO271510** | **Test Number : C2-4-1574** | **Completion Date : 10/17/2011**

**Lab Fluid Code : LO-271510** | **Steel Plate Batch: 10/09/2008** | **Fric Plate Batch : LOT 6**

| Plates | Location of Tooth (Clockwise) | Near Inner Diameter Before | Near Inner Diameter After | Near Outer Diameter Before | Near Outer Diameter After | Inner Diameter Change | Average Overall Change | Outer Diameter Change |
|---|---|---|---|---|---|---|---|---|
| FRICTION MATERIAL | | | | | | | | |
| 2 | Top | 2.0630 | 1.9430 | 2.0540 | 1.9380 | 0.1200 | | 0.1160 |
| | 120 | 2.0770 | 1.9460 | 2.0620 | 1.9480 | 0.1310 | | 0.1140 |
| | 240 | 2.0860 | 1.9570 | 2.0790 | 1.9640 | 0.1290 | | 0.1150 |
| | Average | | | | | 0.1267 | 0.1208 | 0.1150 |
| 5 | Top | 2.0820 | 1.9690 | 2.0760 | 1.9730 | 0.1130 | | 0.1030 |
| | 120 | 2.0820 | 1.9620 | 2.0670 | 1.9640 | 0.1200 | | 0.1030 |
| | 240 | 2.0700 | 1.9440 | 2.0660 | 1.9470 | 0.1260 | | 0.1190 |
| | Average | | | | | 0.1197 | 0.1140 | 0.1083 |
| STEELS SEPARATORS | | | | | | | | |
| 1 | Top | 1.7540 | 1.7540 | 1.7540 | 1.7540 | 0.0000 | | 0.0000 |
| | 120 | 1.7590 | 1.7590 | 1.7580 | 1.7580 | 0.0000 | | 0.0000 |
| | 240 | 1.7570 | 1.7570 | 1.7570 | 1.7570 | 0.0000 | | 0.0000 |
| | Average | | | | | 0.0000 | 0.0000 | 0.0000 |
| 3 | Top | 1.7550 | 1.7540 | 1.7560 | 1.7560 | 0.0010 | | 0.0000 |
| | 120 | 1.7540 | 1.7530 | 1.7540 | 1.7530 | 0.0010 | | 0.0010 |
| | 240 | 1.7550 | 1.7550 | 1.7510 | 1.7500 | 0.0000 | | 0.0010 |
| | Average | | | | | 0.0007 | 0.0007 | 0.0007 |
| 4 | Top | 1.7520 | 1.7510 | 1.7520 | 1.7520 | 0.0010 | | 0.0000 |
| | 120 | 1.7510 | 1.7510 | 1.7510 | 1.7500 | 0.0000 | | 0.0010 |
| | 240 | 1.7510 | 1.7500 | 1.7540 | 1.7530 | 0.0010 | | 0.0010 |
| | Average | | | | | 0.0007 | 0.0007 | 0.0007 |
| 6 | Top | 1.7510 | 1.7510 | 1.7510 | 1.7500 | 0.0000 | | 0.0010 |
| | 120 | 1.7520 | 1.7520 | 1.7520 | 1.7520 | 0.0000 | | 0.0000 |
| | 240 | 1.7510 | 1.7500 | 1.7500 | 1.7500 | 0.0010 | | 0.0000 |
| | Average | | | | | 0.0003 | 0.0003 | 0.0003 |

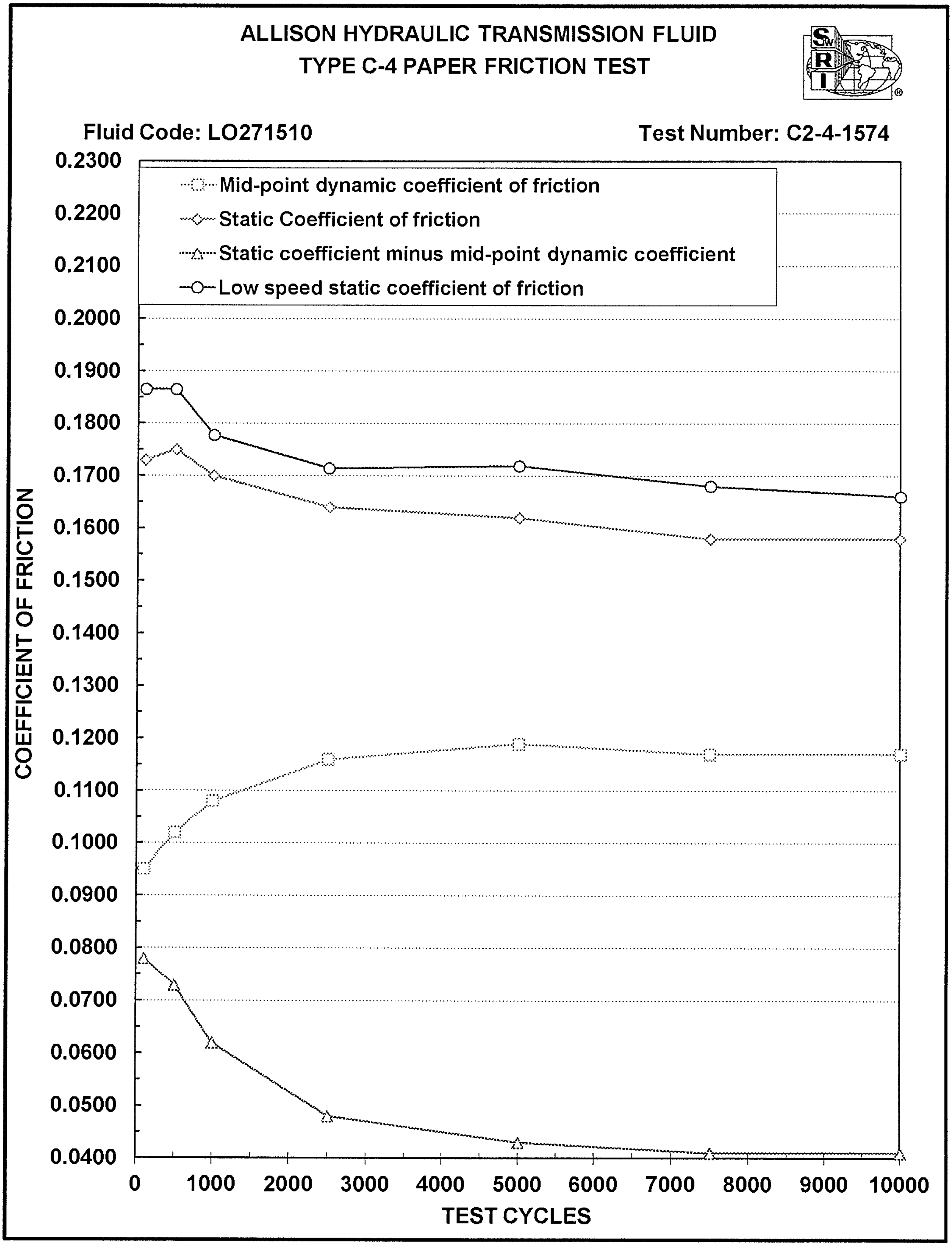
**PLATE CONDITION AT E.O.T.:** (Anything Unusual) PLATES IN GOOD CONDITION WITH VERY LIGHT DISCOLORATION ON INNER STEEL PLATES. MICROMETER #0221190

Test Date and Operator's Name: 9/28/2011 MARK HOLMES

Reviewed By (Signature and Date) 10/24/11

Pack ID#: 4659

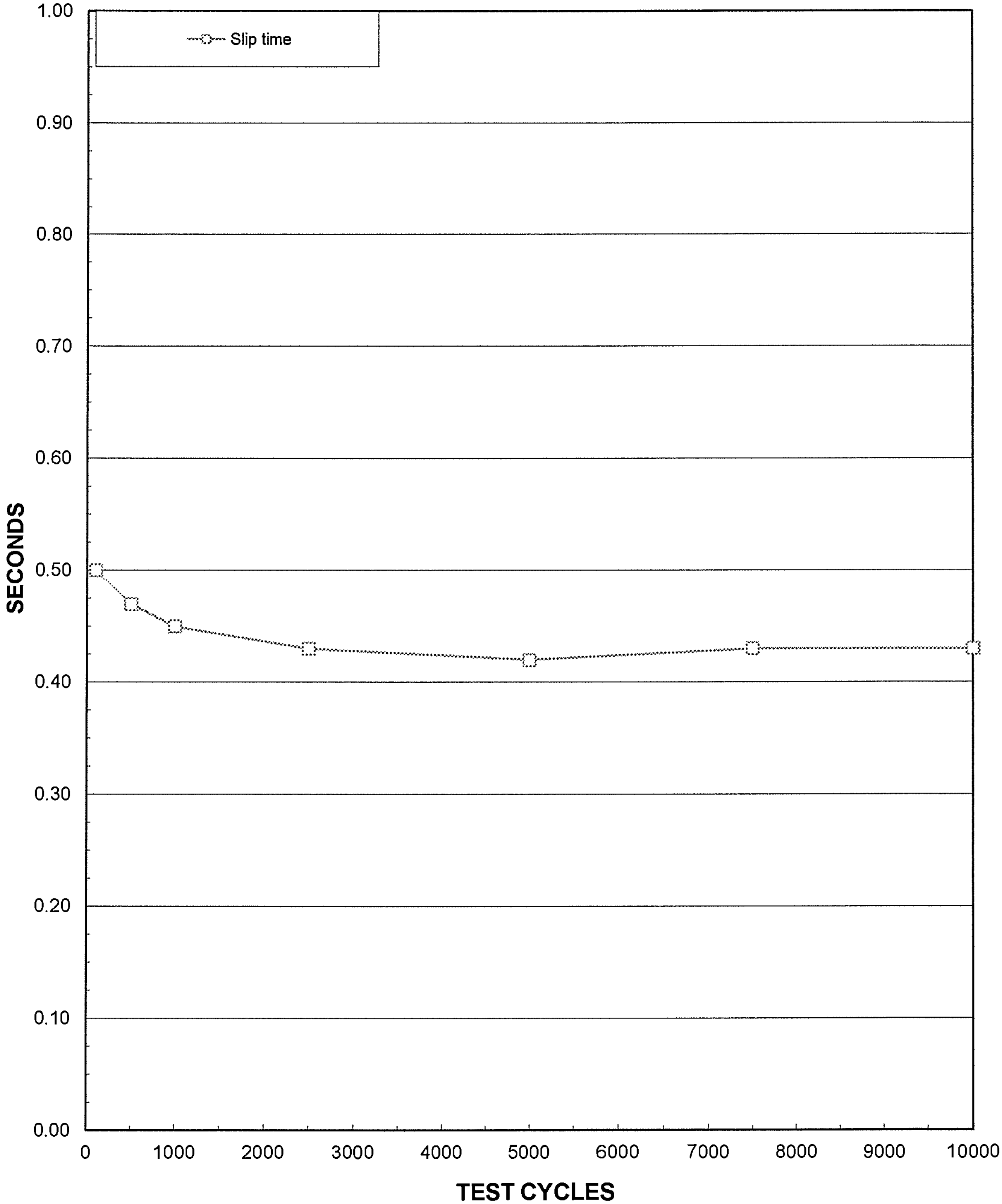
C4 Paper Version 1.3 April 26, 2001

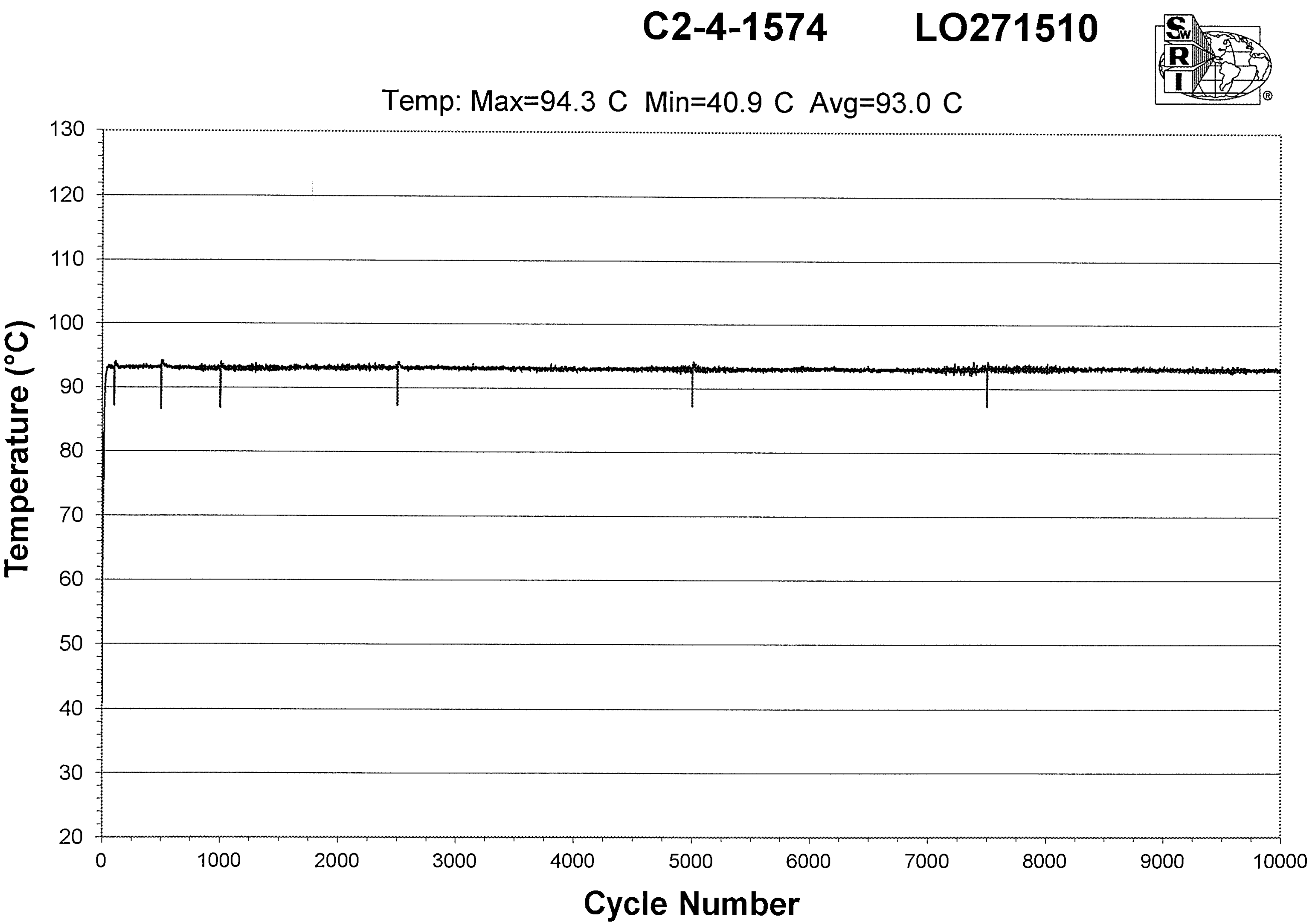

ALLISON HYDRAULIC TRANSMISSION FLUID
TYPE C-4 PAPER FRICTION TEST
Fluid Code: LO271510
Test Number: C2-4-1574
Mid-point dynamic coefficient of friction
Static Coefficient of friction
Static coefficient minus mid-point dynamic coefficient
Low speed static coefficient of friction
COEFFICIENT OF FRICTION
0.2300
0.2200
0.2100
0.2000
0.1900
0.1800
0.1700
0.1600
0.1500
0.1400
0.1300
0.1200
0.1100
0.1000
0.0900
0.0800
0.0700
0.0600
0.0500
0.0400
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
TEST CYCLES

ALLISON HYDRAULIC TRANSMISSION FLUID
TYPE C-4 PAPER FRICTION TEST

Fluid Code: LO271510

Test Number: C2-4-1574

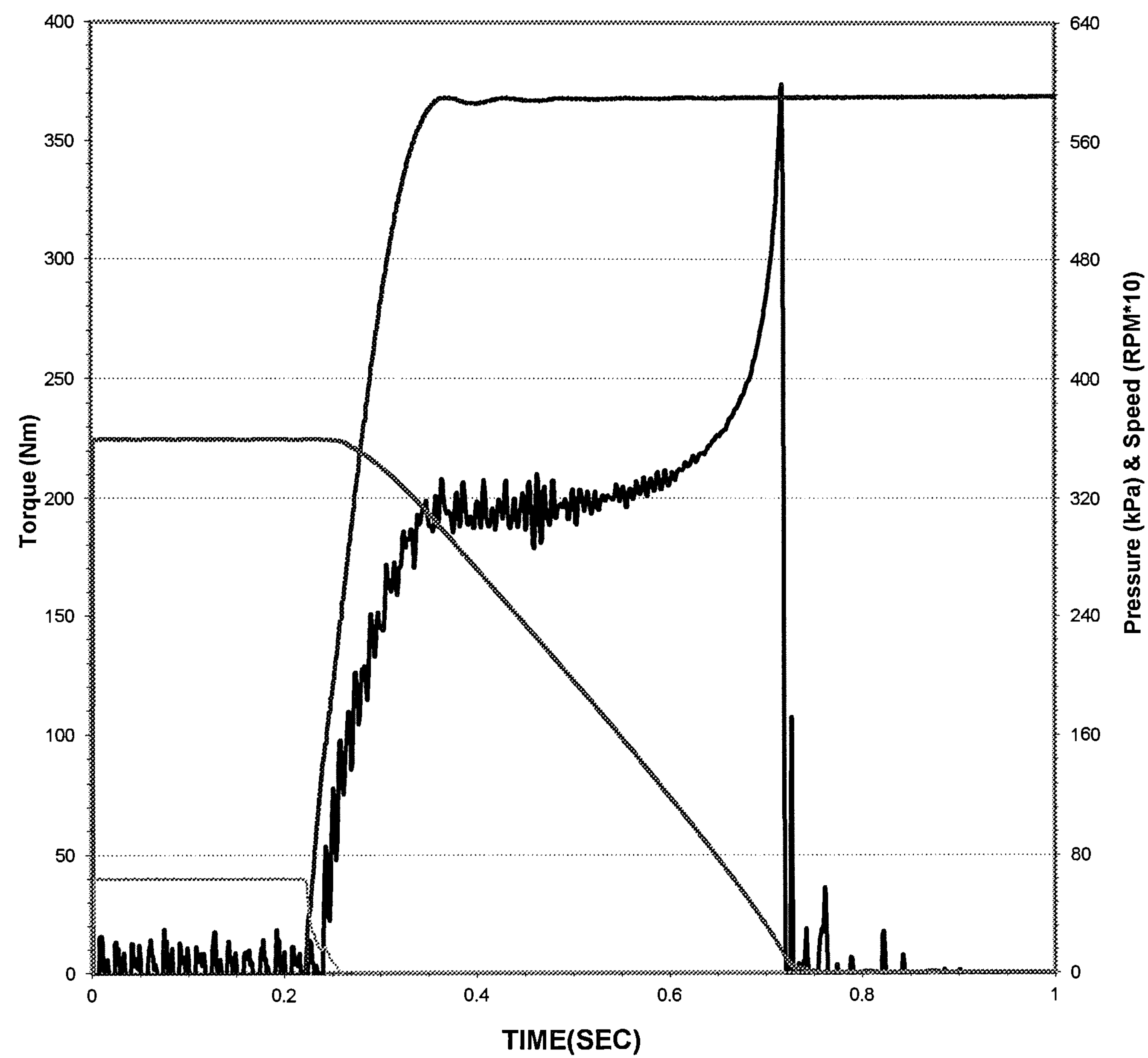



C2-4-1574 LO271510
Temp: Max=94.3 C Min=40.9 C Avg=93.0 C
Temperature (°C)
130
120
110
100
90
80
70
60
50
40
30
20
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Cycle Number

## DYNAMIC TRACES

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 9:29:03 |
| Test Number: | C2-4-1574 |
| Fluid Code: | LO271510 |
| Cycle Number: | 10 |
| Temperature: | 75.6 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 589 kPa (586 ± 7 KPa) |
| Apply Rate: | 0.14 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ (18.7 ± 0.40 KJ) |
| Engage Time: | 0.498 Sec |

**Torque**

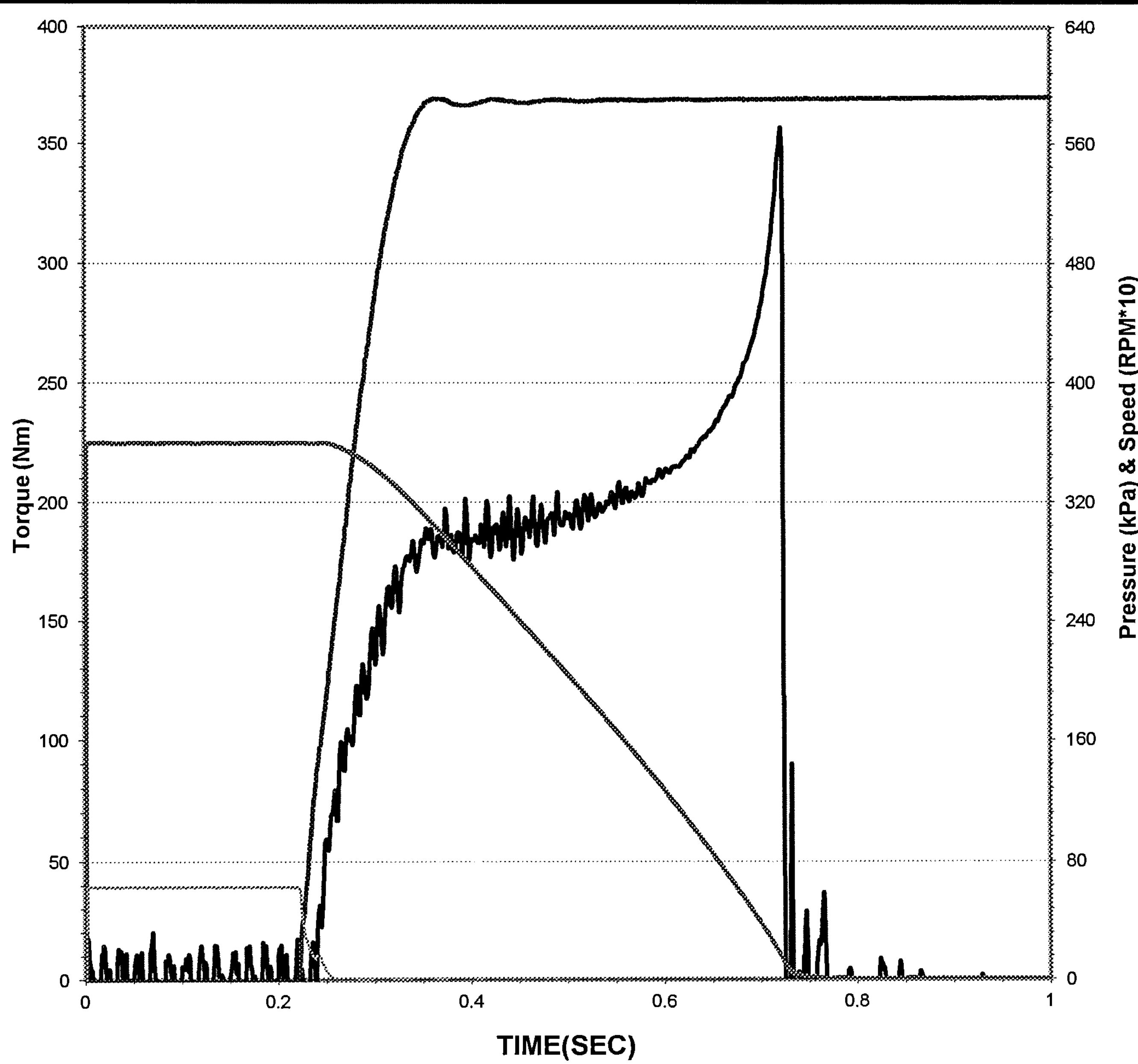
| | |
|---|---|
| 0.2 Sec Dyn: | 199 N*m |
| Midpoint Dyn: | 199 N*m |
| LwSpd Dynamic: | 377 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.097 |
| Midpoint Dyn: | 0.097 |
| LwSpd Dynamic: | 0.184 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 9:51:34 |
| Test Number: | C2-4-1574 |
| Fluid Code: | LO271510 |
| Cycle Number: | 99 |
| Temperature: | 93.2 °C<br>(93.3 ± 3.0 °C) |
| Apply Pressure: | 590 kPa<br>(586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec<br>(0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ<br>(18.7 ± 0.40 KJ) |
| Engage Time: | 0.502 Sec |

**Torque**

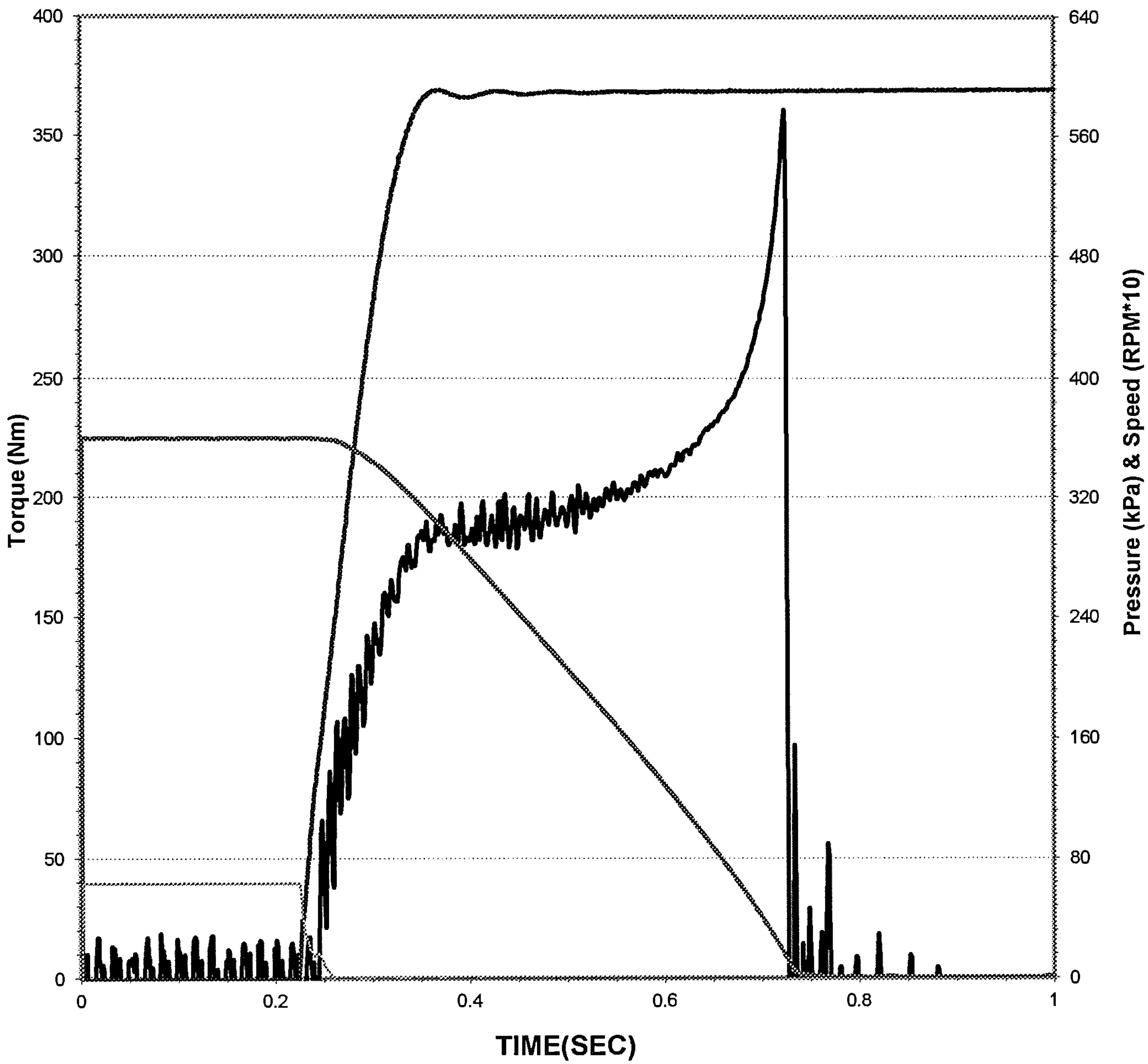
| | |
|---|---|
| 0.2 Sec Dyn: | 191 N*m |
| Midpoint Dyn: | 194 N*m |
| LwSpd Dynamic: | 353 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.093 |
| Midpoint Dyn: | 0.095 |
| LwSpd Dynamic: | 0.172 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 9:51:49 |
| Test Number: | C2-4-1574 |
| Fluid Code: | LO271510 |
| Cycle Number: | 100 |
| Temperature: | 93.1 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 590 kPa (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ (18.7 ± 0.40 KJ) |
| Engage Time: | 0.502 Sec |

**Torque**

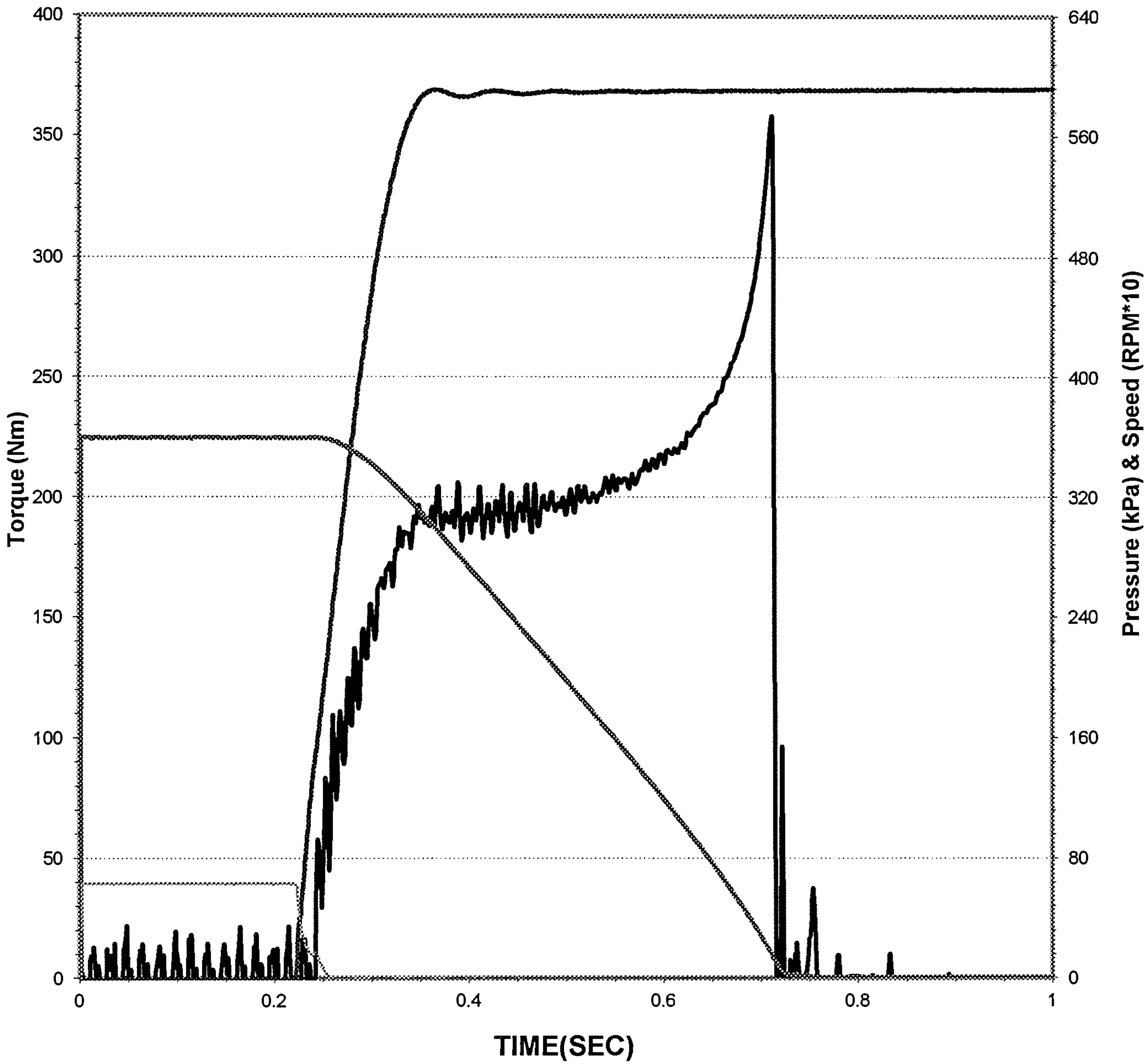
| | |
|---|---|
| 0.2 Sec Dyn: | 190 N*m |
| Midpoint Dyn: | 195 N*m |
| LwSpd Dynamic: | 360 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.093 |
| Midpoint Dyn: | 0.095 |
| LwSpd Dynamic: | 0.175 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 9:52:20 |
| Test Number: | C2-4-1574 |
| Fluid Code: | LO271510 |
| Cycle Number: | 101 |
| Temperature: | 87.2 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 590 kPa (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.4 KJ (18.7 ± 0.40 KJ) |
| Engage Time: | 0.493 Sec |

**Torque**

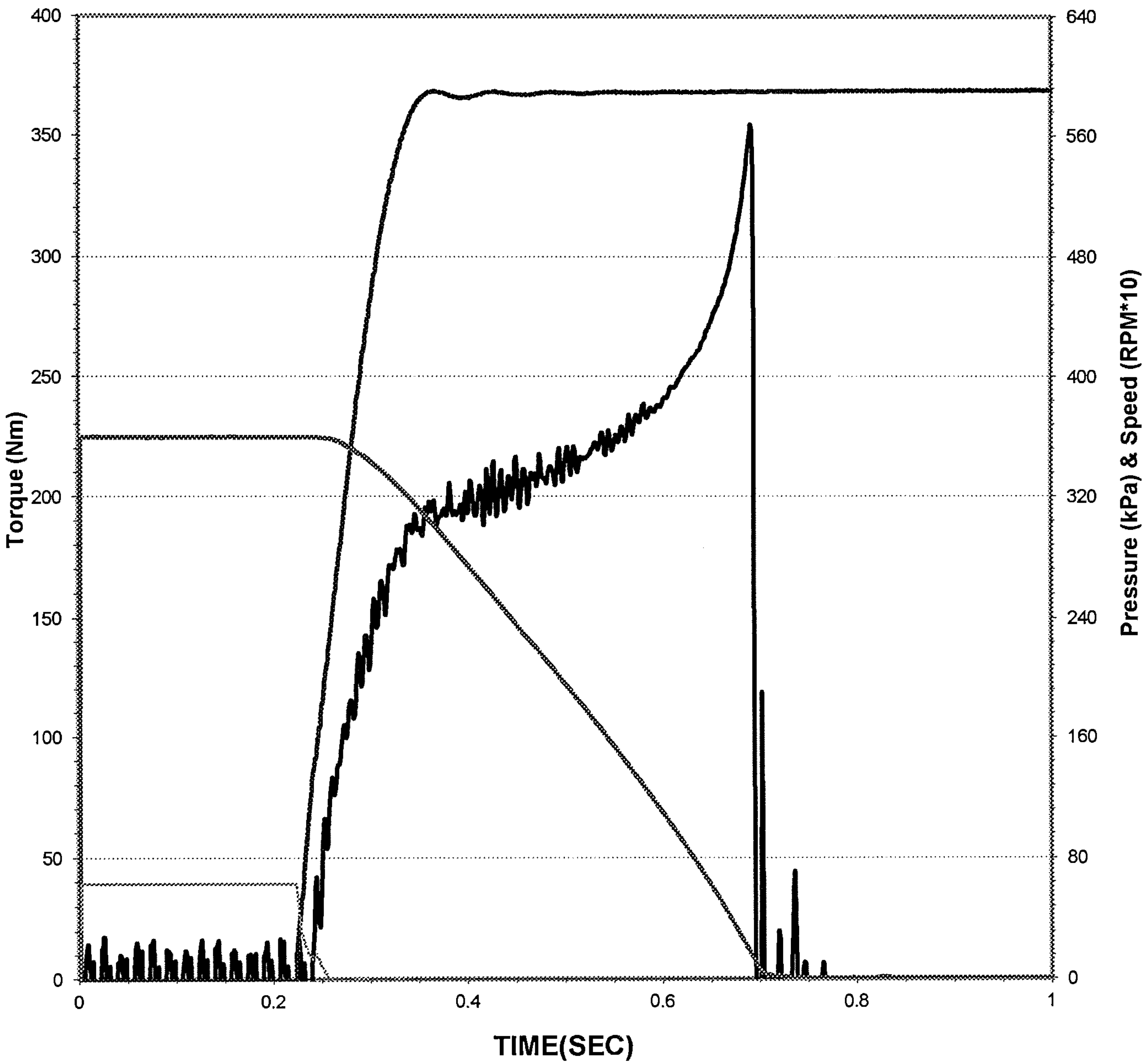
| | |
|---|---|
| 0.2 Sec Dyn: | 195 N*m |
| Midpoint Dyn: | 198 N*m |
| LwSpd Dynamic: | 354 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.095 |
| Midpoint Dyn: | 0.097 |
| LwSpd Dynamic: | 0.173 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 11:31:50 |
| Test Number: | C2-4-1574 |
| Fluid Code: | LO271510 |
| Cycle Number: | 499 |
| Temperature: | 93.4 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 589 kPa (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.5 KJ (18.7 ± 0.40 KJ) |
| Engage Time: | 0.472 Sec |

**Torque**

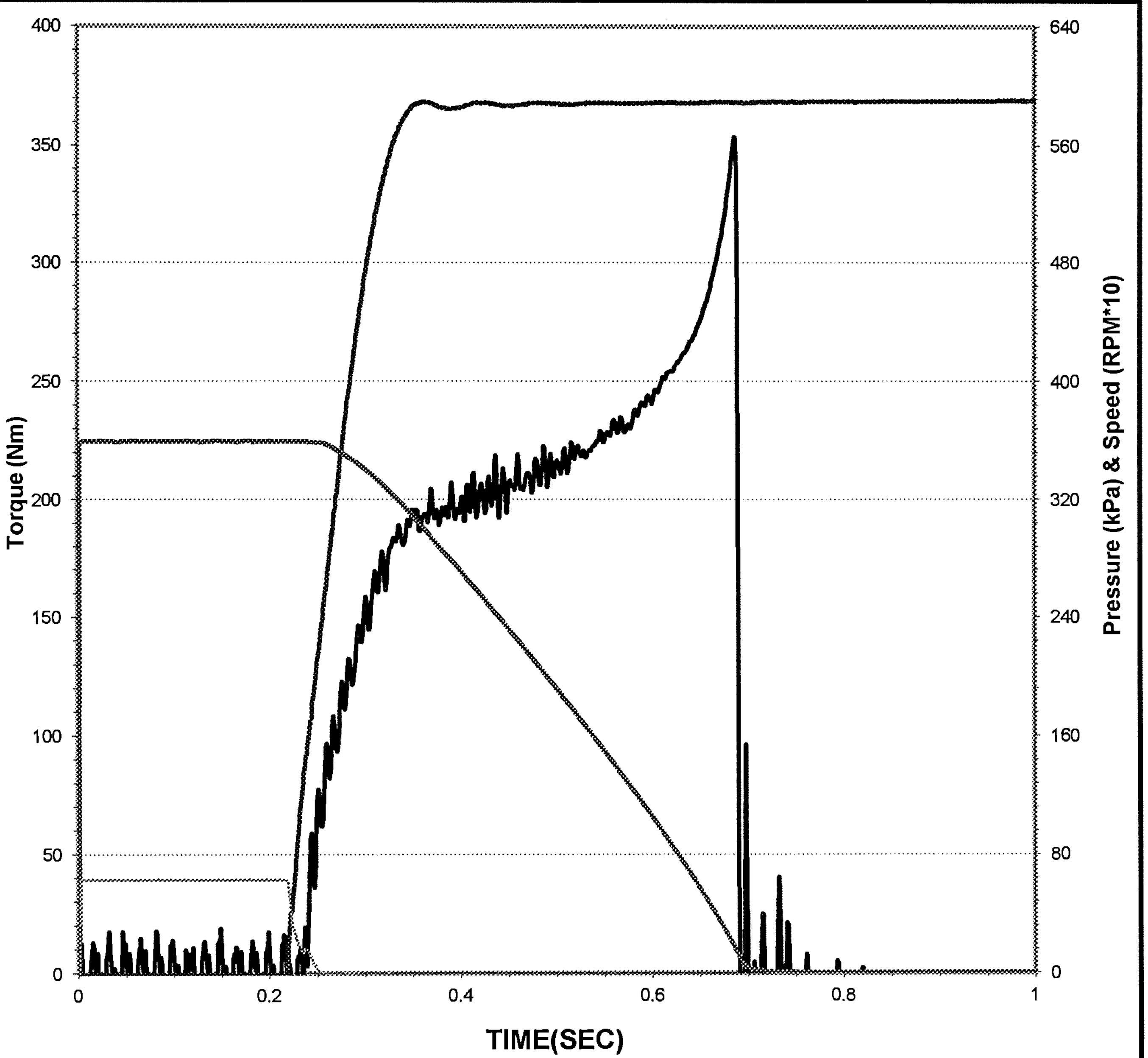
| | |
|---|---|
| 0.2 Sec Dyn: | 205 N*m |
| Midpoint Dyn: | 210 N*m |
| LwSpd Dynamic: | 357 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.100 |
| Midpoint Dyn: | 0.102 |
| LwSpd Dynamic: | 0.174 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 11:32:05 |
| Test Number: | C2-4-1574 |
| Fluid Code: | LO271510 |
| Cycle Number: | 500 |
| Temperature: | 93.4 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 589 kPa (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.5 KJ (18.7 ± 0.40 KJ) |
| Engage Time: | 0.471 Sec |

**Torque**

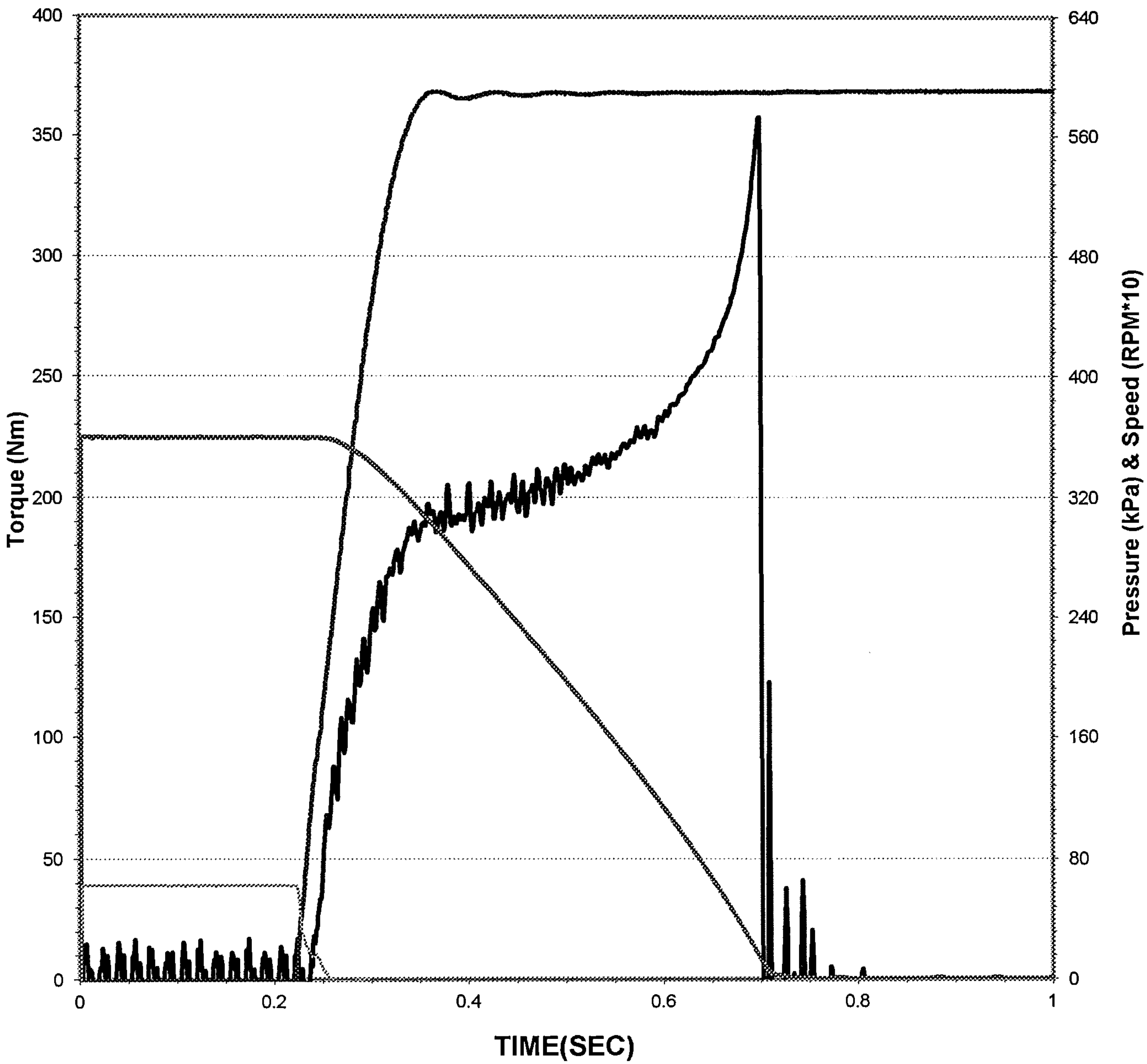
| | |
|---|---|
| 0.2 Sec Dyn: | 205 N*m |
| Midpoint Dyn: | 210 N*m |
| LwSpd Dynamic: | 357 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.100 |
| Midpoint Dyn: | 0.102 |
| LwSpd Dynamic: | 0.174 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 11:32:36 |
| Test Number: | C2-4-1574 |
| Fluid Code: | LO271510 |
| Cycle Number: | 501 |
| Temperature: | 86.7 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 589 kPa (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.5 KJ (18.7 ± 0.40 KJ) |
| Engage Time: | 0.477 Sec |

**Torque**

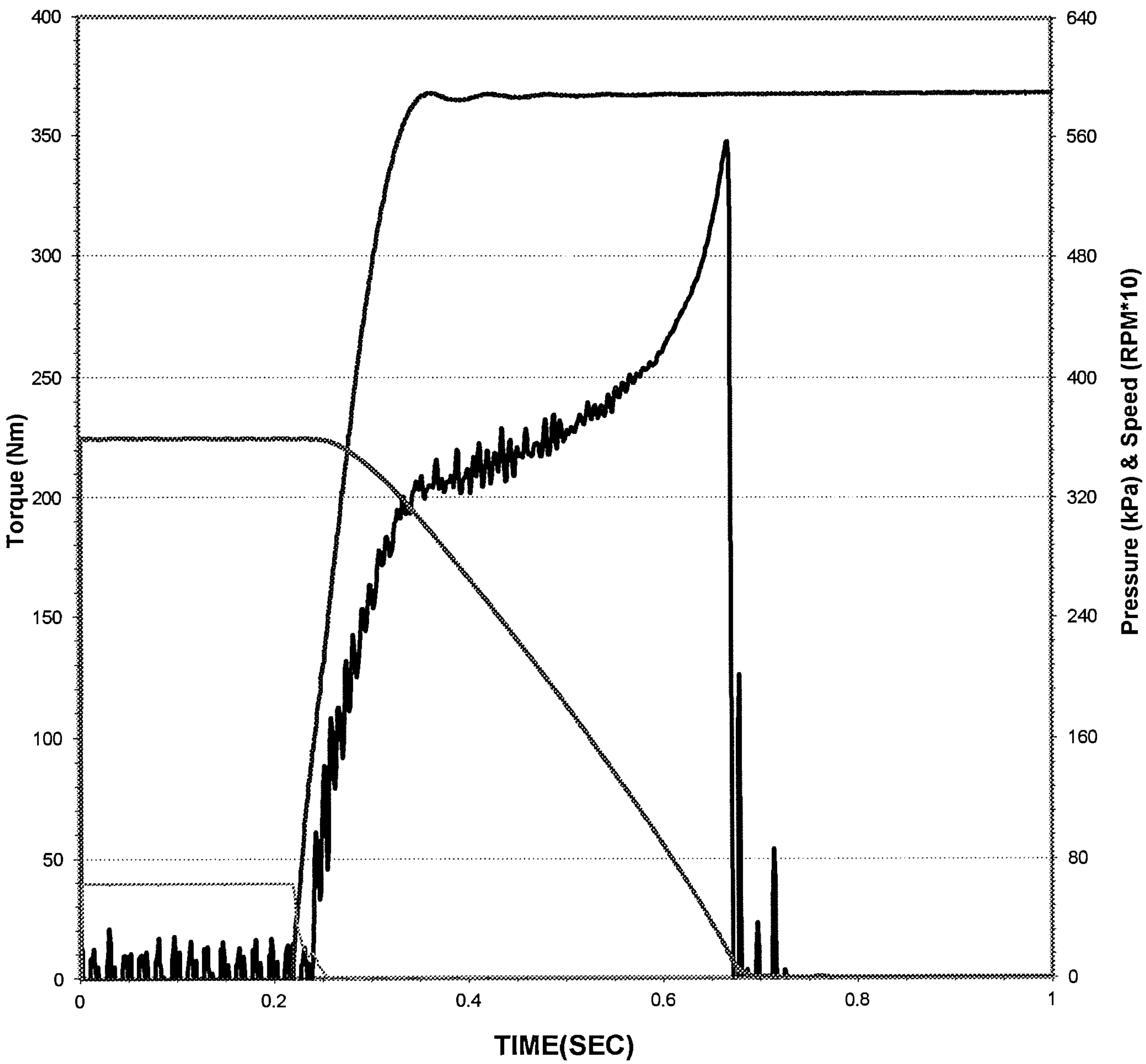
| | |
|---|---|
| 0.2 Sec Dyn: | 202 N*m |
| Midpoint Dyn: | 206 N*m |
| LwSpd Dynamic: | 362 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.098 |
| Midpoint Dyn: | 0.100 |
| LwSpd Dynamic: | 0.176 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 13:37:06 |
| Test Number: | C2-4-1574 |
| Fluid Code: | LO271510 |
| Cycle Number: | 999 |
| Temperature: | 93.0 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 588 kPa (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.5 KJ (18.7 ± 0.40 KJ) |
| Engage Time: | 0.452 Sec |

**Torque**

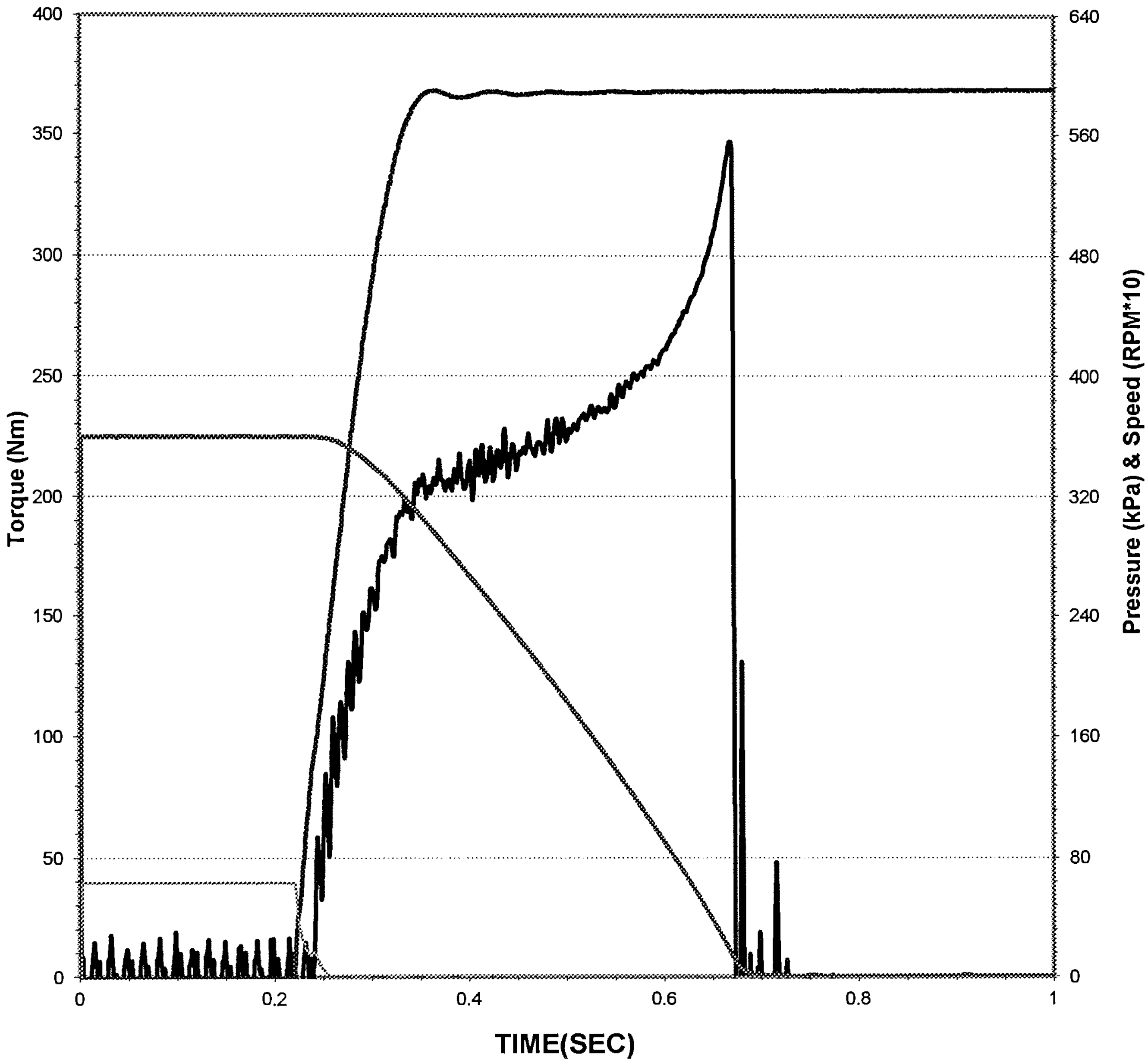
| | |
|---|---|
| 0.2 Sec Dyn: | 217 N*m |
| Midpoint Dyn: | 222 N*m |
| LwSpd Dynamic: | 348 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.106 |
| Midpoint Dyn: | 0.108 |
| LwSpd Dynamic: | 0.169 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 13:37:21 |
| Test Number: | C2-4-1574 |
| Fluid Code: | LO271510 |
| Cycle Number: | 1000 |
| Temperature: | 93.0 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 588 kPa (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.5 KJ (18.7 ± 0.40 KJ) |
| Engage Time: | 0.451 Sec |

**Torque**

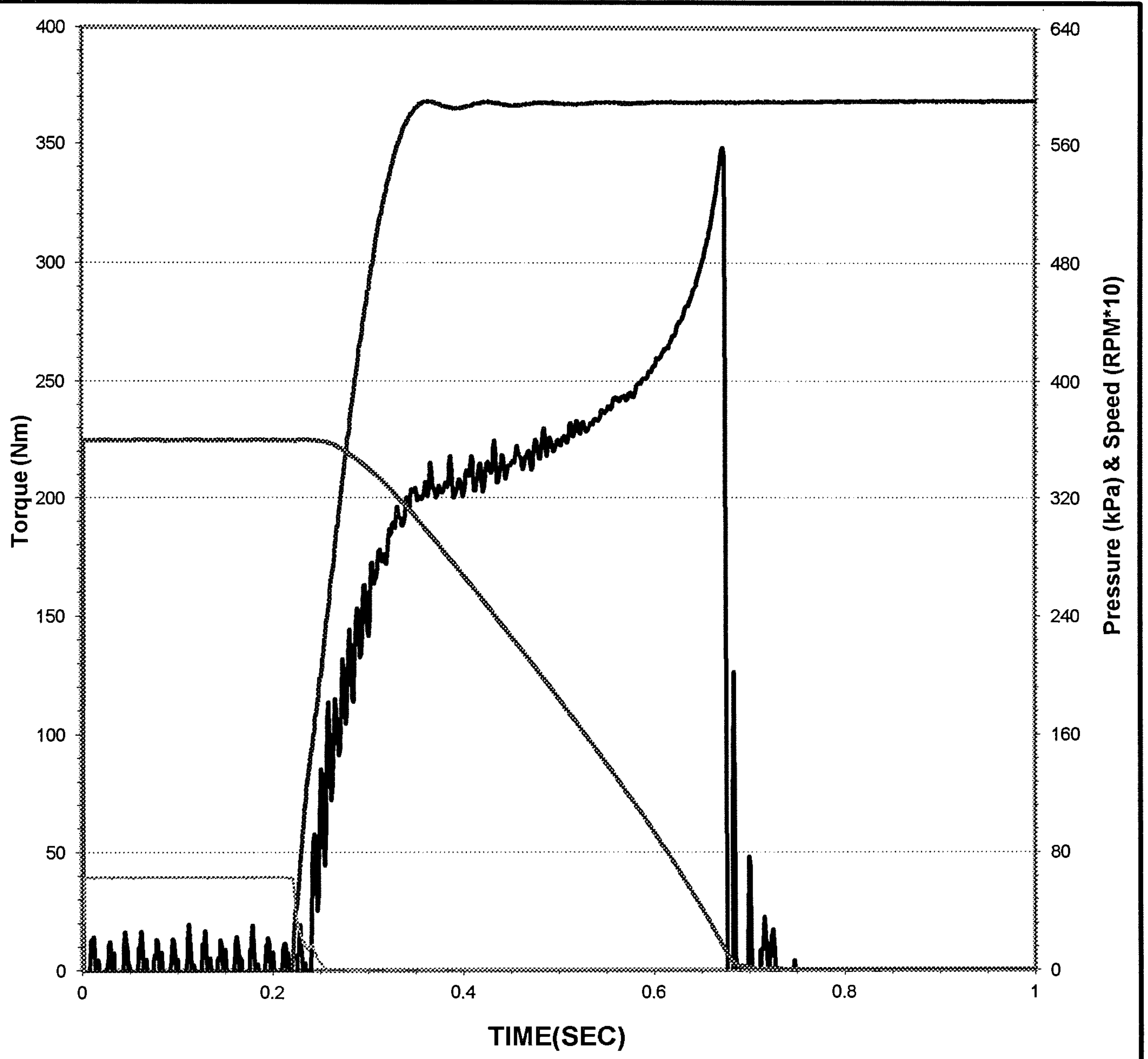
| | |
|---|---|
| 0.2 Sec Dyn: | 217 N*m |
| Midpoint Dyn: | 222 N*m |
| LwSpd Dynamic: | 349 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.106 |
| Midpoint Dyn: | 0.108 |
| LwSpd Dynamic: | 0.170 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 13:37:53 |
| Test Number: | C2-4-1574 |
| Fluid Code: | LO271510 |
| Cycle Number: | 1001 |
| Temperature: | 86.9 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 589 kPa (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.5 KJ (18.7 ± 0.40 KJ) |
| Engage Time: | 0.455 Sec |

**Torque**

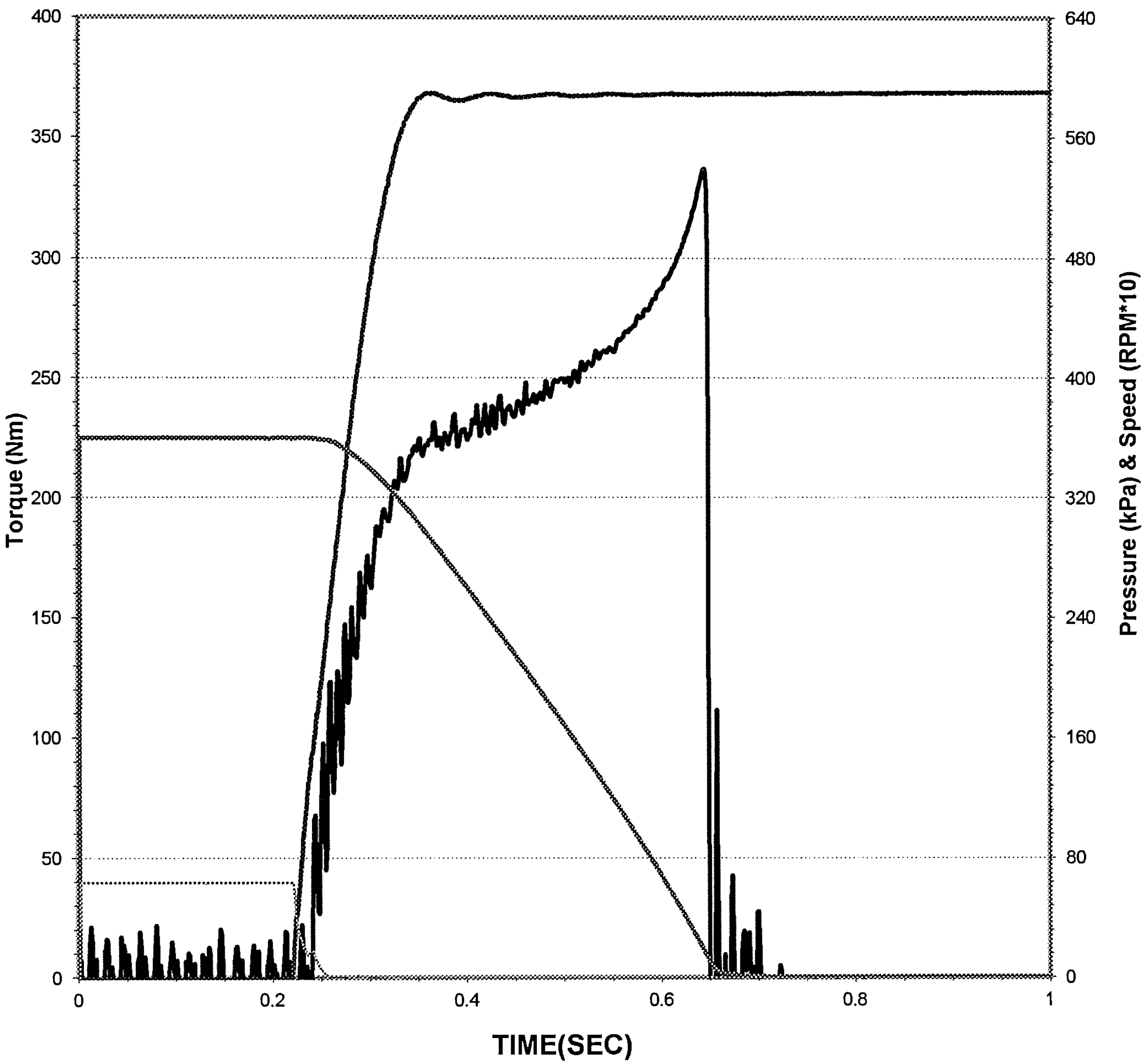
| | |
|---|---|
| 0.2 Sec Dyn: | 215 N*m |
| Midpoint Dyn: | 219 N*m |
| LwSpd Dynamic: | 350 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.105 |
| Midpoint Dyn: | 0.107 |
| LwSpd Dynamic: | 0.171 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 19:52:23 |
| Test Number: | C2-4-1574 |
| Fluid Code: | LO271510 |
| Cycle Number: | 2499 |
| Temperature: | 93.3 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 589 kPa (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.6 KJ (18.7 ± 0.40 KJ) |
| Engage Time: | 0.428 Sec |

**Torque**

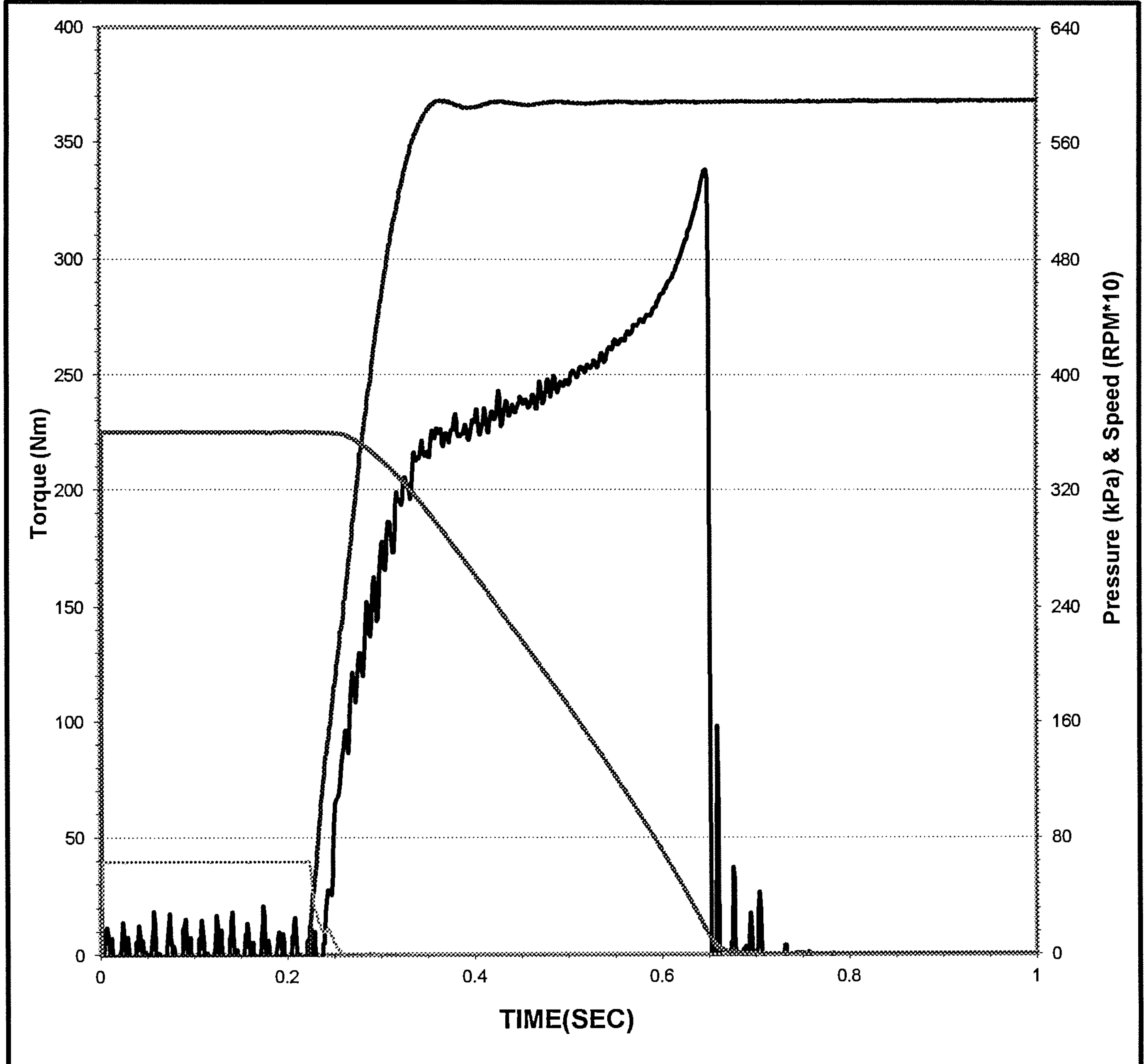
| | |
|---|---|
| 0.2 Sec Dyn: | 236 N*m |
| Midpoint Dyn: | 239 N*m |
| LwSpd Dynamic: | 333 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.115 |
| Midpoint Dyn: | 0.116 |
| LwSpd Dynamic: | 0.162 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 19:52:38 |
| Test Number: | C2-4-1574 |
| Fluid Code: | LO271510 |
| Cycle Number: | 2500 |
| Temperature: | 93.0 °C |
| | (93.3 ± 3.0 °C) |
| Apply Pressure: | 589 kPa |
| | (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec |
| | (0.15 ± 0.02 Sec) |
| Energy: | 18.6 KJ |
| | (18.7 ± 0.40 KJ) |
| Engage Time: | 0.429 Sec |

**Torque**

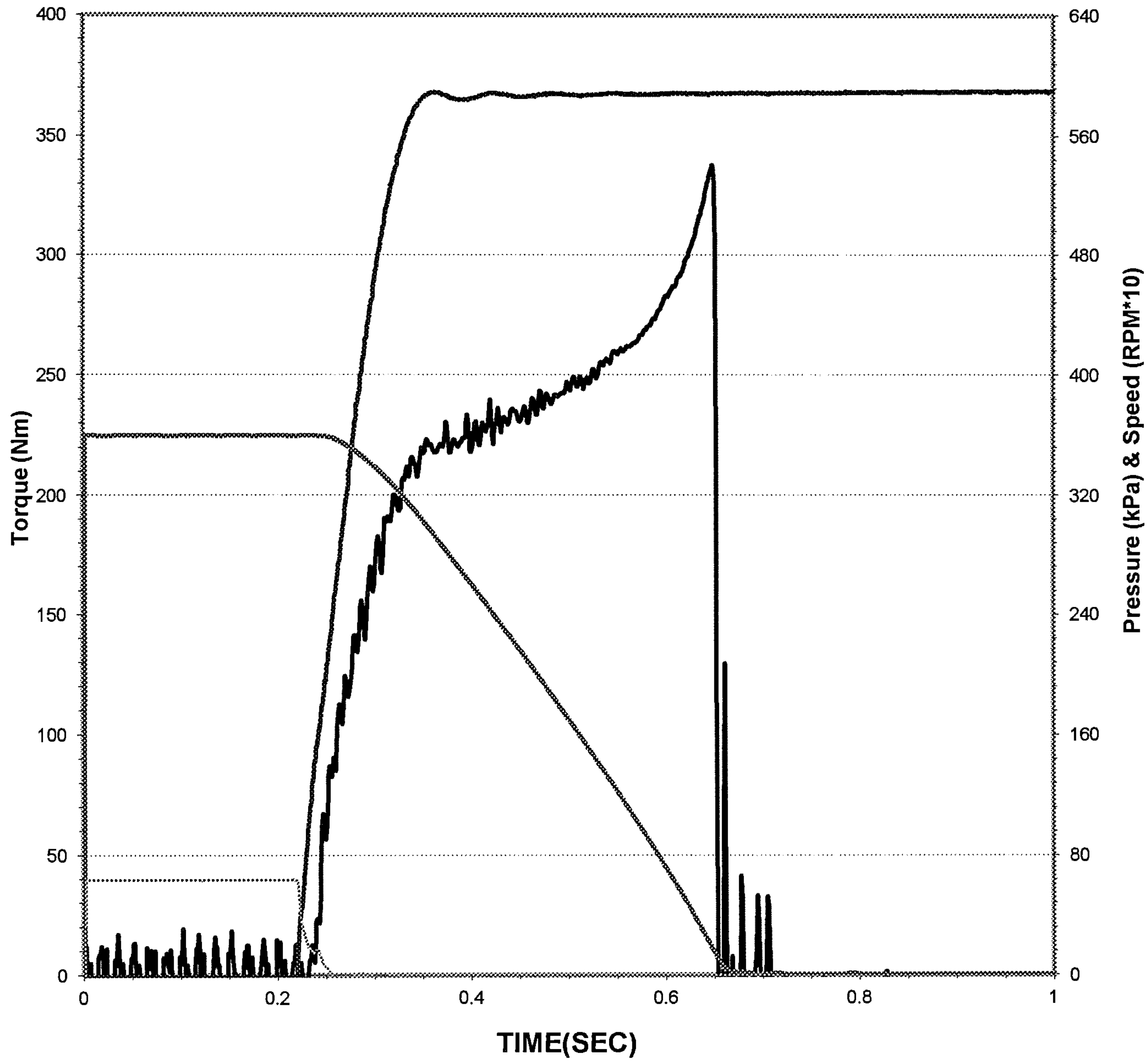
| | |
|---|---|
| 0.2 Sec Dyn: | 238 N*m |
| Midpoint Dyn: | 239 N*m |
| LwSpd Dynamic: | 339 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.116 |
| Midpoint Dyn: | 0.116 |
| LwSpd Dynamic: | 0.165 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/15/2011 |
| Time of Test: | 19:53:09 |
| Test Number: | C2-4-1574 |
| Fluid Code: | LO271510 |
| Cycle Number: | 2501 |
| Temperature: | 87.3 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 589 kPa (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.6 KJ (18.7 ± 0.40 KJ) |
| Engage Time: | 0.433 Sec |

**Torque**

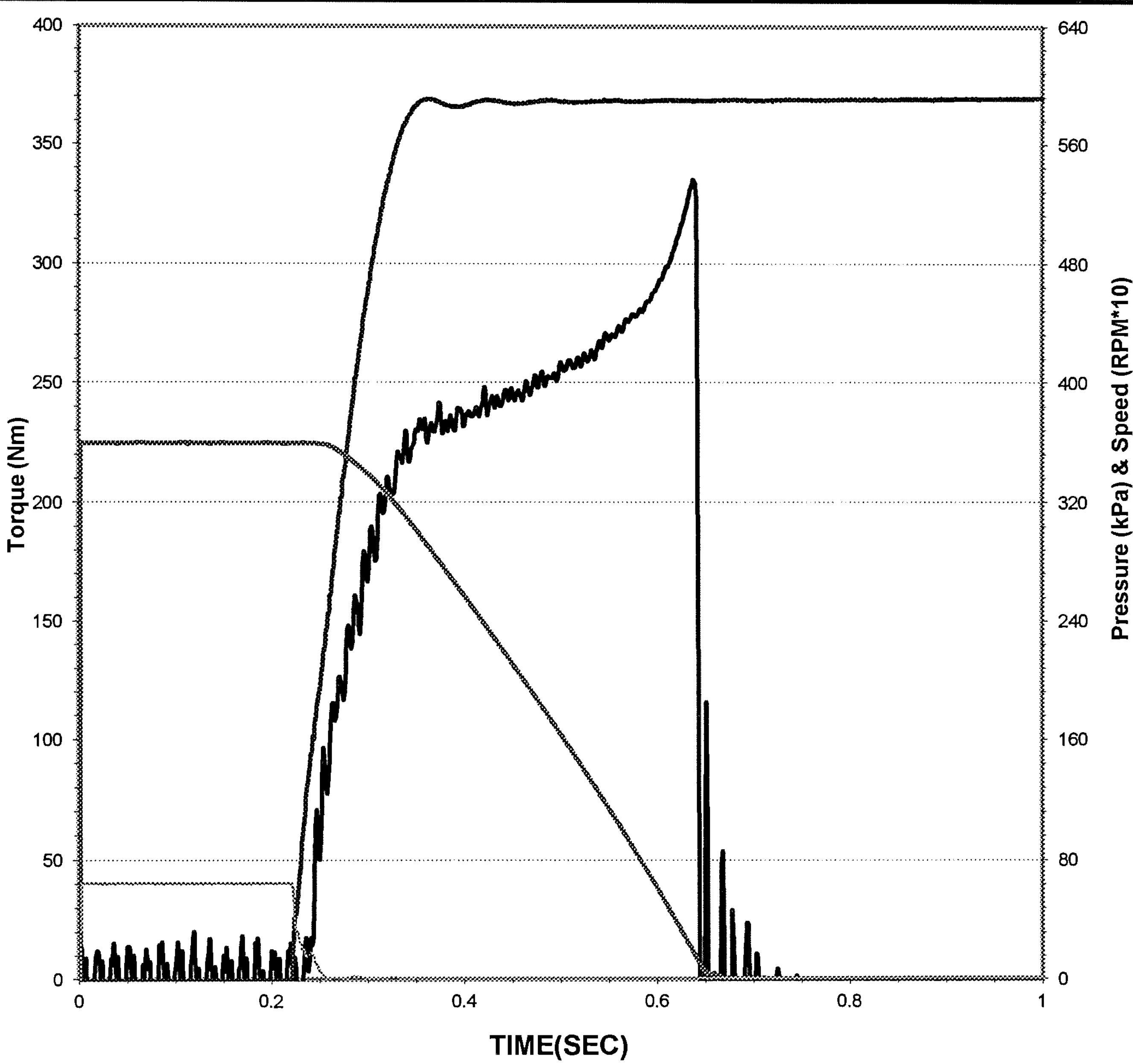
| | |
|---|---|
| 0.2 Sec Dyn: | 234 N*m |
| Midpoint Dyn: | 236 N*m |
| LwSpd Dynamic: | 335 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.114 |
| Midpoint Dyn: | 0.115 |
| LwSpd Dynamic: | 0.163 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/16/2011 |
| Time of Test: | 6:17:39 |
| Test Number: | C2-4-1574 |
| Fluid Code: | LO271510 |
| Cycle Number: | 4999 |
| Temperature: | 92.7 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 590 kPa (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.6 KJ (18.7 ± 0.40 KJ) |
| Engage Time: | 0.422 Sec |

**Torque**

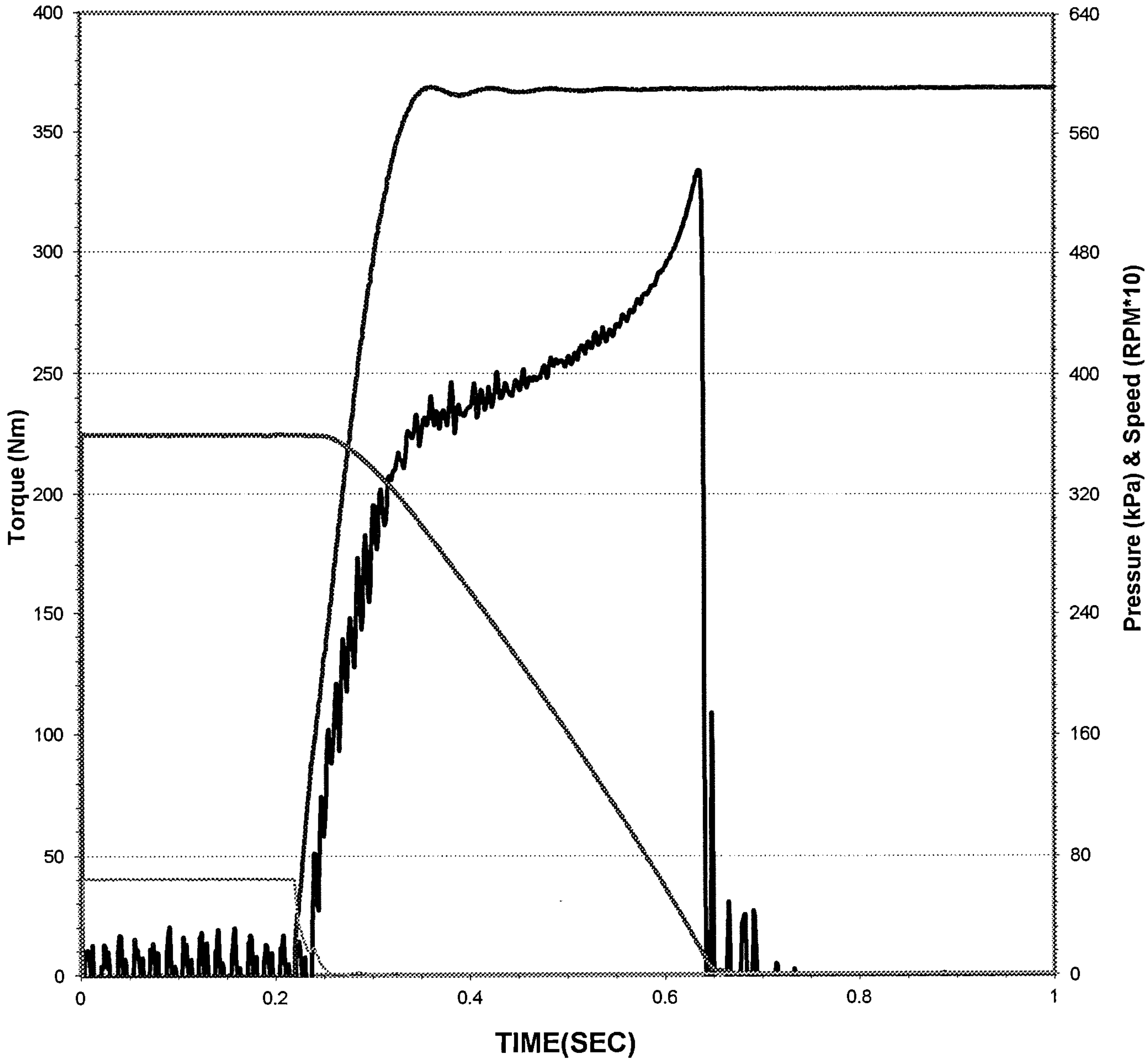
| | |
|---|---|
| 0.2 Sec Dyn: | 244 N*m |
| Midpoint Dyn: | 245 N*m |
| LwSpd Dynamic: | 332 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.119 |
| Midpoint Dyn: | 0.119 |
| LwSpd Dynamic: | 0.162 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




Date of Test: 10/16/2011

Time of Test: 6:17:54

Test Number: C2-4-1574

Fluid Code: LO271510

Cycle Number: 5000

Temperature: 93.2 °C (93.3 ± 3.0 °C)

Apply Pressure: 590 kPa (586 ± 7 KPa)

Apply Rate: 0.13 Sec (0.15 ± 0.02 Sec)

Energy: 18.6 KJ (18.7 ± 0.40 KJ)

Engage Time: 0.422 Sec

**Torque**

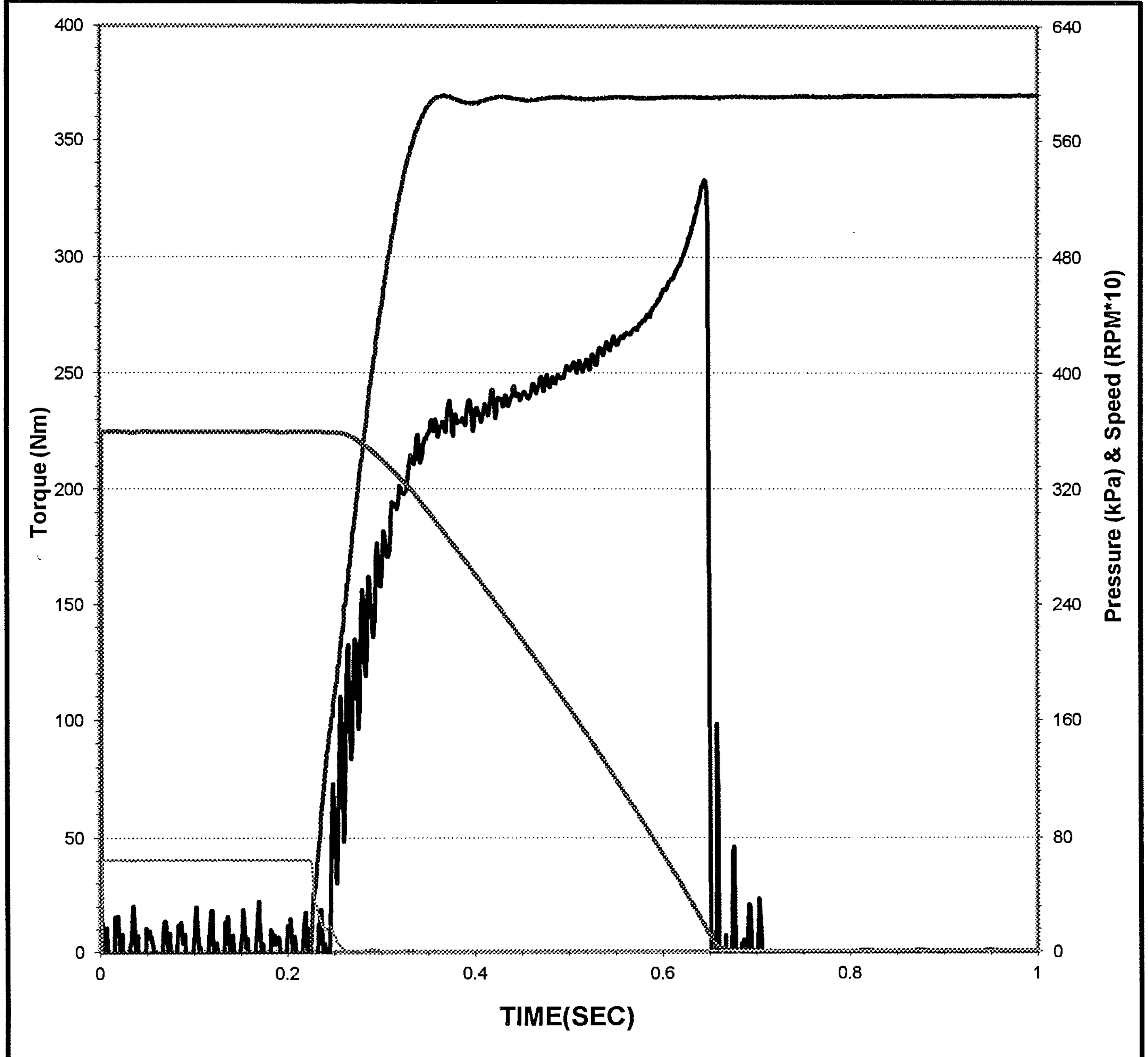
| | |
|---|---|
| 0.2 Sec Dyn: | 244 N*m |
| Midpoint Dyn: | 245 N*m |
| LwSpd Dynamic: | 335 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.119 |
| Midpoint Dyn: | 0.119 |
| LwSpd Dynamic: | 0.163 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/16/2011 |
| Time of Test: | 6:18:25 |
| Test Number: | C2-4-1574 |
| Fluid Code: | LO271510 |
| Cycle Number: | 5001 |
| Temperature: | 87.3 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 590 kPa (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.5 KJ (18.7 ± 0.40 KJ) |
| Engage Time: | 0.425 Sec |

**Torque**

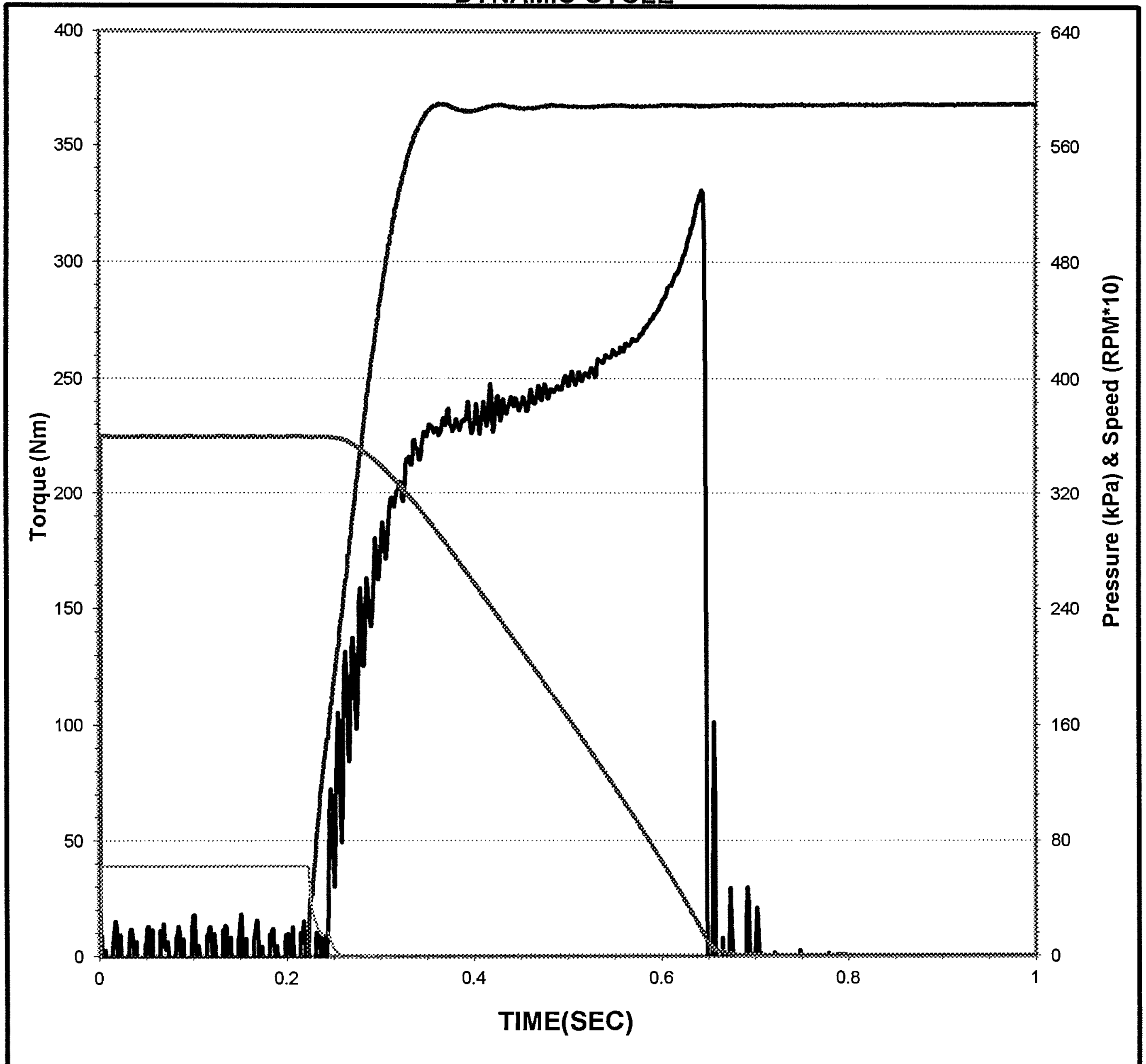
| | |
|---|---|
| 0.2 Sec Dyn: | 241 N*m |
| Midpoint Dyn: | 242 N*m |
| LwSpd Dynamic: | 332 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.117 |
| Midpoint Dyn: | 0.118 |
| LwSpd Dynamic: | 0.162 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/16/2011 |
| Time of Test: | 16:42:55 |
| Test Number: | C2-4-1574 |
| Fluid Code: | LO271510 |
| Cycle Number: | 7499 |
| Temperature: | 92.8 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 589 kPa (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.5 KJ (18.7 ± 0.40 KJ) |
| Engage Time: | 0.426 Sec |

**Torque**

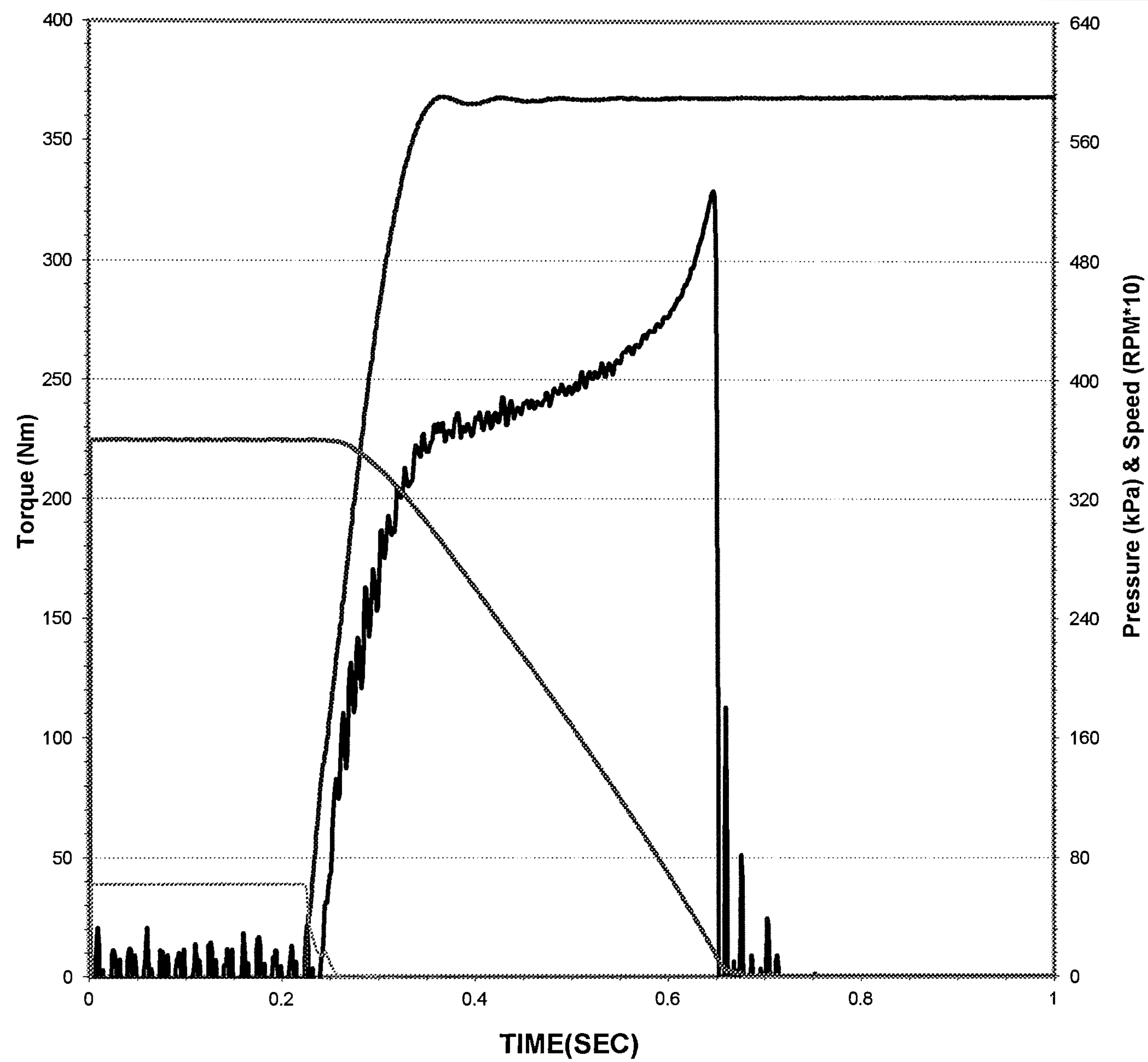
| | |
|---|---|
| 0.2 Sec Dyn: | 242 N*m |
| Midpoint Dyn: | 242 N*m |
| LwSpd Dynamic: | 330 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.118 |
| Midpoint Dyn: | 0.118 |
| LwSpd Dynamic: | 0.161 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




Date of Test: 10/16/2011

Time of Test: 16:43:10

Test Number: C2-4-1574

Fluid Code: LO271510

Cycle Number: 7500

Temperature: 92.9 °C
(93.3 ± 3.0 °C)

Apply Pressure: 589 kPa
(586 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.5 KJ
(18.7 ± 0.40 KJ)

Engage Time: 0.428 Sec

**Torque**

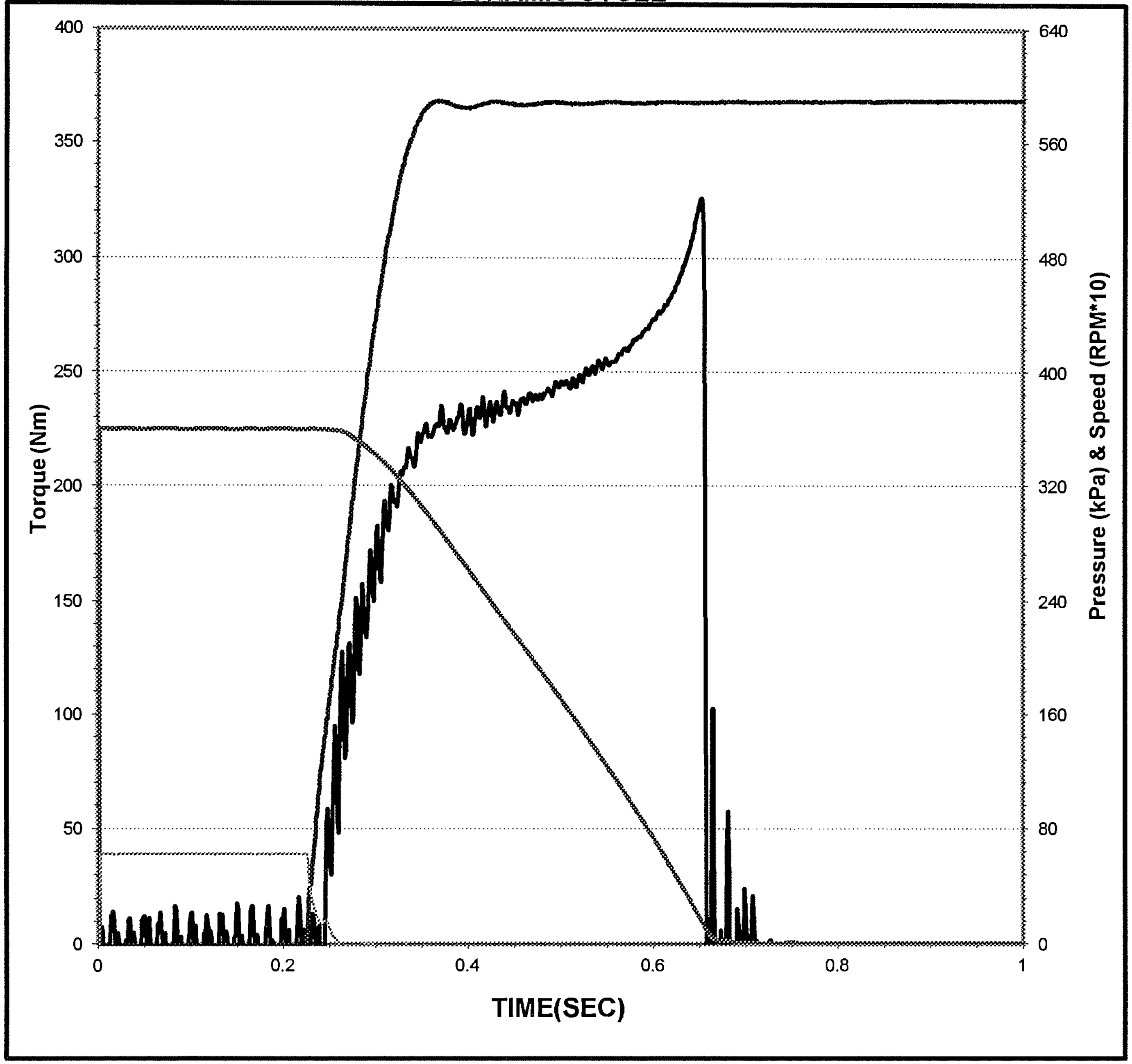
0.2 Sec Dyn: 240 N*m
Midpoint Dyn: 241 N*m
LwSpd Dynamic: 326 N*m

**Coefficient of Friction**

.2 Sec Dyn: 0.117
Midpoint Dyn: 0.117
LwSpd Dynamic: 0.159

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/16/2011 |
| Time of Test: | 16:43:41 |
| Test Number: | C2-4-1574 |
| Fluid Code: | LO271510 |
| Cycle Number: | 7501 |
| Temperature: | 87.3 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 589 kPa (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.5 KJ (18.7 ± 0.40 KJ) |
| Engage Time: | 0.431 Sec |

**Torque**

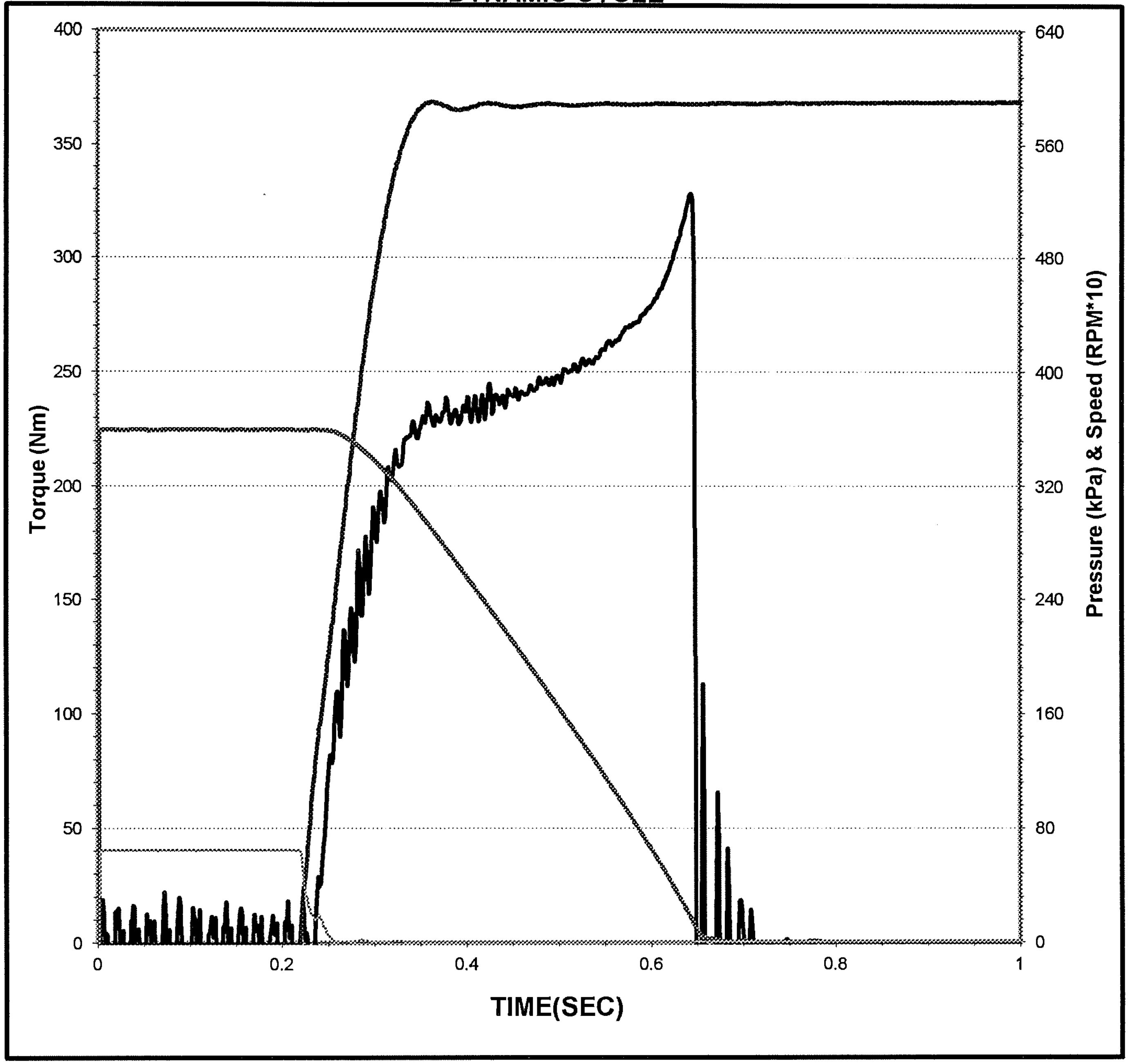
| | |
|---|---|
| 0.2 Sec Dyn: | 237 N*m |
| Midpoint Dyn: | 239 N*m |
| LwSpd Dynamic: | 320 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.115 |
| Midpoint Dyn: | 0.116 |
| LwSpd Dynamic: | 0.156 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/17/2011 |
| Time of Test: | 3:07:57 |
| Test Number: | C2-4-1574 |
| Fluid Code: | LO271510 |
| Cycle Number: | 9998 |
| Temperature: | 93.1 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 590 kPa (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.6 KJ (18.7 ± 0.40 KJ) |
| Engage Time: | 0.428 Sec |

**Torque**

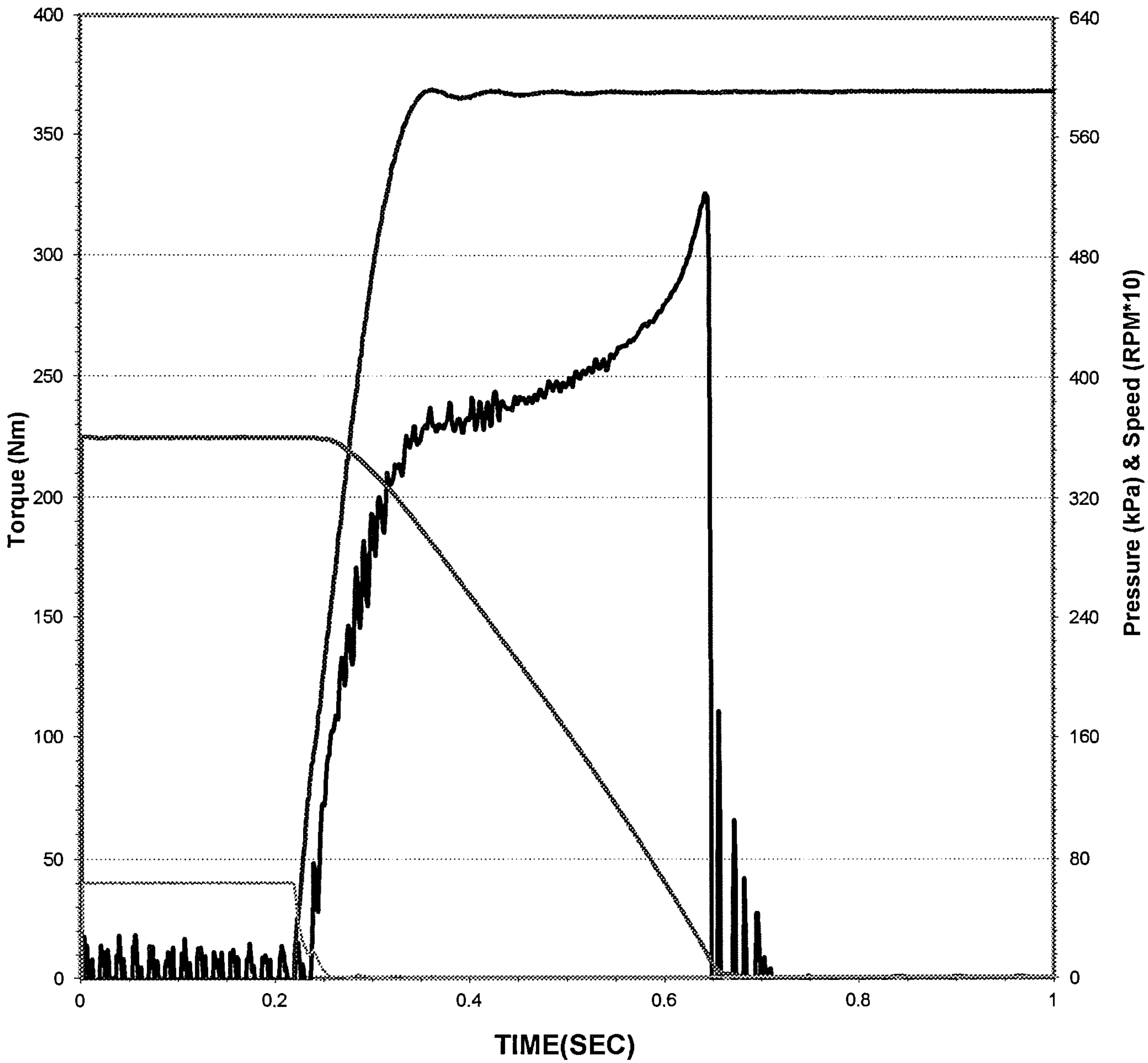
| | |
|---|---|
| 0.2 Sec Dyn: | 239 N*m |
| Midpoint Dyn: | 241 N*m |
| LwSpd Dynamic: | 323 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.117 |
| Midpoint Dyn: | 0.117 |
| LwSpd Dynamic: | 0.157 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/17/2011 |
| Time of Test: | 3:08:12 |
| Test Number: | C2-4-1574 |
| Fluid Code: | LO271510 |
| Cycle Number: | 9999 |
| Temperature: | 92.7 °C (93.3 ± 3.0 °C) |
| Apply Pressure: | 590 kPa (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec (0.15 ± 0.02 Sec) |
| Energy: | 18.6 KJ (18.7 ± 0.40 KJ) |
| Engage Time: | 0.428 Sec |

**Torque**

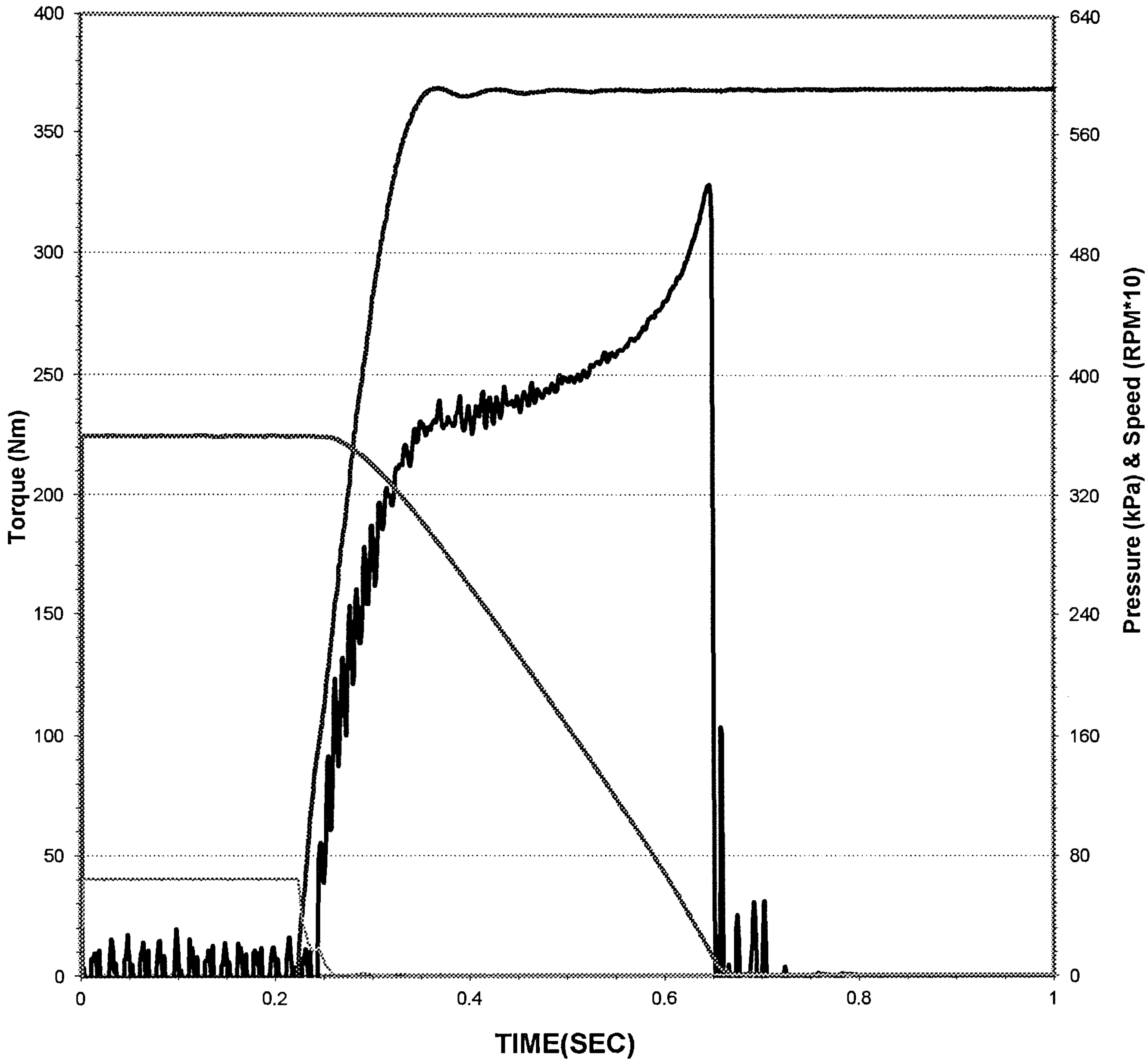
| | |
|---|---|
| 0.2 Sec Dyn: | 239 N*m |
| Midpoint Dyn: | 240 N*m |
| LwSpd Dynamic: | 322 N*m |

**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.116 |
| Midpoint Dyn: | 0.117 |
| LwSpd Dynamic: | 0.157 |

# ALLISON C-4 PAPER DATA

## DYNAMIC CYCLE




| | |
|---|---|
| Date of Test: | 10/17/2011 |
| Time of Test: | 3:08:27 |
| Test Number: | C2-4-1574 |
| Fluid Code: | LO271510 |
| Cycle Number: | 10000 |
| Temperature: | 92.7 °C |
| | (93.3 ± 3.0 °C) |
| Apply Pressure: | 590 kPa |
| | (586 ± 7 KPa) |
| Apply Rate: | 0.13 Sec |
| | (0.15 ± 0.02 Sec) |
| Energy: | 18.6 KJ |
| | (18.7 ± 0.40 KJ) |
| Engage Time: | 0.427 Sec |

**Torque**

| | |
|---|---|
| 0.2 Sec Dyn: | 239 N*m |
| Midpoint Dyn: | 241 N*m |
| LwSpd Dynamic: | 328 N*m |

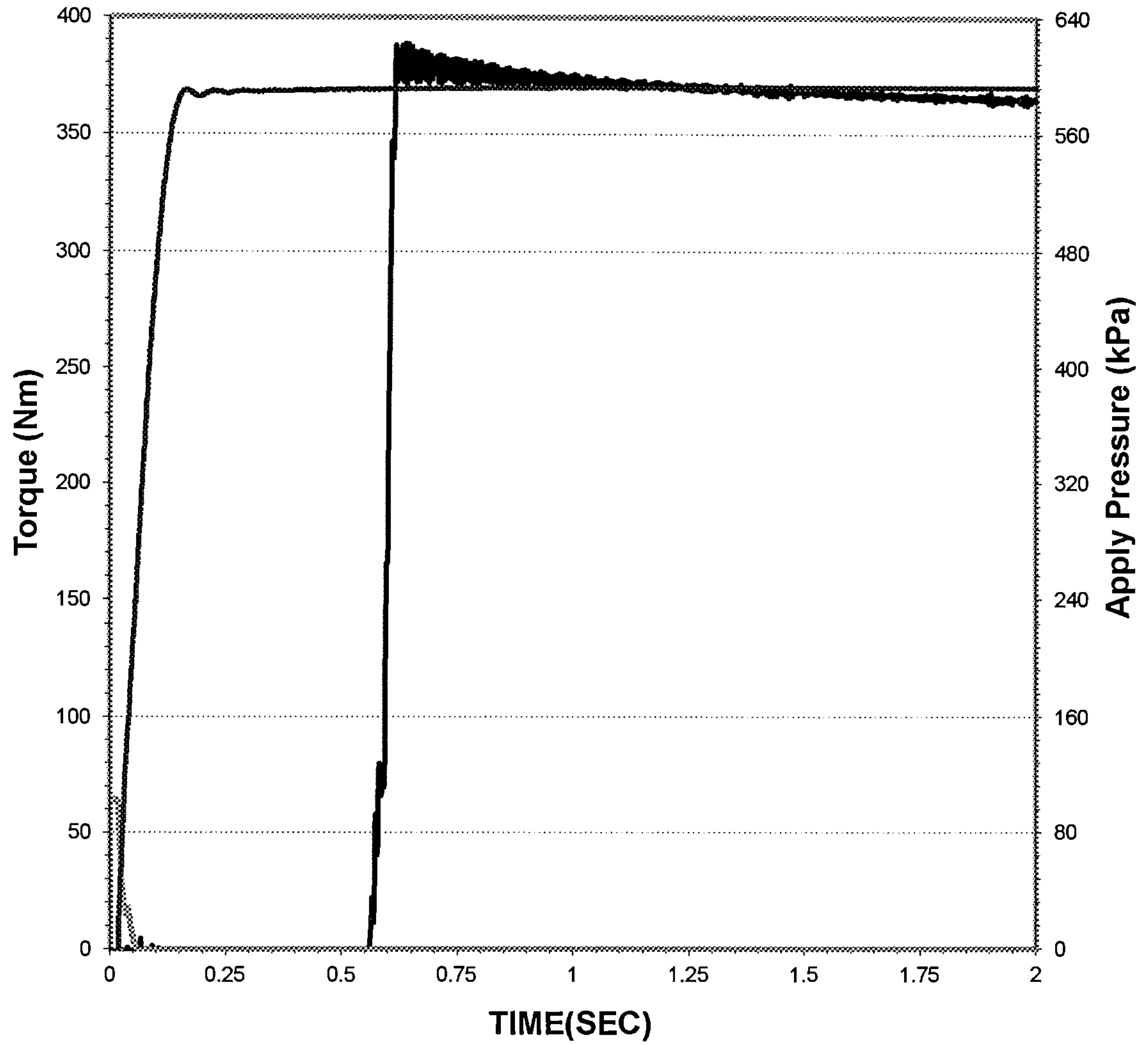
**Coefficient of Friction**

| | |
|---|---|
| .2 Sec Dyn: | 0.116 |
| Midpoint Dyn: | 0.117 |
| LwSpd Dynamic: | 0.160 |

## STATIC TRACES

# ALLISON C-4 PAPER DATA

## STATIC CYCLE




Date of Test: 10/15/2011

Time of Test: 9:29:19

Test Number: C2-4-1574

Fluid Code: LO271510

Cycle Number: 10

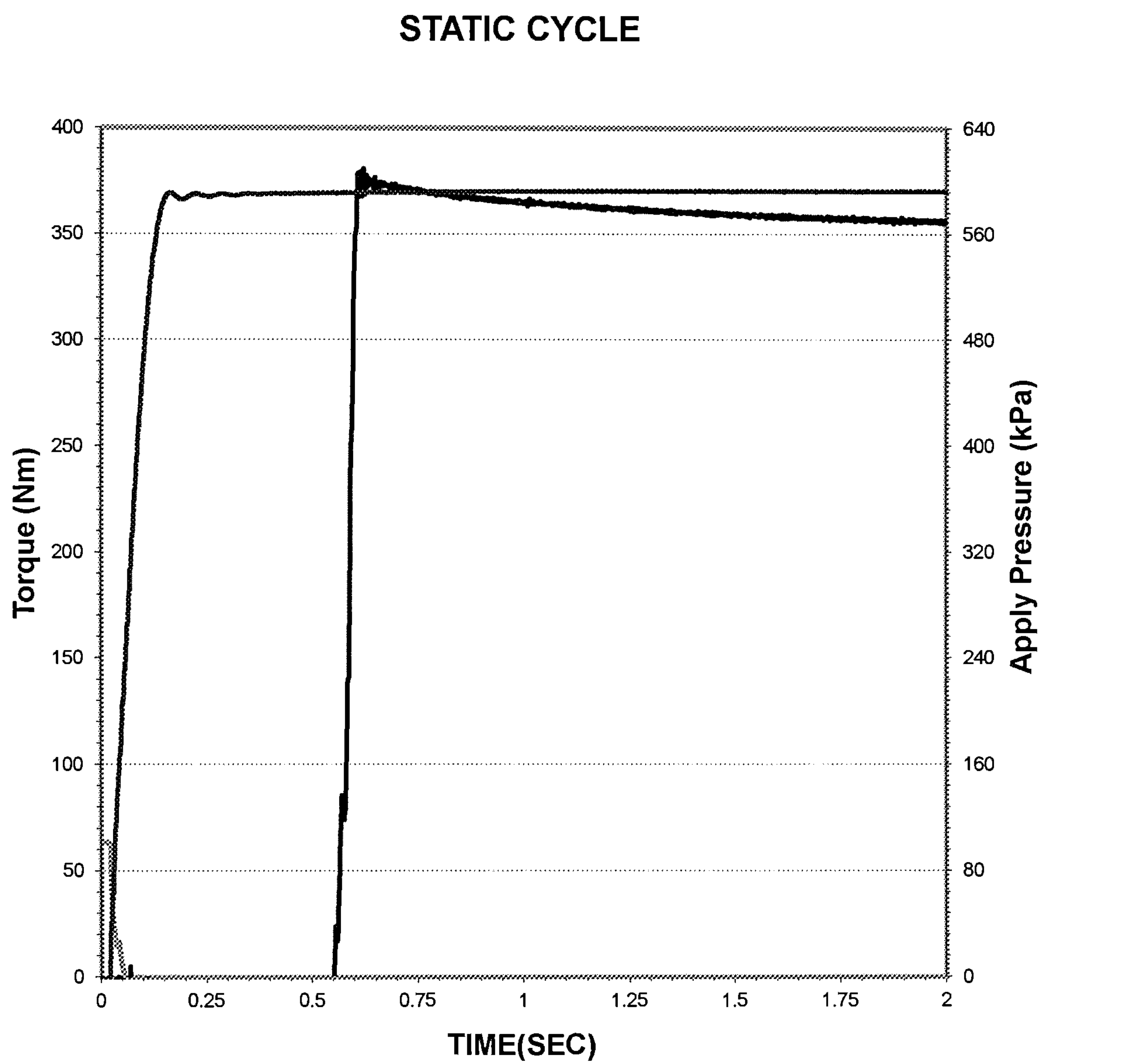
**STATIC CYCLE**

Apply Pressure:
At .25 Second: 589 kPa

**Torque**
Static Peak: 391 Nm
.25 Second: 375 Nm

**Coefficient of Friction**
Static Peak: 0.191
.25 Second: 0.182

# ALLISON C-4 PAPER DATA




Date of Test: 10/15/2011

Time of Test: 9:52:05

Test Number: C2-4-1574

Fluid Code: LO271510

Cycle Number: 100

**STATIC CYCLE**

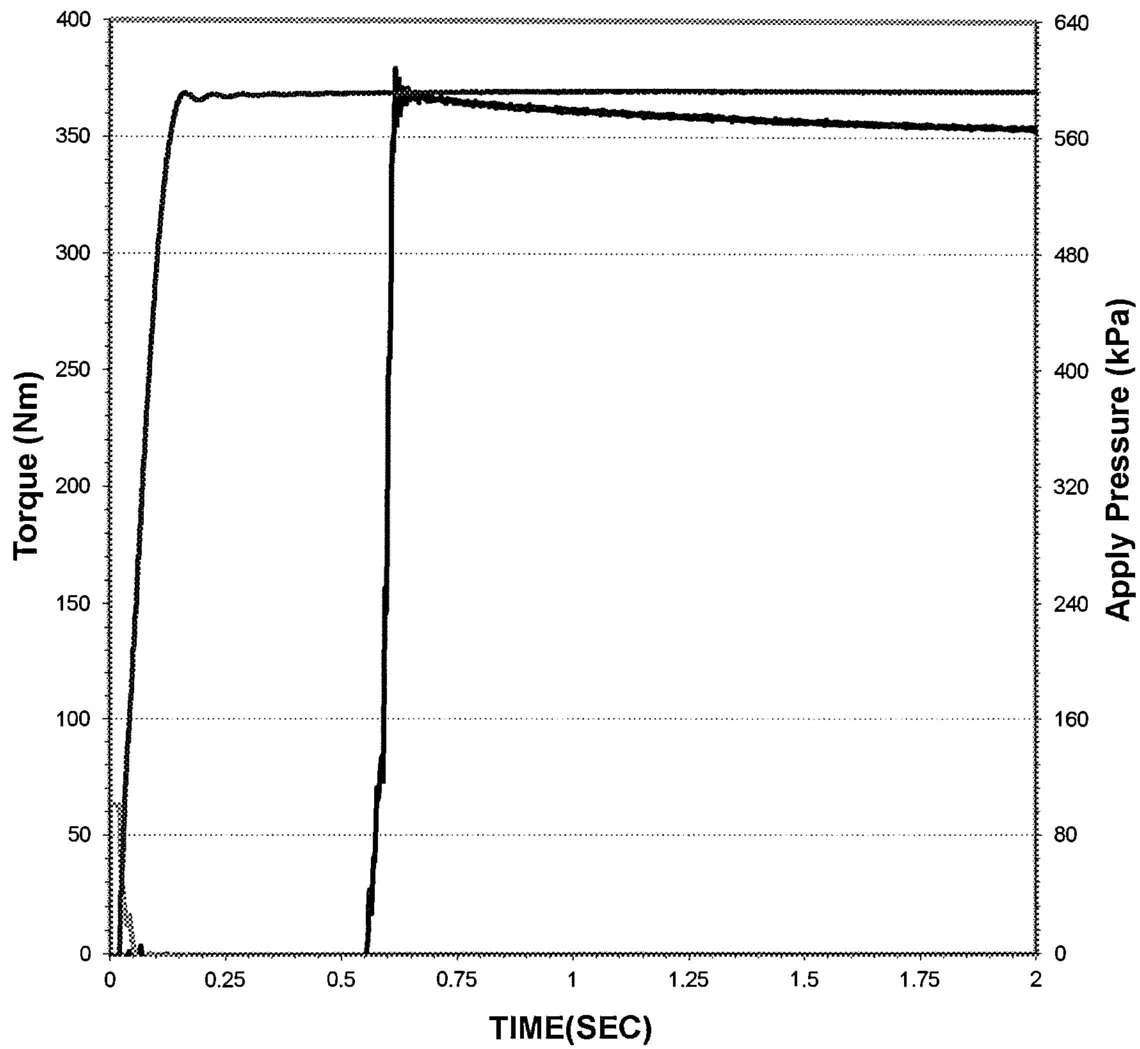
Apply Pressure:
At .25 Second: 590 kPa

**Torque**
Static Peak: 383 Nm
.25 Second: 371 Nm

**Coefficient of Friction**
Static Peak: 0.187
.25 Second: 0.181

# ALLISON C-4 PAPER DATA

## STATIC CYCLE




Date of Test: 10/15/2011

Time of Test: 11:32:21

Test Number: C2-4-1574

Fluid Code: LO271510

Cycle Number: 500

**STATIC CYCLE**

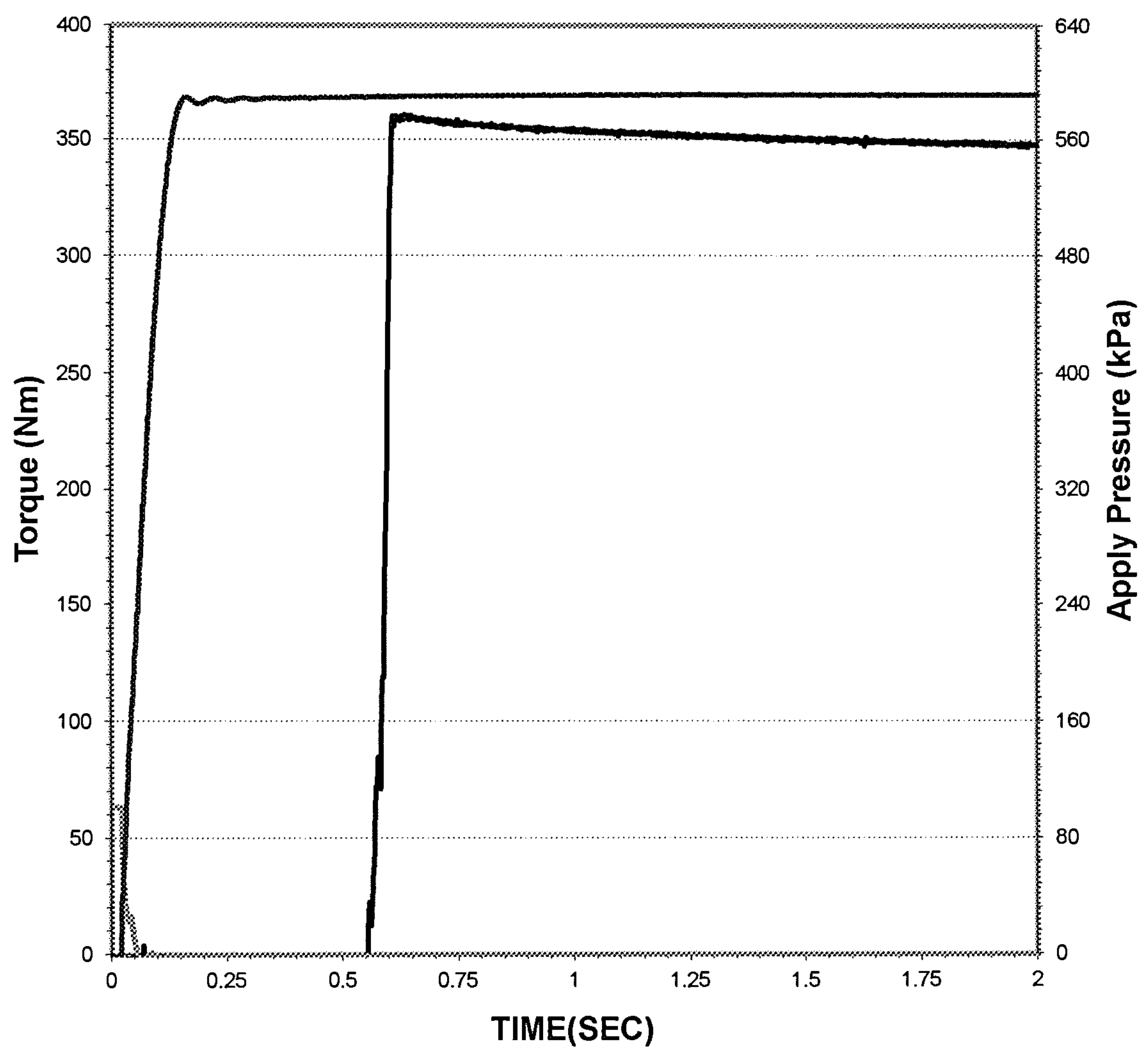
Apply Pressure:
At .25 Second: 589 kPa

**Torque**
Static Peak: 383 Nm
.25 Second: 368 Nm

**Coefficient of Friction**
Static Peak: 0.186
.25 Second: 0.179

# ALLISON C-4 PAPER DATA

## STATIC CYCLE




Date of Test: 10/15/2011

Time of Test: 13:37:37

Test Number: C2-4-1574

Fluid Code: LO271510

Cycle Number: 1000

**STATIC CYCLE**

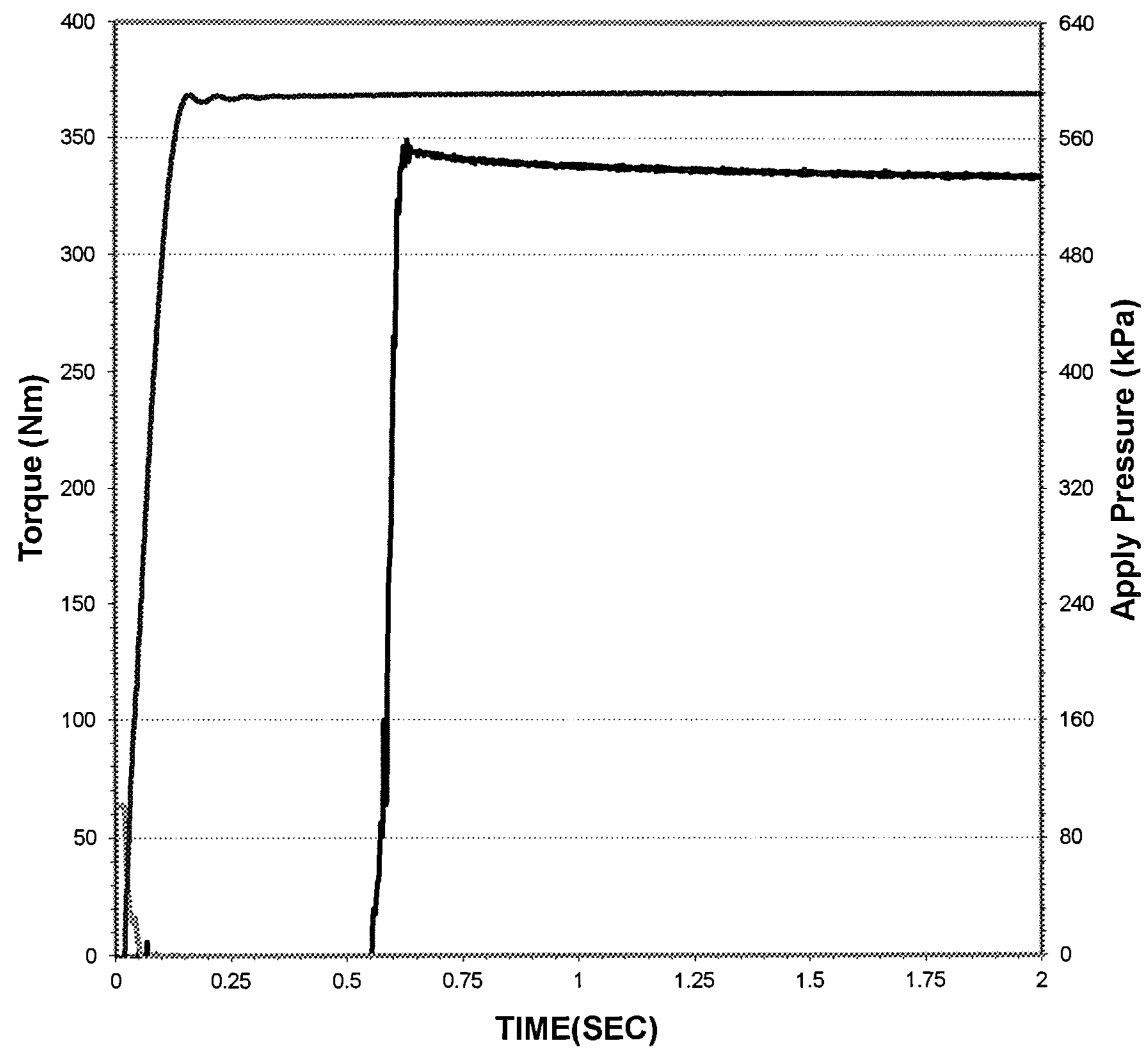
Apply Pressure:
At .25 Second: 588 kPa

**Torque**
Static Peak: 365 Nm
.25 Second: 359 Nm

**Coefficient of Friction**
Static Peak: 0.178
.25 Second: 0.175

# ALLISON C-4 PAPER DATA

## STATIC CYCLE




Date of Test: 10/15/2011

Time of Test: 19:52:54

Test Number: C2-4-1574

Fluid Code: LO271510

Cycle Number: 2500

**STATIC CYCLE**

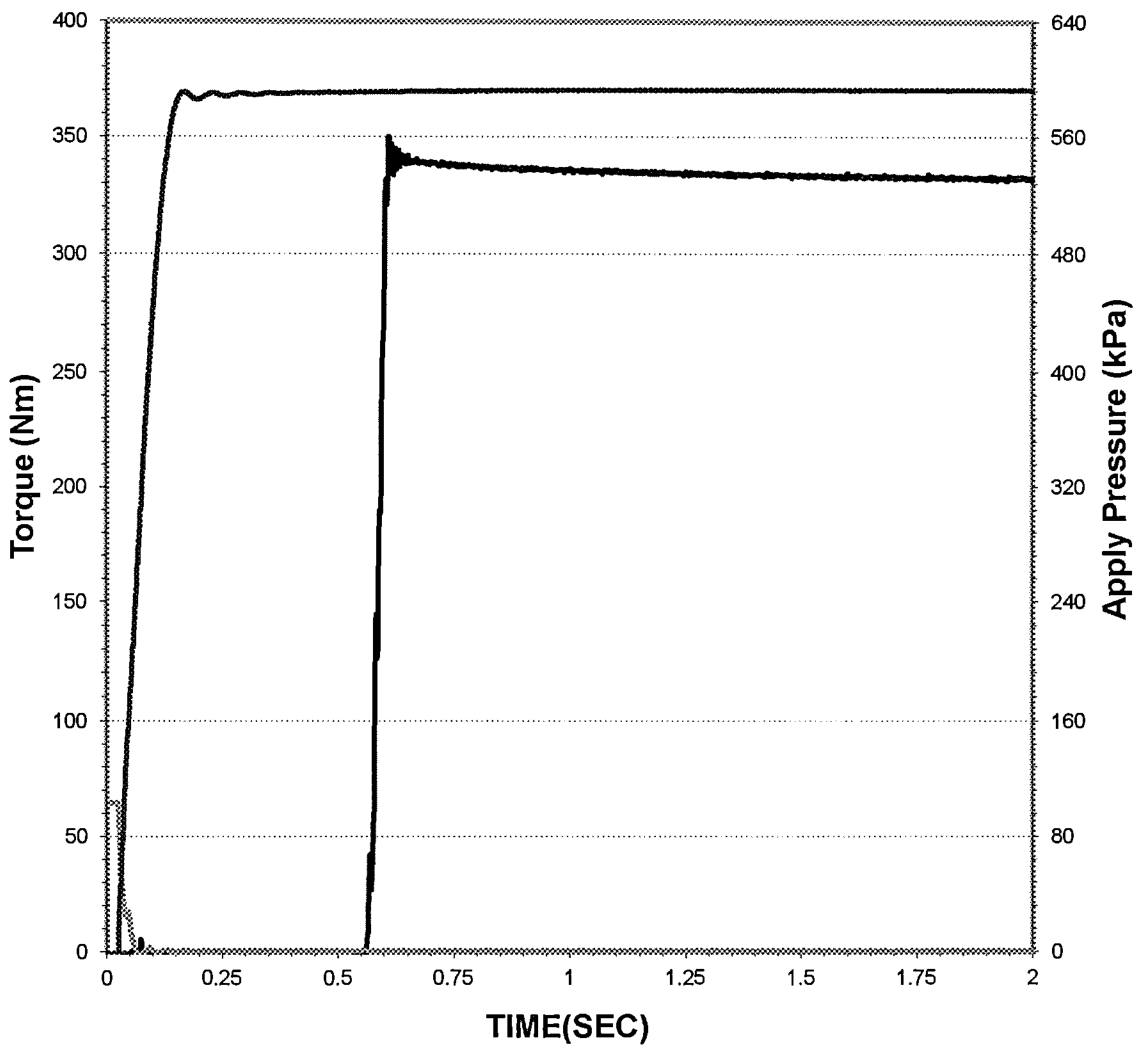
Apply Pressure:
At .25 Second: 589 kPa

**Torque**
Static Peak: 352 Nm
.25 Second: 343 Nm

**Coefficient of Friction**
Static Peak: 0.172
.25 Second: 0.167

# ALLISON C-4 PAPER DATA

## STATIC CYCLE




Date of Test: 10/16/2011

Time of Test: 6:18:10

Test Number: C2-4-1574

Fluid Code: LO271510

Cycle Number: 5000

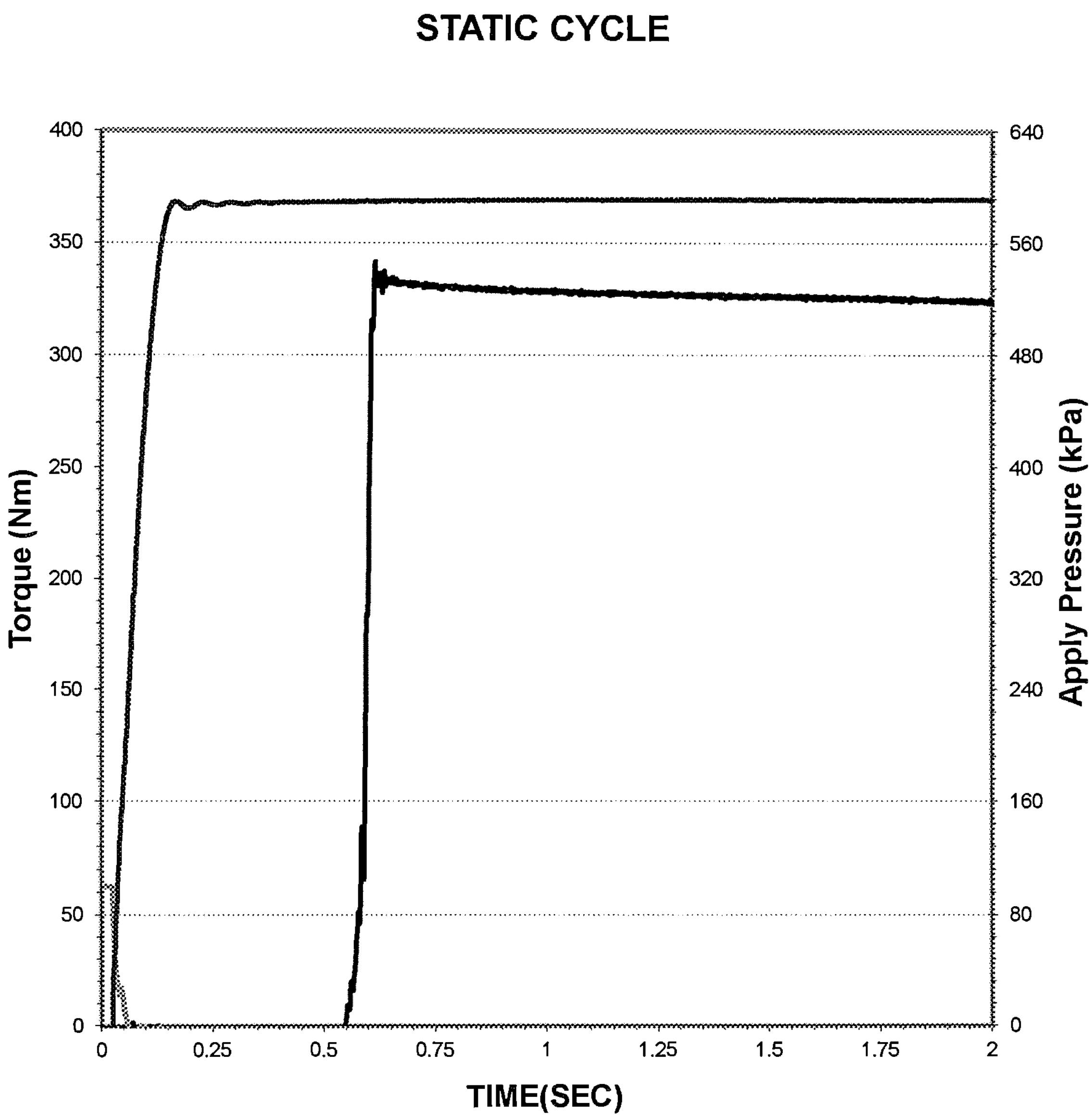
**STATIC CYCLE**

Apply Pressure:
At .25 Second: 590 kPa

**Torque**
Static Peak: 353 Nm
.25 Second: 340 Nm

**Coefficient of Friction**
Static Peak: 0.172
.25 Second: 0.166

# ALLISON C-4 PAPER DATA




Date of Test: 10/16/2011

Time of Test: 16:43:26

Test Number: C2-4-1574

Fluid Code: LO271510

Cycle Number: 7500

**STATIC CYCLE**

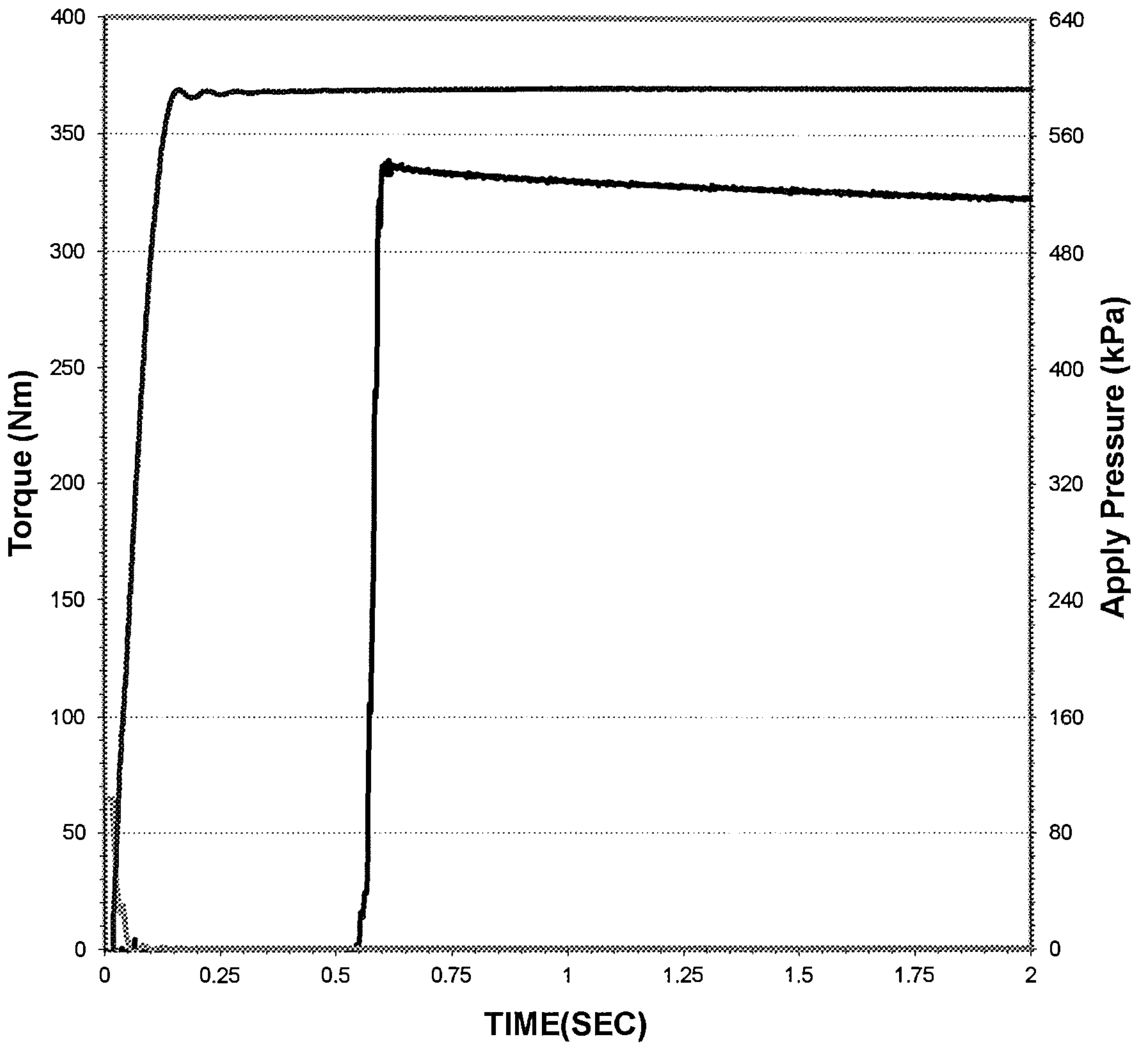
Apply Pressure:
At .25 Second: 589 kPa

**Torque**
Static Peak: 345 Nm
.25 Second: 334 Nm

**Coefficient of Friction**
Static Peak: 0.168
.25 Second: 0.163

# ALLISON C-4 PAPER DATA

## STATIC CYCLE




Date of Test: 10/17/2011

Time of Test: 3:08:43

Test Number: C2-4-1574

Fluid Code: LO271510

Cycle Number: 10000

**STATIC CYCLE**

Apply Pressure:
At .25 Second: 590 kPa

**Torque**
Static Peak: 341 Nm
.25 Second: 335 Nm

**Coefficient of Friction**
Static Peak: 0.166
.25 Second: 0.163

# APPENDIX – E1
# CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70
# LO268869

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

# CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70

Conducted for

**ARMY LAB**

Oil Code:
**LO268869**

Test Number:
**VC70-A-163-J**

October 19, 2011

Submitted by:

Brian Koehler
Principal Engineer
Specialty & Driveline Fluid Evaluation

The results of this report relate only to the fluid tested.
This report shall not be reproduced, except in full, without the written approval of Southwest Research Institute®.

# CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70

## Summary Sheet

**Company:** ARMY LAB

**Test start date:** 10/18/2011
**End of test date:** 10/19/2011
**Oil Code:** LO268869

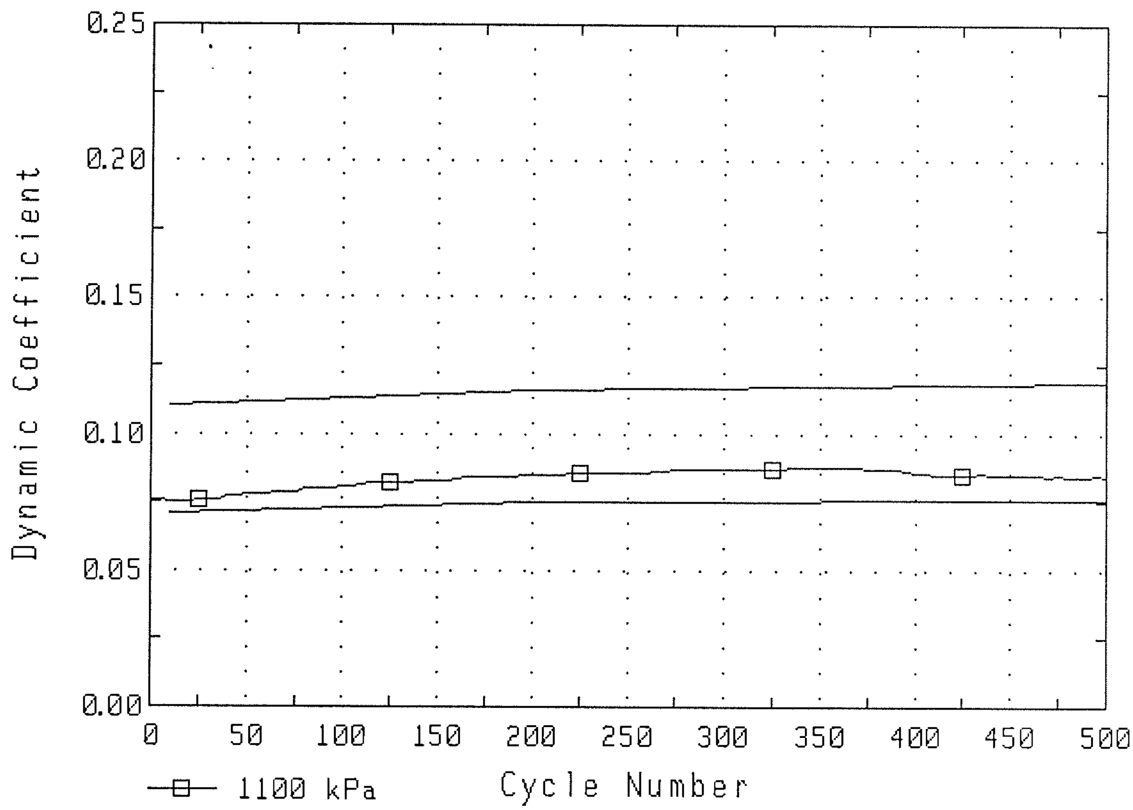
| Sequence Number | 1219 | 1220 | 1221 | 1222 | 1223 | 1224 | Friction Retention |
|---|---|---|---|---|---|---|---|
| Dynamic Coefficient Vs. Cycle: | | P | | F | | | |
| Dynamic Coefficient Vs. Load: | | P | | F | | | |
| Dynamic Coefficient Vs. Speed: | | P | | F | | | |
| Energy Limit: | | P | | P | | | |
| Static Coefficient Vs. Load: | | P | | F | | | |
| Static Coefficient Vs. Speed: | | P | | F | | | |
| Energy Limit: | | P | | P | | | |
| Total Wear: | | 0.016 | | 0.029 | | | |
| Wear Limit: | 0.030 | 0.040 | 0.070 | 0.070 | 0.070 | 0.040 | |

**Comments:** This testing was conducted on a referenced test stand. The results are compared to TO-4 testing limits. 2009 Batch parts were used for this sequence.

F = Fail
P = Pass
N/A = Not Applicable

SOUTHWEST RESEARCH INSTITUTE
"J" MACHINE OIL TEST LO268869 / LO-268869

| | |
|---|---|
| Test name: | A-163-J |
| Test date: | 10/18/11 |
| Test description: | J MACHINE LO268869 |
| Oil type: | LO268869 / LO-268869 |
| Viscosity: | N/A |
| Miscellaneous: | |
| Software version: | 1.40 |
| | |
| Run name & desc: | J0508336 - LO268869 |
| Run date: | 08/28/11 |
| Oil temperature: | 82 degrees C |
| Oil flow rate: | 3.78 liter/minute |
| Operator: | HC |
| Remarks: | "J" MACHINE OIL TEST LO268869 / LO-268869 |
| Sequence name: | SEQ1220 |
| Remarks: | Use 1Y0709 Disc and 8E4095 Plate |
| Number of cycles run: | 1097 |
| | |
| Machine: | J |
| Coast down check run: | 02/01/00 |
| Result: | 71.40 seconds |
| Inertia check run: | 02/01/00 |
| Result: | 1.0349 N-m-$s^2$ |
| | |
| Disc name & desc: | 1Y0709 - Sintered Bronze |
| Material: | Raybestos 1349-ET Bronze |
| Groove pattern: | Single Lead Spiral - 12 Radial |
| Miscellaneous: | Use with 8E4095 Steel Plate for performance run |
| Outer diameter (mm): | 285.80 |
| Inner diameter (mm): | 223.20 |
| Mean radius (mm): | 128.21 |
| Batch number: | 007080C800012 |
| Remarks: | SINTERED BRONZE |
| | |
| Plate name & desc: | 8E4095 - Steel Plate |
| Surface: | 0.70 to 1.00 micron Roughness |
| Miscellaneous: | Install the side marked with the average roughness |
| Batch number: | 007080C800012 |
| Remarks: | 0.80 SURFACE FINISH |
| | |
| Report limit name: | LIM1220 - Reference run: J0508081 |
| Limit file generated: | 10/19/11 |
| Report format name: | REP1220 - SINTERED BRONZE |



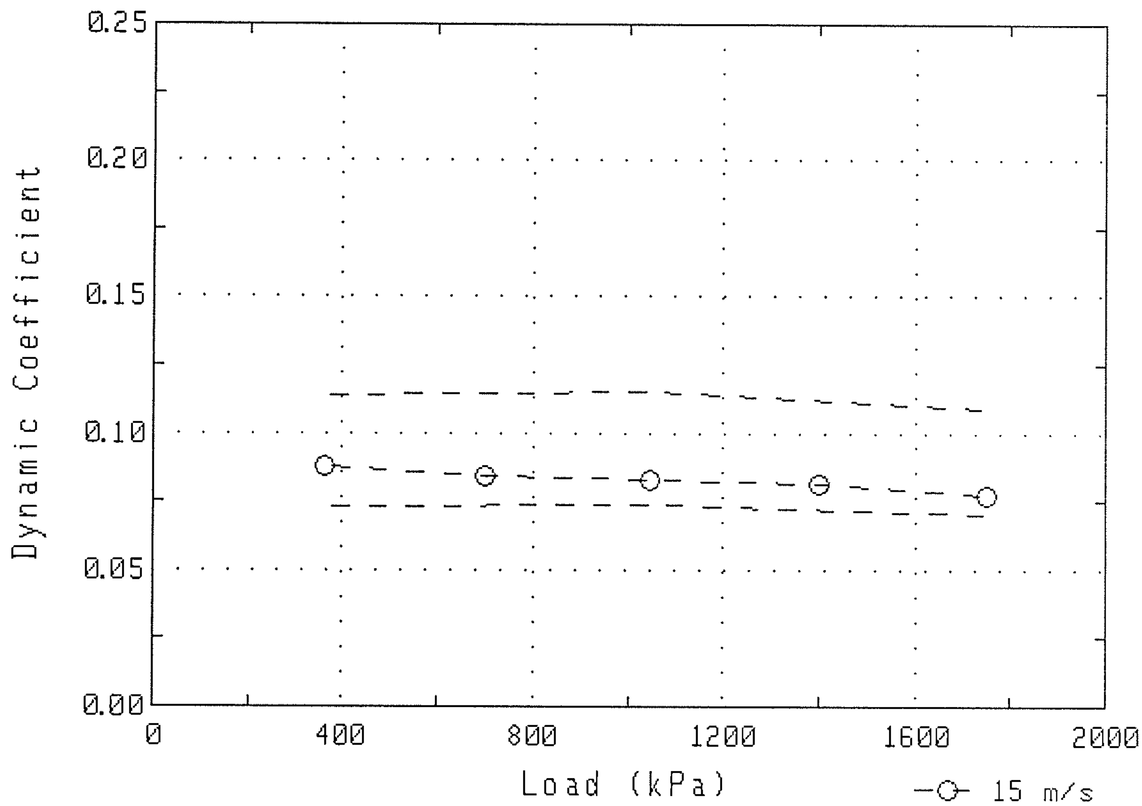

1Y0709 DISC
THICKNESS

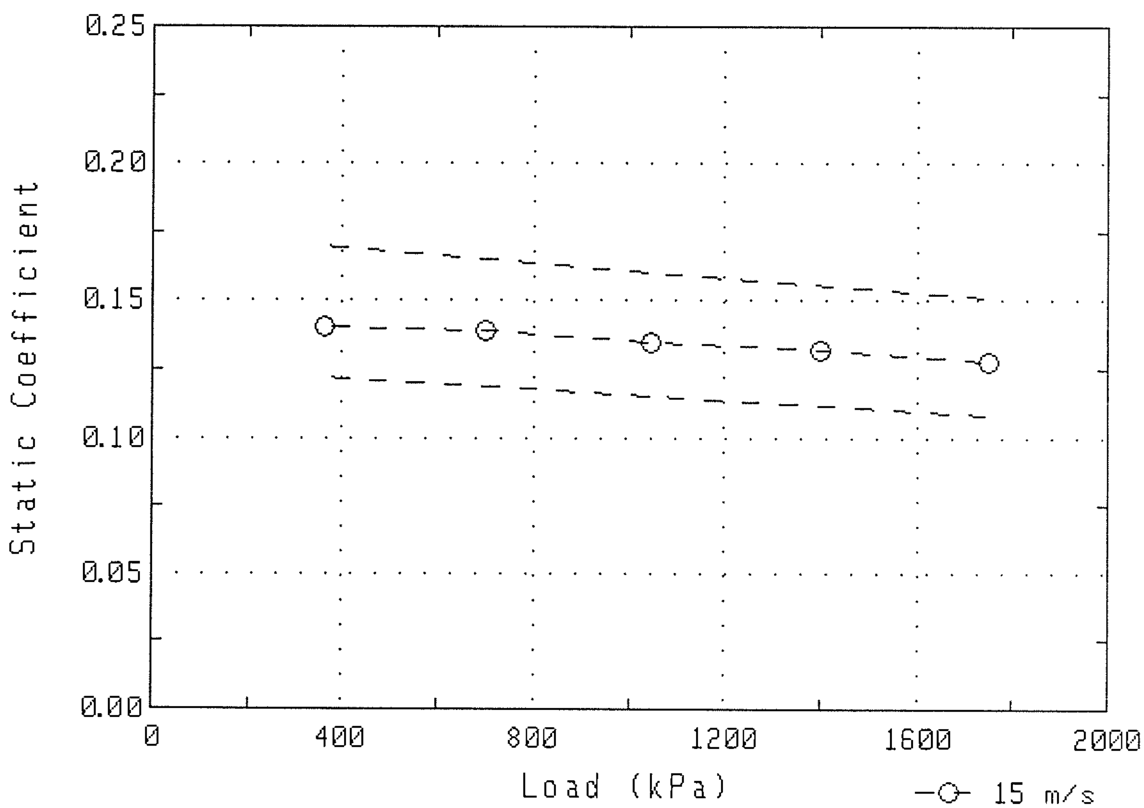
| Loc | Outer Diameter M1 | M2 | M3 | Inner Diameter M1 | M2 | M3 |
|---|---|---|---|---|---|---|
| 1 | 4.96 | 4.95 | 4.94 | 4.96 | 4.95 | 4.94 |
| 2 | 4.96 | 4.95 | 4.94 | 4.96 | 4.94 | 4.94 |
| 3 | 4.97 | 4.95 | 4.95 | 4.96 | 4.95 | 4.95 |
| 4 | 4.97 | 4.95 | 4.95 | 4.96 | 4.95 | 4.95 |
| 5 | 4.96 | 4.95 | 4.95 | 4.96 | 4.95 | 4.95 |
| 6 | 4.96 | 4.95 | 4.95 | 4.96 | 4.94 | 4.94 |
| Avg | 4.96 | 4.95 | 4.95 | 4.96 | 4.95 | 4.94 |

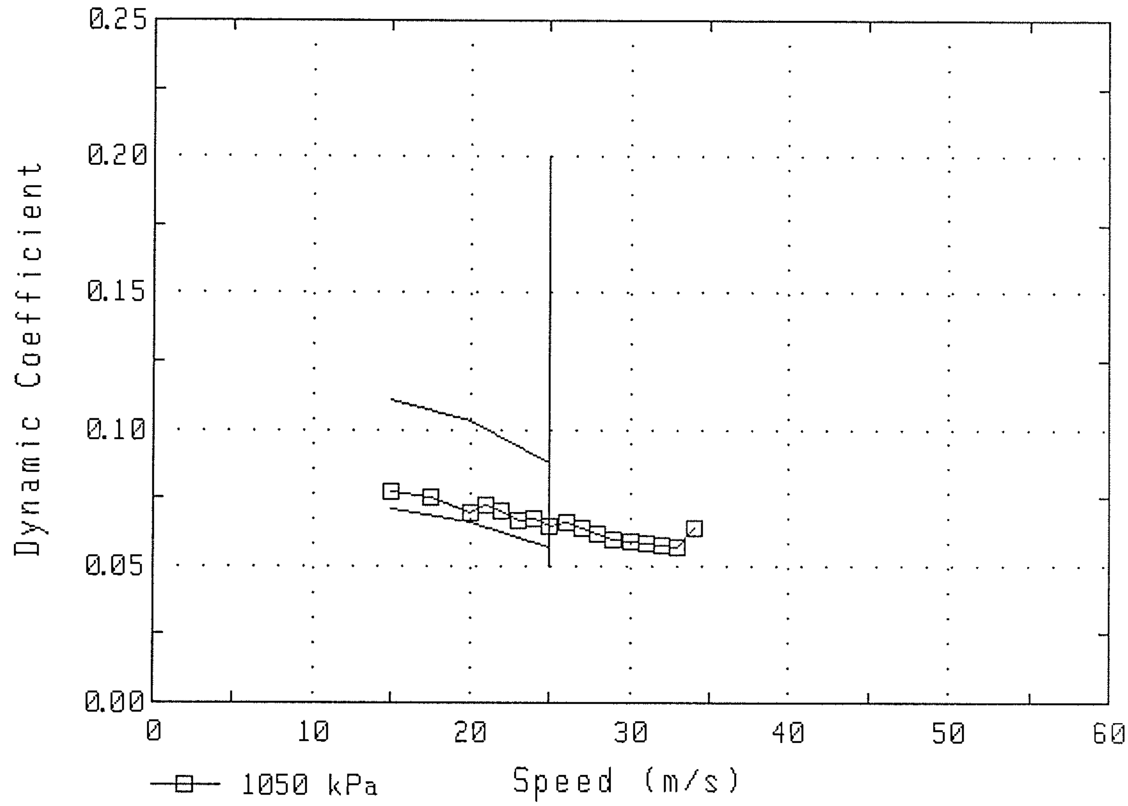
Compression set average wear:  0.013
M2 - M3 average Wear:  0.003

Total Wear (all measurements in mm):  0.016

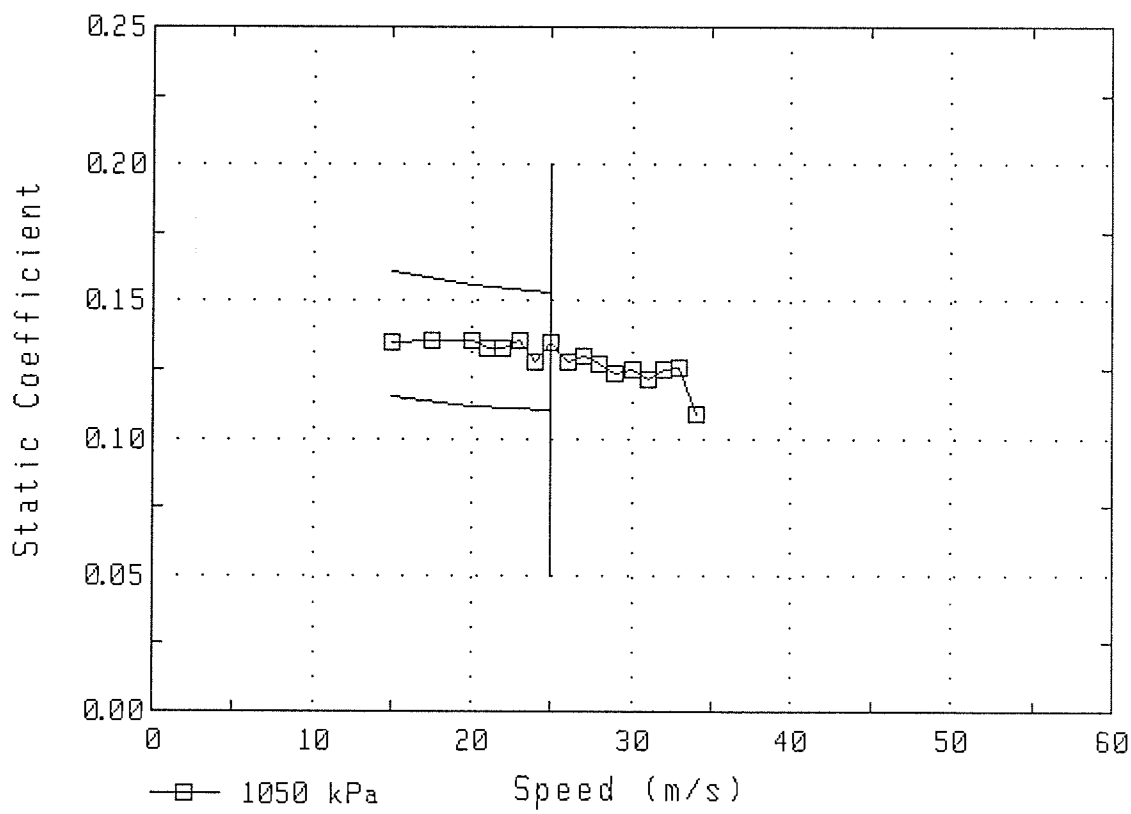
Test: A-163-J  Run: J0508336  Started on 08/28/11 at 07:25



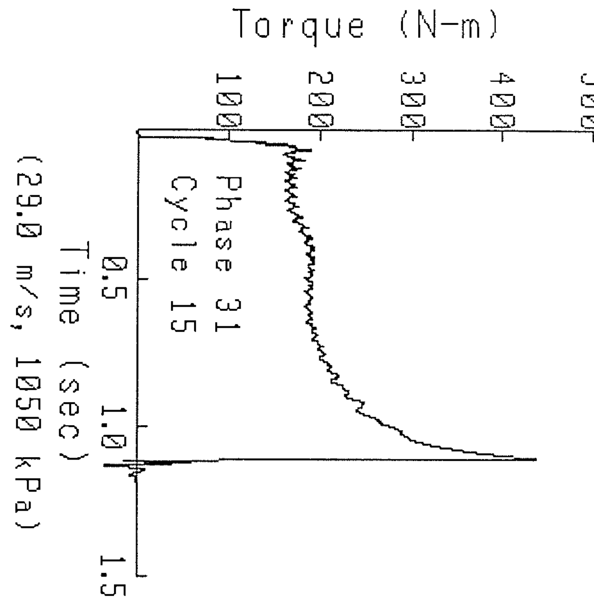



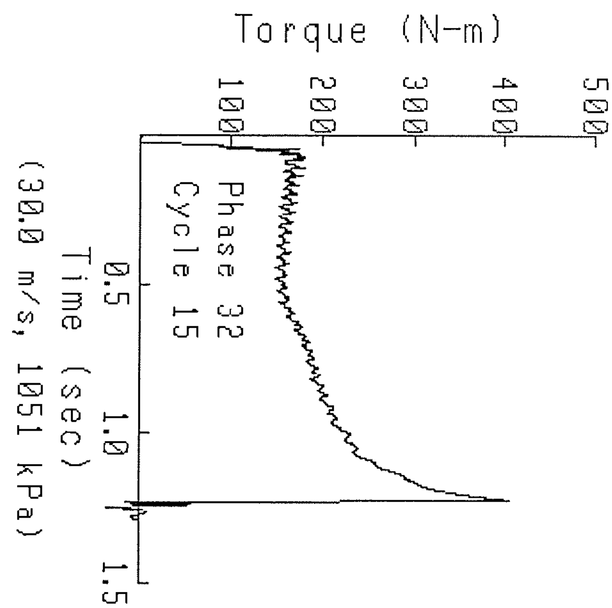


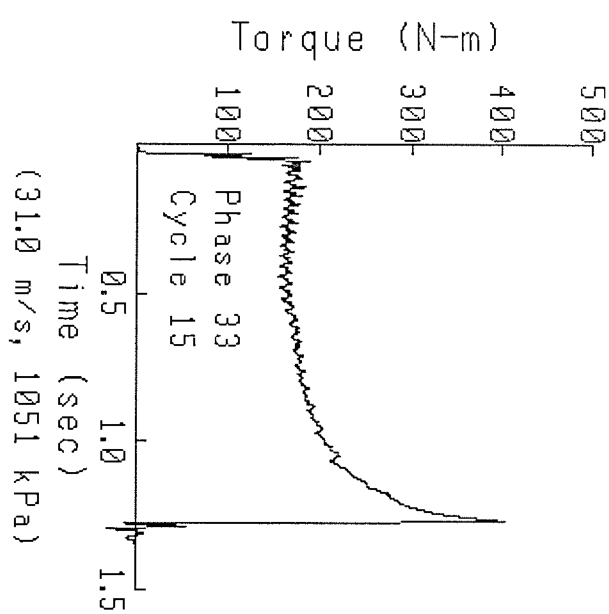
0.25
0.20
0.15
0.10
0.05
0.00
Dynamic Coefficient
0
10
20
30
40
50
60
Speed (m/s)
1050 kPa

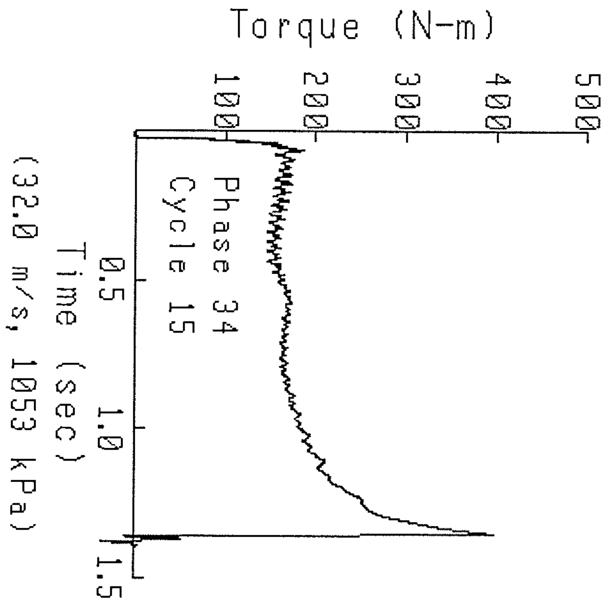



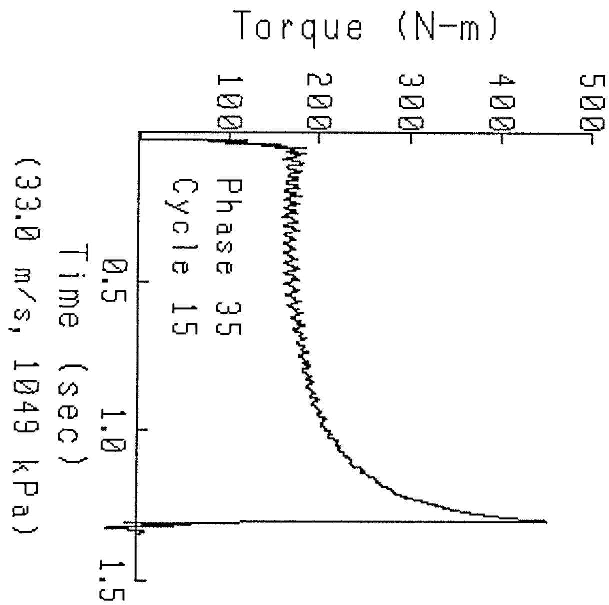
0.25
0.20
0.15
0.10
0.05
0.00
Static Coefficient
0
10
20
30
40
50
60
Speed (m/s)
1050 kPa

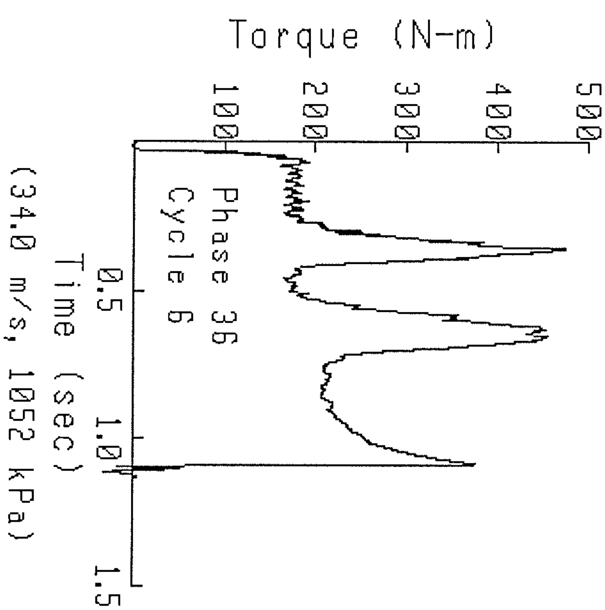

Torque (N-m)
100 200 300 400 500
Phase 31
Cycle 15
0.5 1.0 1.5
Time (sec)
(29.0 m/s, 1050 kPa)


Torque (N-m)
100 200 300 400 500
Phase 32
Cycle 15
0.5 1.0 1.5
Time (sec)
(30.0 m/s, 1051 kPa)


Torque (N-m)
100 200 300 400 500
Phase 33
Cycle 15
0.5 1.0 1.5
Time (sec)
(31.0 m/s, 1051 kPa)


Torque (N-m)
100 200 300 400 500
Phase 34
Cycle 15
0.5 1.0 1.5
Time (sec)
(32.0 m/s, 1053 kPa)


Torque (N-m)
100 200 300 400 500
Phase 35
Cycle 15
0.5 1.0 1.5
Time (sec)
(33.0 m/s, 1049 kPa)


Torque (N-m)
100 200 300 400 500
Phase 36
Cycle 6
0.5 1.0 1.5
Time (sec)
(34.0 m/s, 1052 kPa)

SOUTHWEST RESEARCH INSTITUTE
"J" MACHINE OIL TEST LO268869 / LO-268869

| | |
|---|---|
| Test name: | A-163-J |
| Test date: | 10/19/11 |
| Test description: | J MACHINE LO268869 |
| Oil type: | LO268869 / LO-268869 |
| Viscosity: | N/A |
| Miscellaneous: | |
| Software version: | 1.40 |

| | |
|---|---|
| Run name & desc: | J0508337 - J MACHINE LO268869 |
| Run date: | 08/29/11 |
| Oil temperature: | 82 degrees C |
| Oil flow rate: | 3.78 liter/minute |
| Operator: | HC |
| Remarks: | "J" MACHINE OIL TEST LO268869 / LO-268869 |
| Sequence name: | SEQ1222 |
| Remarks: | Use 1Y0711 Disc and 1Y0726 Plate |
| Number of cycles run: | 1145 |

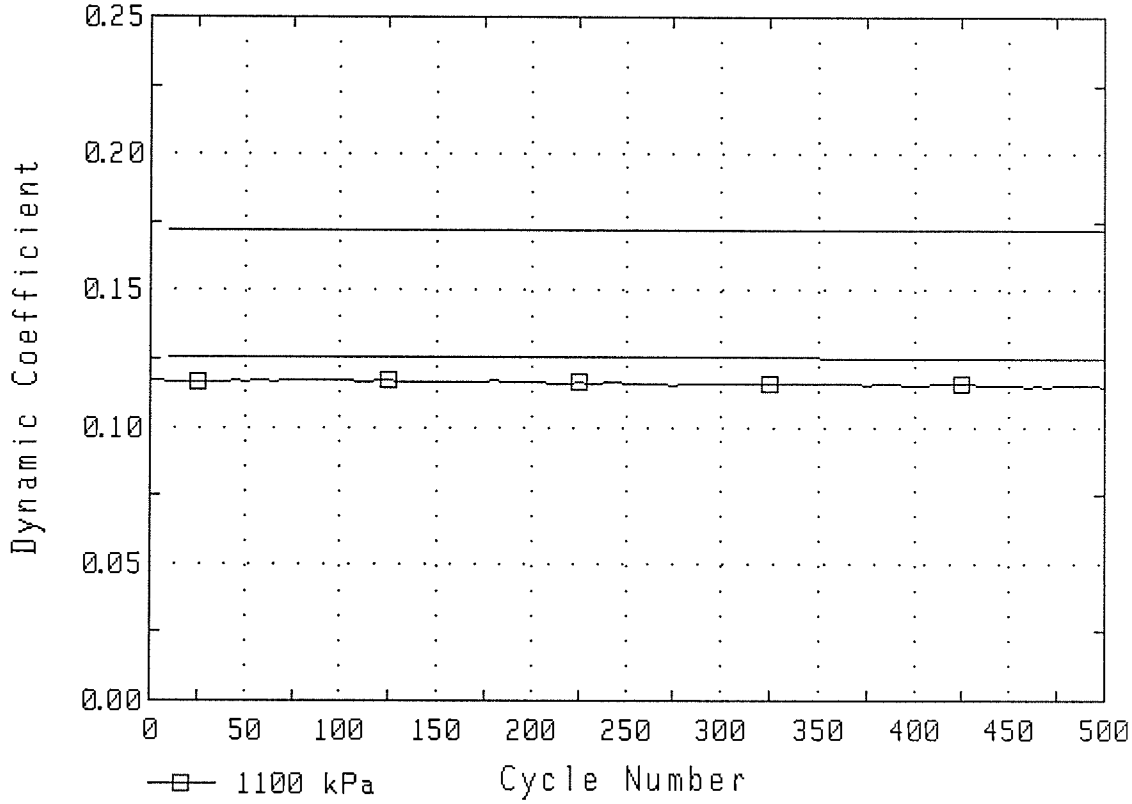
| | |
|---|---|
| Machine: | J |
| Coast down check run: | 02/01/00 |
| Result: | 71.40 seconds |
| Inertia check run: | 02/01/00 |
| Result: | 1.0349 N-m-$s^2$ |

| | |
|---|---|
| Disc name & desc: | 1Y0711 - Wheel Brake Paper |
| Material: | Raybestos 7902-1 Paper |
| Groove pattern: | 2 - 37 Multiple Parallel |
| Miscellaneous: | Use with 1Y0726 Steel Plate |
| Outer diameter (mm): | 285.80 |
| Inner diameter (mm): | 223.20 |
| Mean radius (mm): | 128.21 |
| Batch number: | 06MR928188 |
| Remarks: | WHEEL BRAKE PAPER |

| | |
|---|---|
| Plate name & desc: | 1Y0726 - Steel Plate |
| Surface: | 0.30 micron Maximum Roughness |
| Miscellaneous: | Install the side marked with the average roughness |
| Batch number: | 06MR928188 |
| Remarks: | 0.24 SURFACE FINISH |

| | |
|---|---|
| Report limit name: | LIM1222 - Reference run: J0508195 |
| Limit file generated: | 08/04/10 |
| Report format name: | REP1222 - WHEEL BRAKE PAPER |

Test: A-163-J  Run: J0508337  Started on 08/29/11 at 06:11



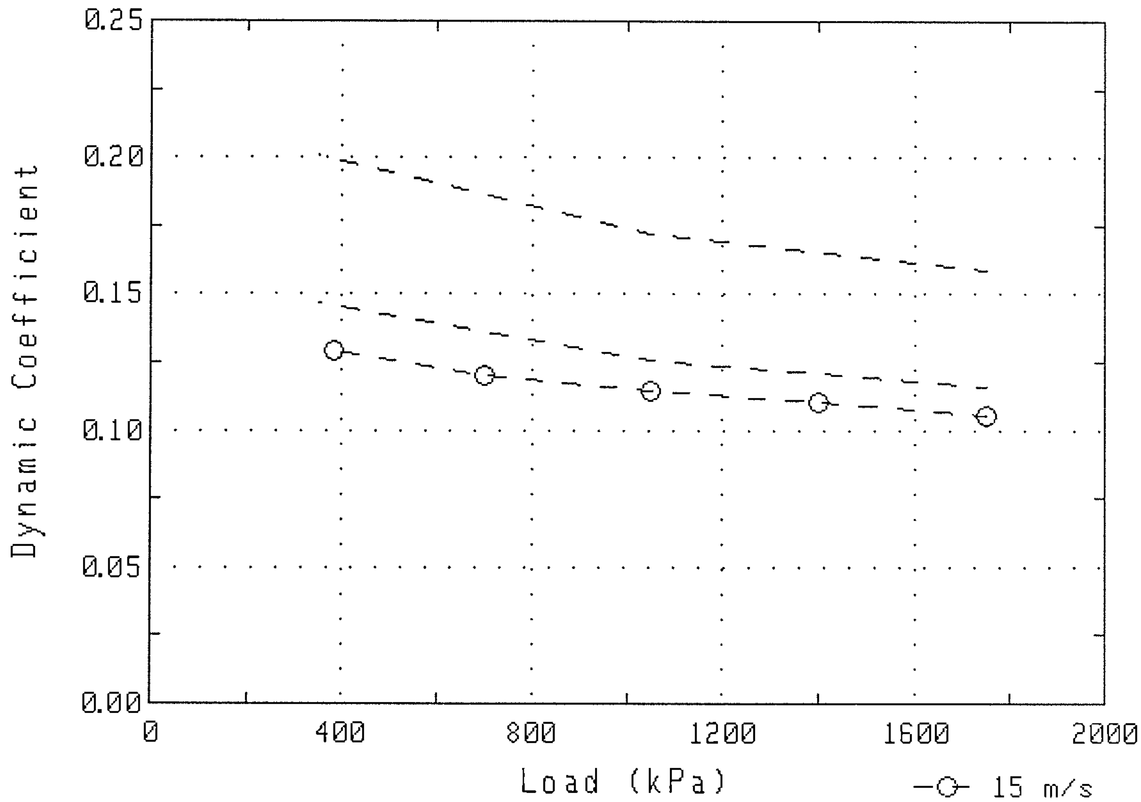

1Y0711 DISC
THICKNESS

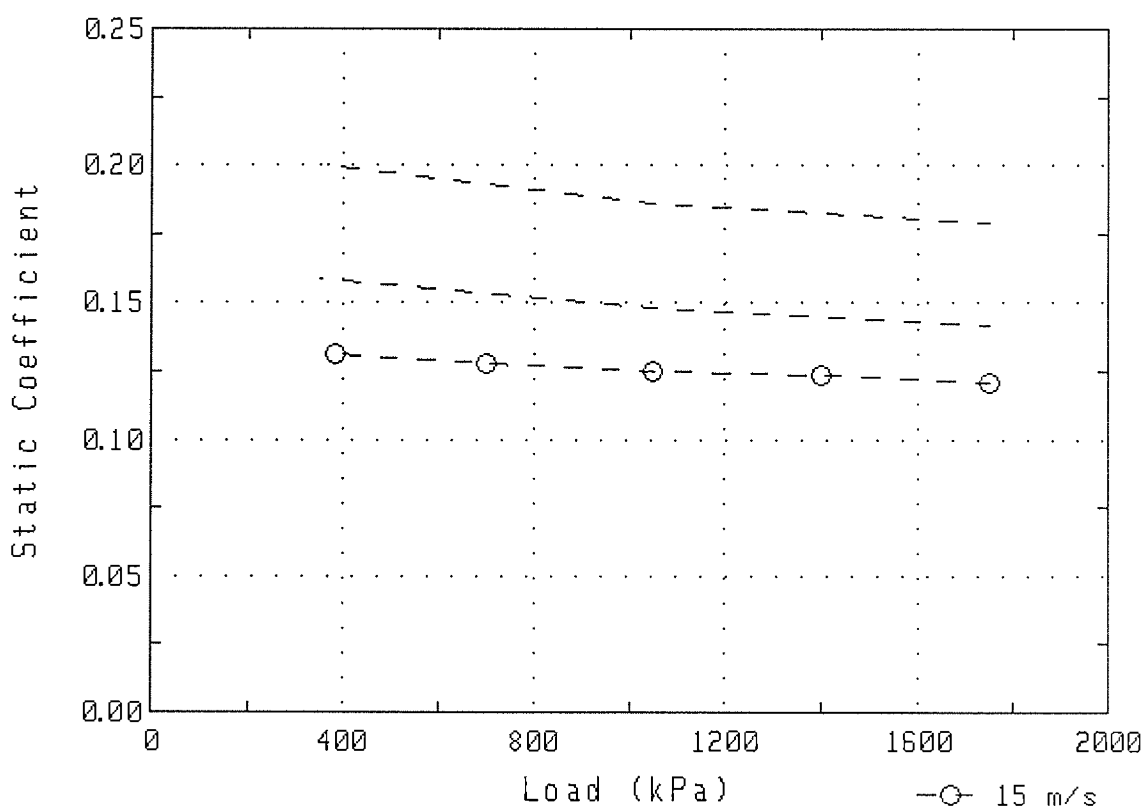
| | Outer Diameter | | | Inner Diameter | | |
|---|---|---|---|---|---|---|
| Loc | M1 | M2 | M3 | M1 | M2 | M3 |
| 1 | 4.98 | 4.96 | 4.95 | 4.98 | 4.97 | 4.95 |
| 2 | 4.98 | 4.96 | 4.94 | 4.97 | 4.96 | 4.94 |
| 3 | 4.97 | 4.96 | 4.94 | 4.97 | 4.96 | 4.94 |
| 4 | 4.98 | 4.96 | 4.95 | 4.98 | 4.96 | 4.95 |
| 5 | 4.98 | 4.97 | 4.96 | 4.98 | 4.98 | 4.96 |
| 6 | 4.99 | 4.98 | 4.96 | 4.99 | 4.98 | 4.96 |
| Avg | 4.98 | 4.97 | 4.95 | 4.98 | 4.97 | 4.95 |

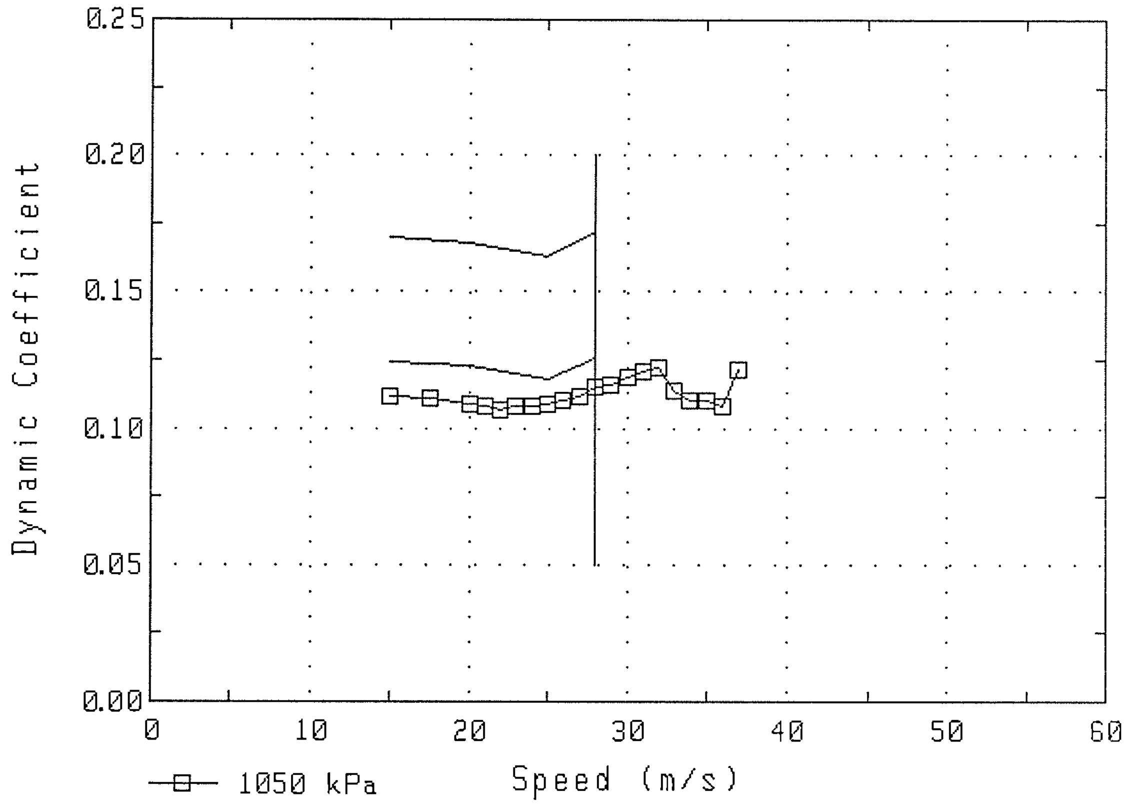
Compression set average wear: 0.013
M2 - M3 average Wear: 0.017

Total Wear (all measurements in mm): 0.029

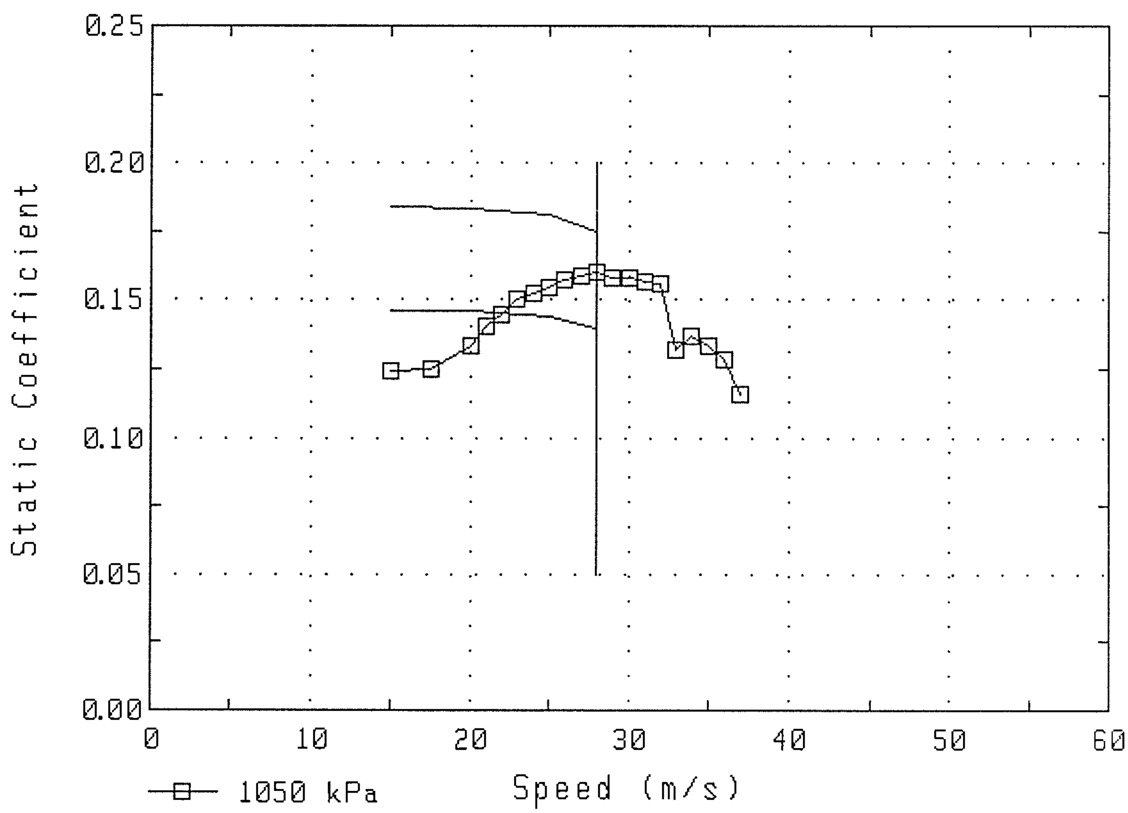
Test: A-163-J Run: J0508337 Started on 08/29/11 at 06:11



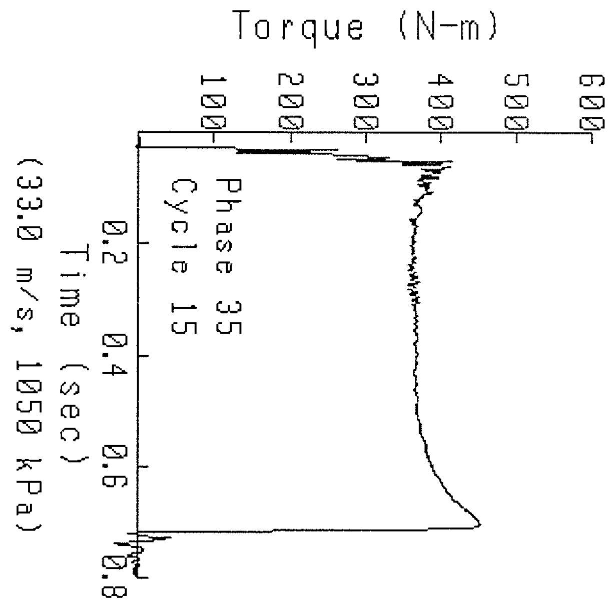



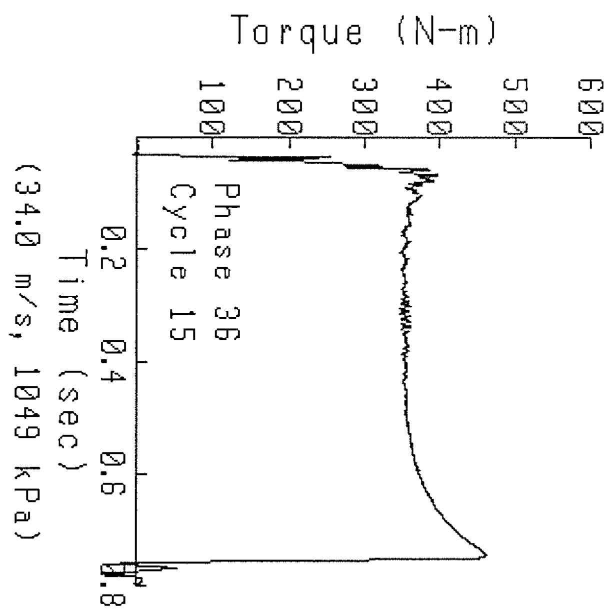


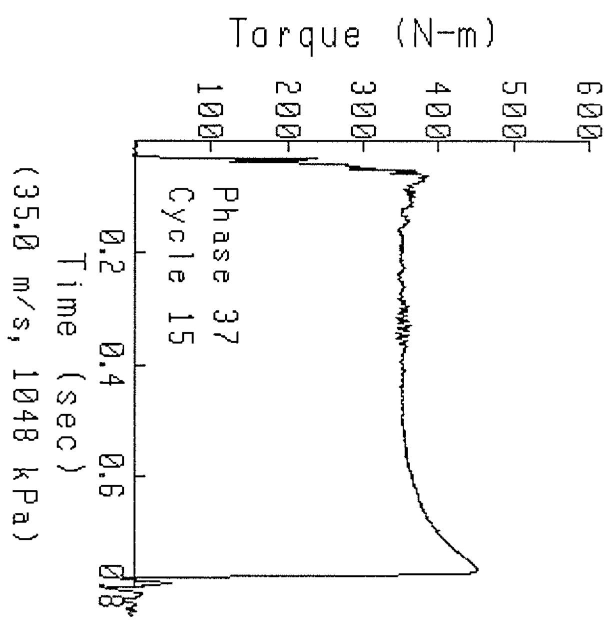
0.25
0.20
0.15
0.10
0.05
0.00
Dynamic Coefficient
0
10
20
30
40
50
60
Speed (m/s)
1050 kPa

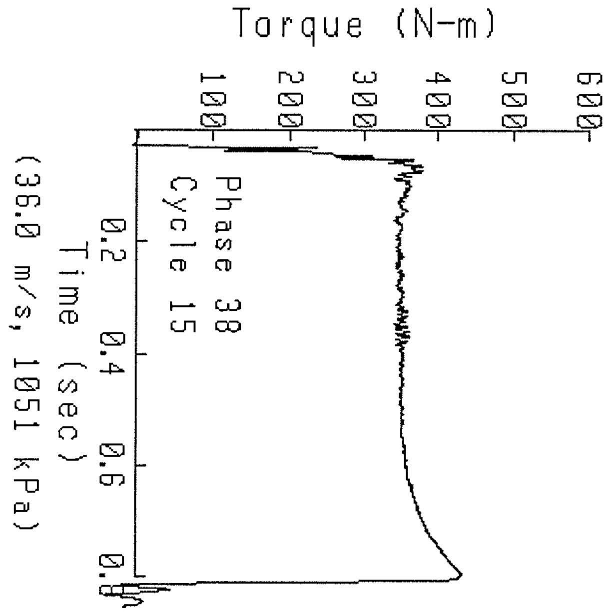



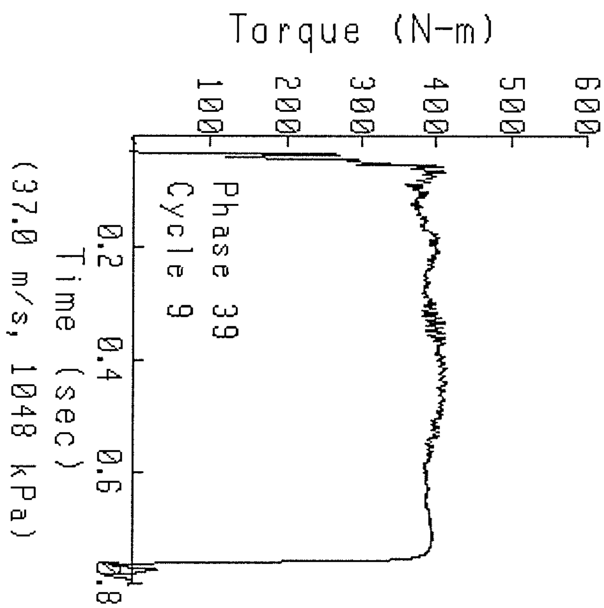
0.25
0.20
0.15
0.10
0.05
0.00
Static Coefficient
0
10
20
30
40
50
60
Speed (m/s)
1050 kPa

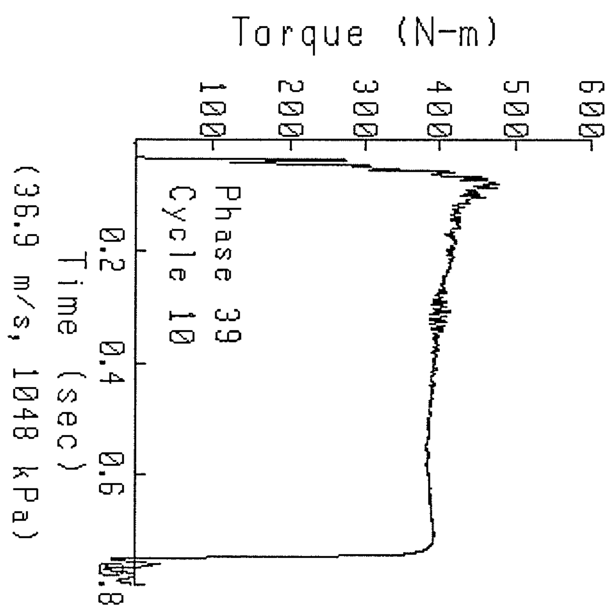

Torque (N-m)
Phase 35
Cycle 15
Time (sec)
(33.0 m/s, 1050 kPa)


Torque (N-m)
Phase 36
Cycle 15
Time (sec)
(34.0 m/s, 1049 kPa)


Torque (N-m)
Phase 37
Cycle 15
Time (sec)
(35.0 m/s, 1048 kPa)


Torque (N-m)
Phase 38
Cycle 15
Time (sec)
(36.0 m/s, 1051 kPa)


Torque (N-m)
Phase 39
Cycle 9
Time (sec)
(37.0 m/s, 1048 kPa)


Torque (N-m)
Phase 39
Cycle 10
Time (sec)
(36.9 m/s, 1048 kPa)

# APPENDIX – E2
# CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70
# LO271510

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

**CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70**

Conducted for

**ARMY LAB**

Oil Code:
**LO271510**

Test Number:
**VC70-A-164-J**

October 21, 2011

Submitted by:

Brian Koehler
Principal Engineer
Specialty & Driveline Fluid Evaluation

The results of this report relate only to the fluid tested.
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# CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70

## Summary Sheet

**Company:** ARMY LAB

**Test start date:** 10/20/2011
**End of test date:** 10/21/2011
**Oil Code:** LO271510

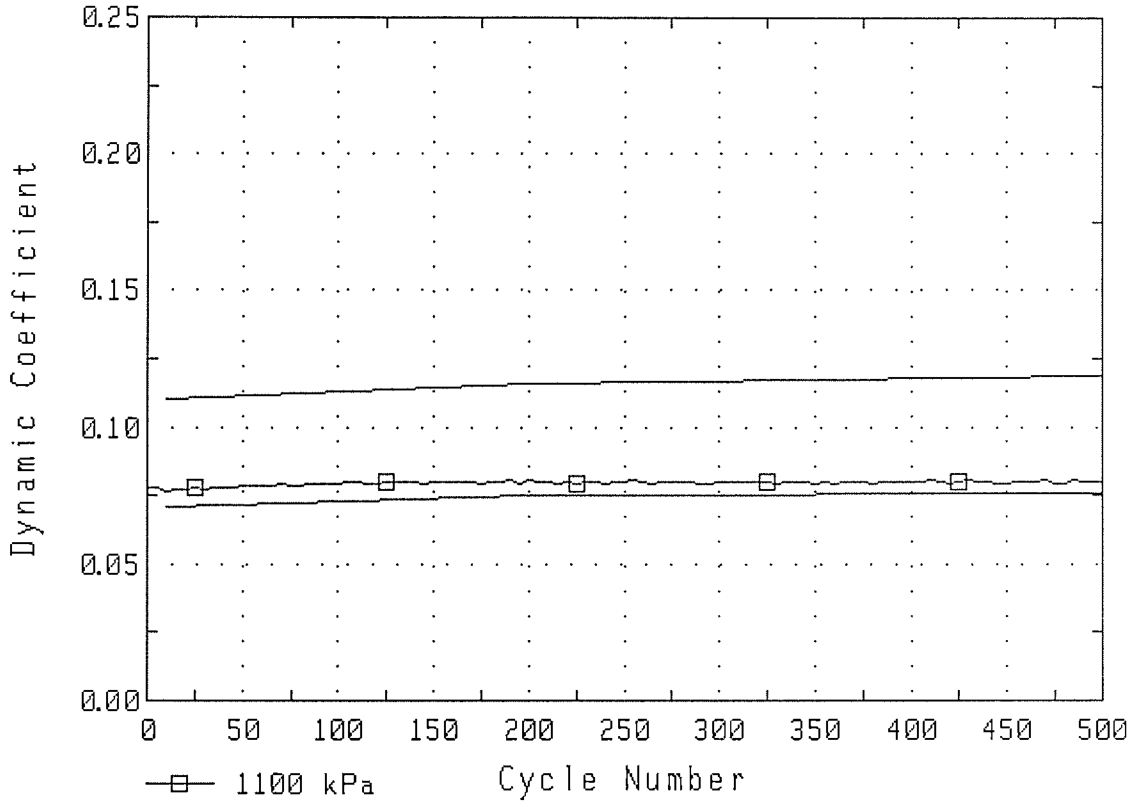
| Sequence Number | 1219 | 1220 | 1221 | 1222 | 1223 | 1224 | Friction Retention |
|---|---|---|---|---|---|---|---|
| Dynamic Coefficient Vs. Cycle: | | P | | F | | | |
| Dynamic Coefficient Vs. Load: | | P | | F | | | |
| Dynamic Coefficient Vs. Speed: | | P | | F | | | |
| Energy Limit: | | P | | P | | | |
| Static Coefficient Vs. Load: | | P | | P | | | |
| Static Coefficient Vs. Speed: | | P | | P | | | |
| Energy Limit: | | P | | P | | | |
| Total Wear: | | 0.006 | | 0.029 | | | |
| Wear Limit: | 0.030 | 0.040 | 0.070 | 0.070 | 0.070 | 0.040 | |

**Comments:** This testing was conducted on a referenced test stand. The results are compared to TO-4 testing limits. 2009 Batch parts were used for this sequence.

F = Fail
P = Pass
N/A = Not Applicable

SOUTHWEST RESEARCH INSTITUTE
"J" MACHINE OIL TEST LO271510 / LO-271510

| | |
|---|---|
| Test name: | A-164-J |
| Test date: | 10/20/11 |
| Test description: | J MACHINE LO271510 |
| Oil type: | LO271510 / LO-271510 |
| Viscosity: | N/A |
| Miscellaneous: | |
| Software version: | 1.40 |
| | |
| Run name & desc: | J0508338 - J MACHINE LO271510 |
| Run date: | 08/30/11 |
| Oil temperature: | 82 degrees C |
| Oil flow rate: | 3.78 liter/minute |
| Operator: | HC |
| Remarks: | "J" MACHINE OIL TEST LO271510 / LO-271510 |
| Sequence name: | SEQ1220 |
| Remarks: | Use 1Y0709 Disc and 8E4095 Plate |
| Number of cycles run: | 1140 |
| | |
| Machine: | J |
| Coast down check run: | 02/01/00 |
| Result: | 71.40 seconds |
| Inertia check run: | 02/01/00 |
| Result: | 1.0349 N-m-$s^2$ |
| | |
| Disc name & desc: | 1Y0709 - Sintered Bronze |
| Material: | Raybestos 1349-ET Bronze |
| Groove pattern: | Single Lead Spiral - 12 Radial |
| Miscellaneous: | Use with 8E4095 Steel Plate for performance run |
| Outer diameter (mm): | 285.80 |
| Inner diameter (mm): | 223.20 |
| Mean radius (mm): | 128.21 |
| Batch number: | 007080C800012 |
| Remarks: | SINTERED BRONZE |
| | |
| Plate name & desc: | 8E4095 - Steel Plate |
| Surface: | 0.70 to 1.00 micron Roughness |
| Miscellaneous: | Install the side marked with the average roughness |
| Batch number: | 007080C800012 |
| Remarks: | 0.90 SURFACE FINISH |
| | |
| Report limit name: | LIM1220 - Reference run: J0508081 |
| Limit file generated: | 10/19/11 |
| Report format name: | REP1220 - SINTERED BRONZE |

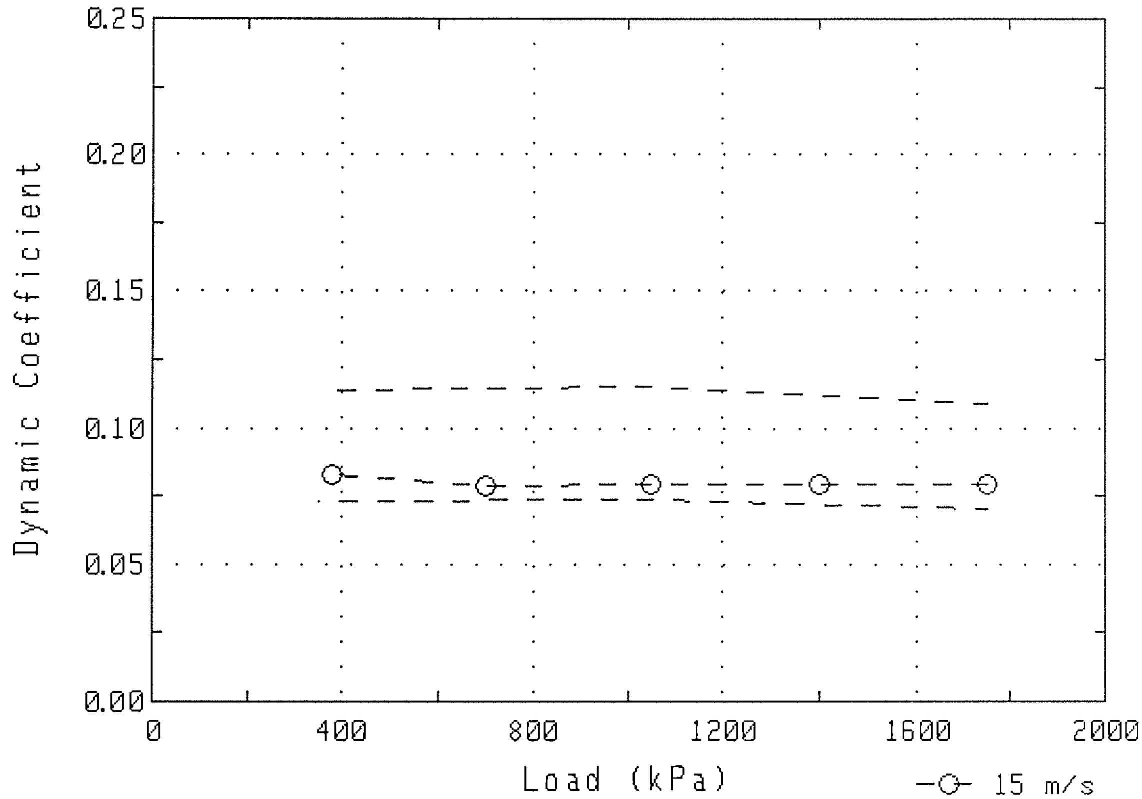



1Y0709 DISC
THICKNESS

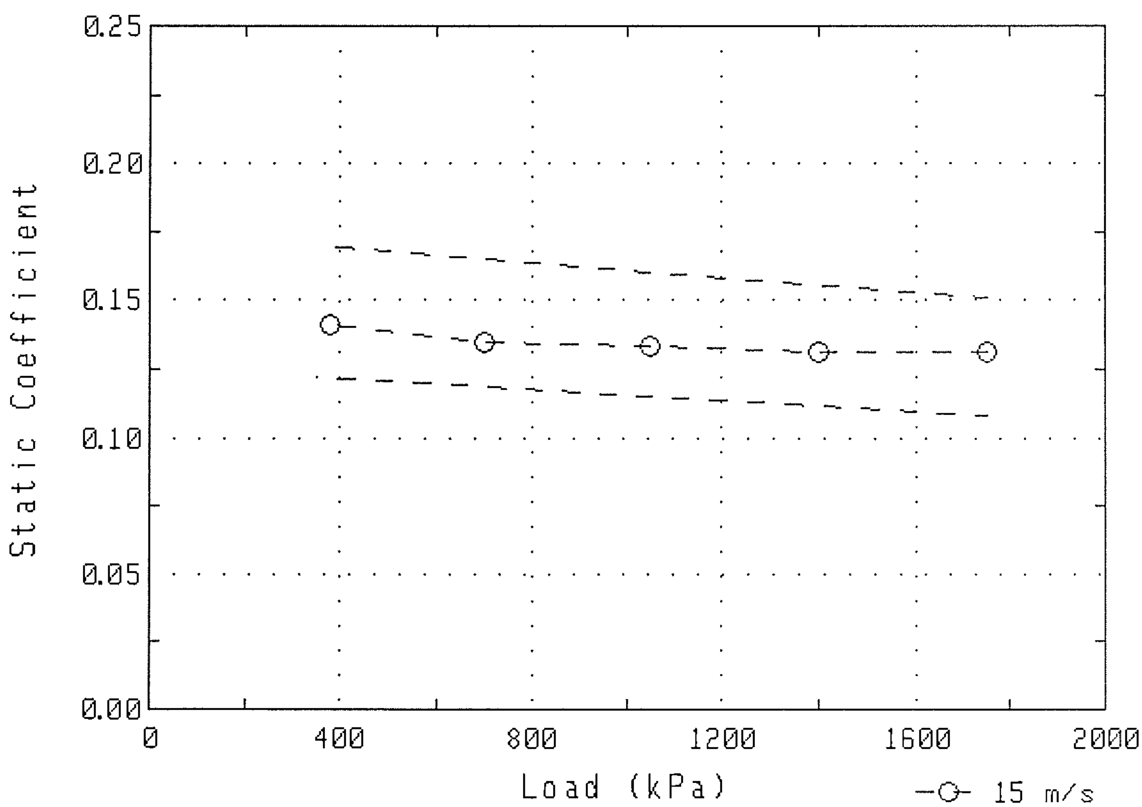
| Loc | Outer Diameter M1 | M2 | M3 | Inner Diameter M1 | M2 | M3 |
|---|---|---|---|---|---|---|
| 1 | 4.92 | 4.92 | 4.92 | 4.92 | 4.92 | 4.92 |
| 2 | 4.95 | 4.94 | 4.94 | 4.94 | 4.93 | 4.93 |
| 3 | 4.93 | 4.93 | 4.93 | 4.93 | 4.93 | 4.93 |
| 4 | 4.93 | 4.92 | 4.92 | 4.93 | 4.92 | 4.92 |
| 5 | 4.93 | 4.92 | 4.92 | 4.92 | 4.92 | 4.92 |
| 6 | 4.93 | 4.92 | 4.92 | 4.93 | 4.92 | 4.92 |
| Avg | 4.93 | 4.93 | 4.93 | 4.93 | 4.92 | 4.92 |

Compression set average wear: 0.006
M2 - M3 average Wear: 0.000

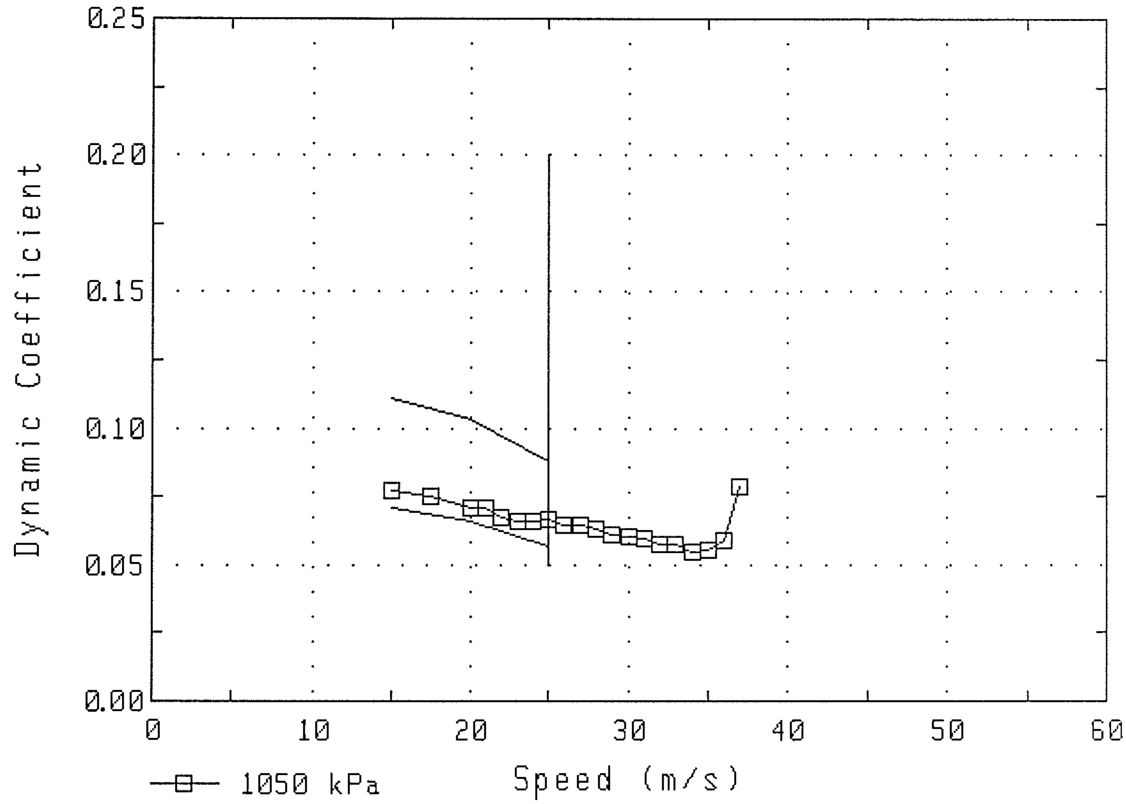
Total Wear (all measurements in mm): 0.006

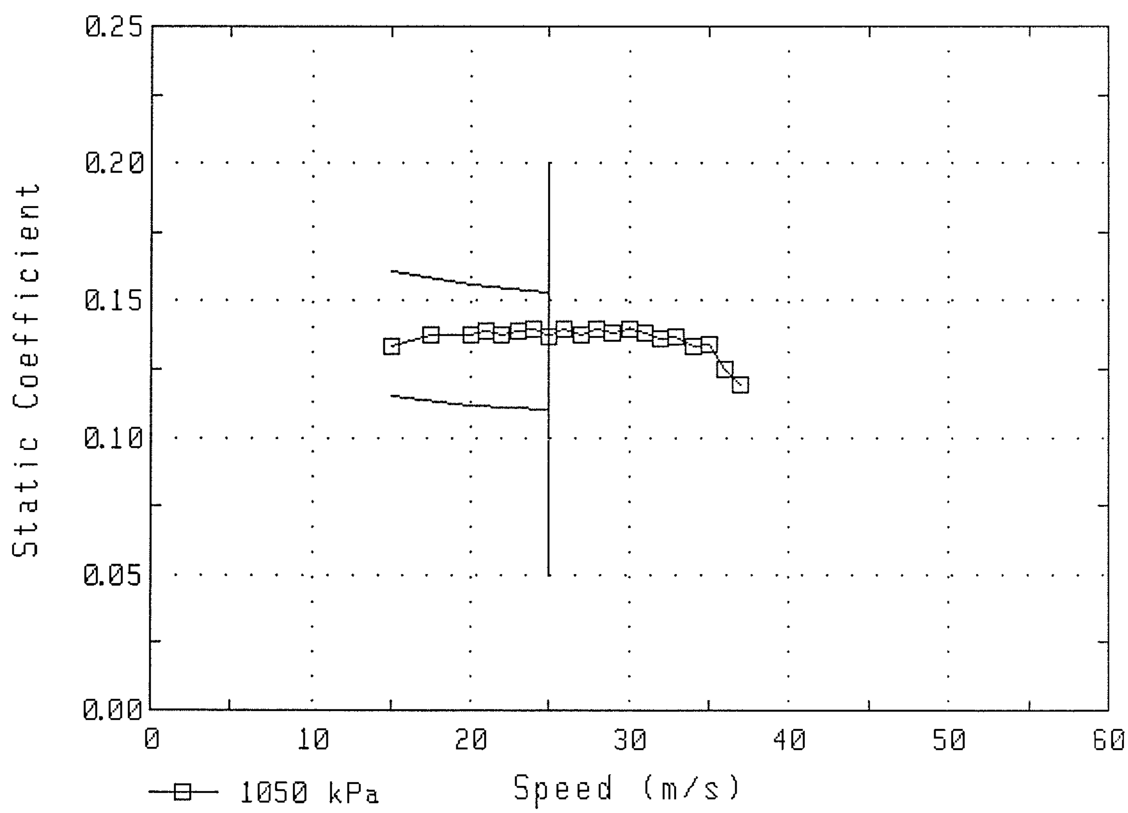


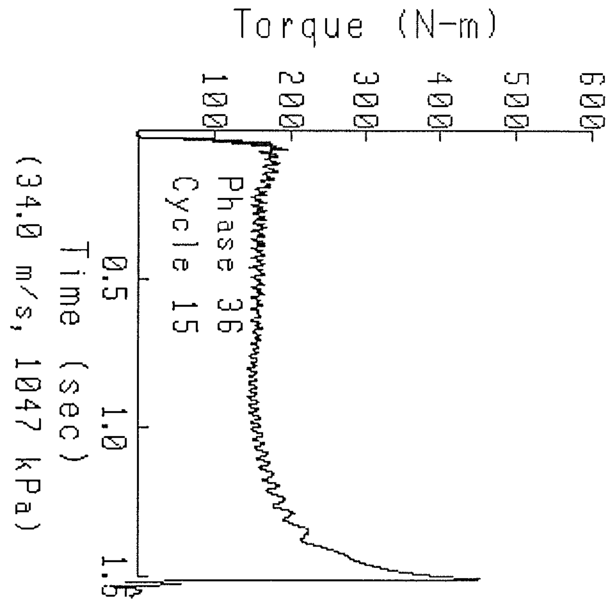
Dynamic Coefficient
0.25
0.20
0.15
0.10
0.05
0.00
0
400
800
1200
1600
2000
Load (kPa)
15 m/s

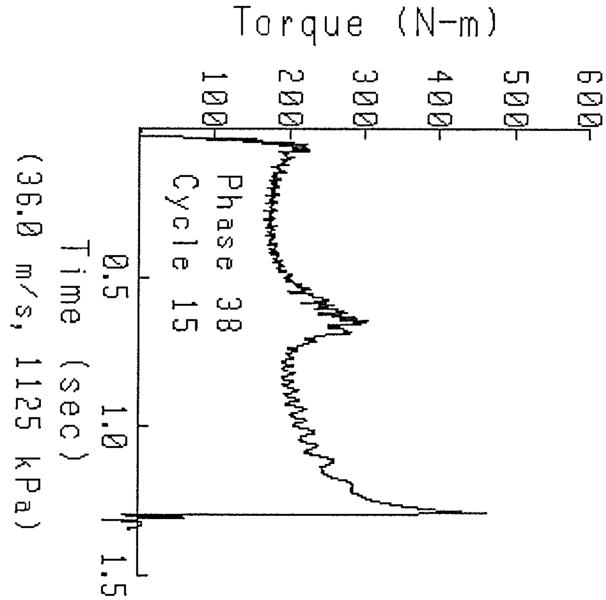



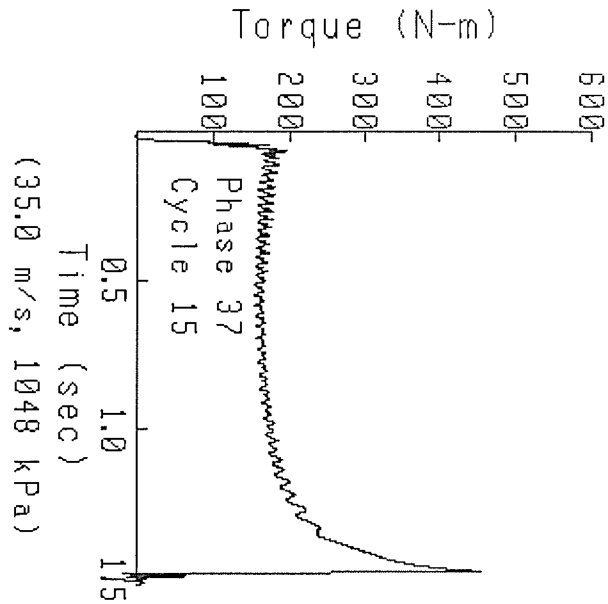
Static Coefficient
0.25
0.20
0.15
0.10
0.05
0.00
0
400
800
1200
1600
2000
Load (kPa)
15 m/s

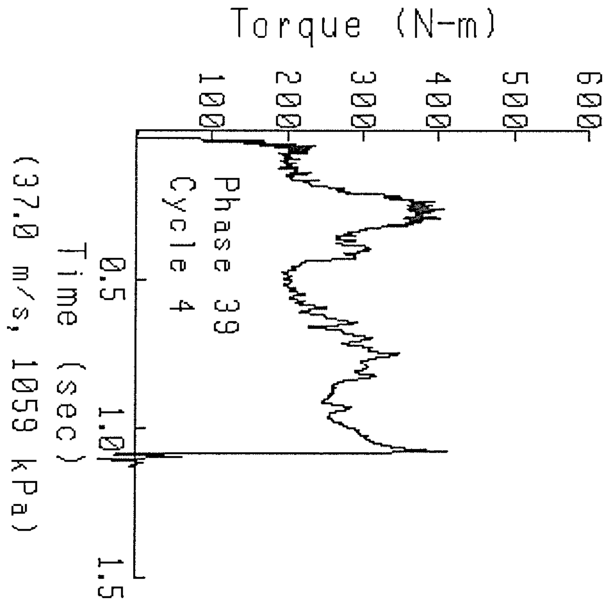

0.25
0.20
0.15
0.10
0.05
0.00
Dynamic Coefficient
0
10
20
30
40
50
60
Speed (m/s)
1050 kPa

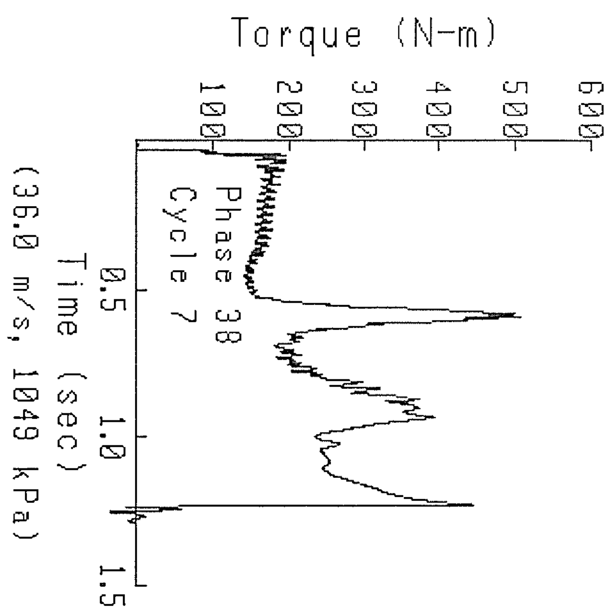

0.25
0.20
0.15
0.10
0.05
0.00
Static Coefficient
0
10
20
30
40
50
60
Speed (m/s)
1050 kPa

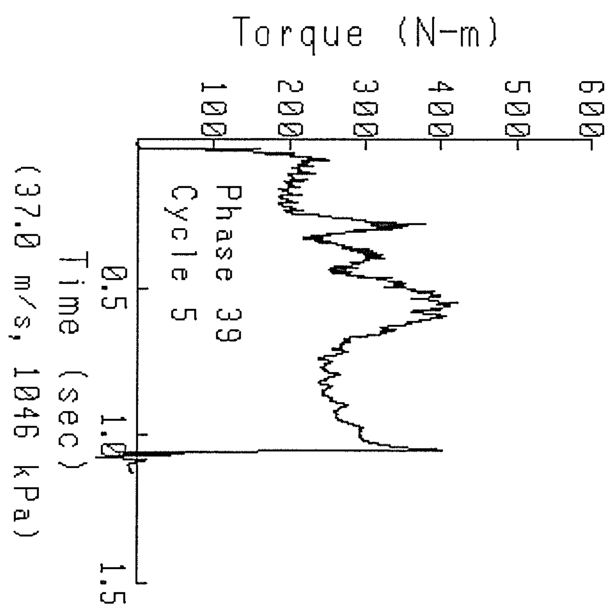

Torque (N-m)
100 200 300 400 500 600
Phase 36
Cycle 15
0.5 1.0 1.5
Time (sec)
(34.0 m/s, 1047 kPa)


Torque (N-m)
100 200 300 400 500 600
Phase 38
Cycle 15
0.5 1.0 1.5
Time (sec)
(36.0 m/s, 1125 kPa)


Torque (N-m)
100 200 300 400 500 600
Phase 37
Cycle 15
0.5 1.0 1.5
Time (sec)
(35.0 m/s, 1048 kPa)


Torque (N-m)
100 200 300 400 500 600
Phase 39
Cycle 4
0.5 1.0 1.5
Time (sec)
(37.0 m/s, 1059 kPa)


Torque (N-m)
100 200 300 400 500 600
Phase 38
Cycle 7
0.5 1.0 1.5
Time (sec)
(36.0 m/s, 1049 kPa)


Torque (N-m)
100 200 300 400 500 600
Phase 39
Cycle 5
0.5 1.0 1.5
Time (sec)
(37.0 m/s, 1046 kPa)

SOUTHWEST RESEARCH INSTITUTE
"J" MACHINE OIL TEST LO271510 / LO-271510

| | |
|---|---|
| Test name: | A-164-J |
| Test date: | 10/21/11 |
| Test description: | J MACHINE LO271510 |
| Oil type: | LO271510 / LO-271510 |
| Viscosity: | N/A |
| Miscellaneous: | |
| Software version: | 1.40 |

| | |
|---|---|
| Run name & desc: | J0508339 - J MACHINE LO271510 |
| Run date: | 08/31/11 |
| Oil temperature: | 82 degrees C |
| Oil flow rate: | 3.78 liter/minute |
| Operator: | HC |
| Remarks: | "J" MACHINE OIL TEST LO271510 / LO-271510 |
| Sequence name: | SEQ1222 |
| Remarks: | Use 1Y0711 Disc and 1Y0726 Plate |
| Number of cycles run: | 1132 |

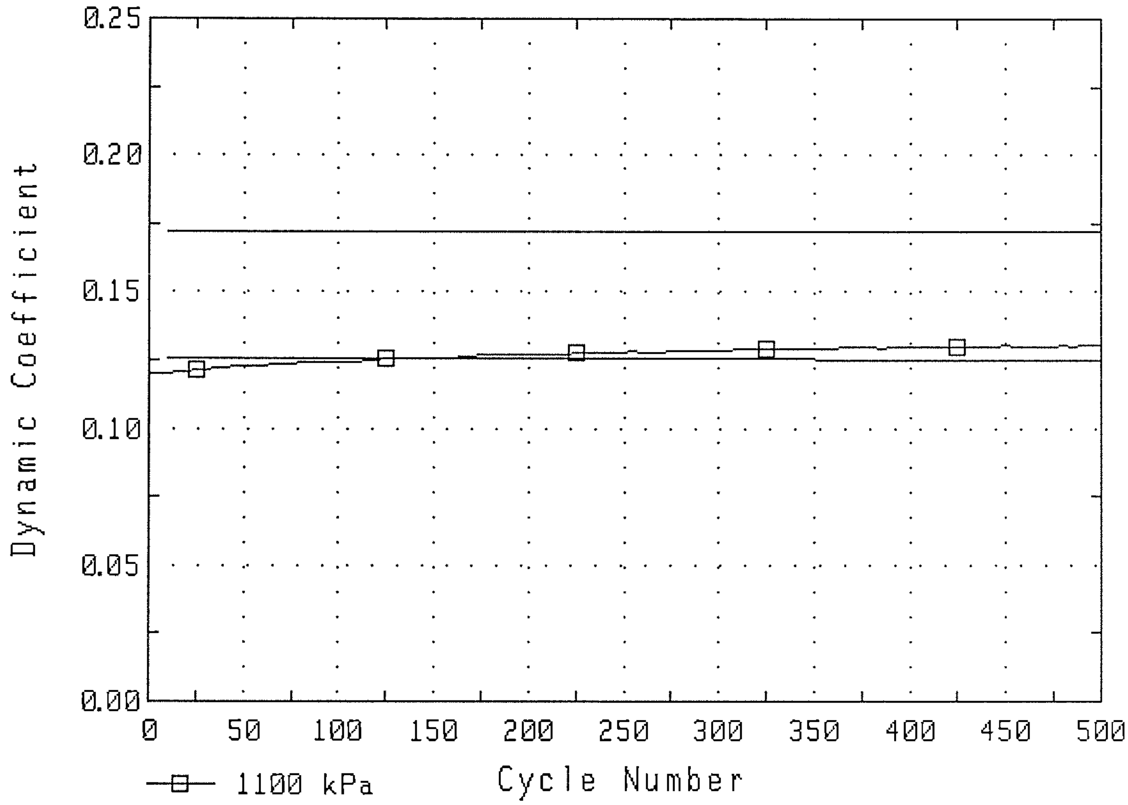
| | |
|---|---|
| Machine: | J |
| Coast down check run: | 02/01/00 |
| Result: | 71.40 seconds |
| Inertia check run: | 02/01/00 |
| Result: | 1.0349 N-m-$s^2$ |

| | |
|---|---|
| Disc name & desc: | 1Y0711 - Wheel Brake Paper |
| Material: | Raybestos 7902-1 Paper |
| Groove pattern: | 2 - 37 Multiple Parallel |
| Miscellaneous: | Use with 1Y0726 Steel Plate |
| Outer diameter (mm): | 285.80 |
| Inner diameter (mm): | 223.20 |
| Mean radius (mm): | 128.21 |
| Batch number: | 06MR928188 |
| Remarks: | WHEEL BRAKE PAPER |

| | |
|---|---|
| Plate name & desc: | 1Y0726 - Steel Plate |
| Surface: | 0.30 micron Maximum Roughness |
| Miscellaneous: | Install the side marked with the average roughness |
| Batch number: | 06MR928188 |
| Remarks: | 0.32 SURFACE FINSH |

| | |
|---|---|
| Report limit name: | LIM1222 - Reference run: J0508195 |
| Limit file generated: | 08/04/10 |
| Report format name: | REP1222 - WHEEL BRAKE PAPER |

Test: A-164-J Run: J0508339 Started on 08/31/11 at 07:25

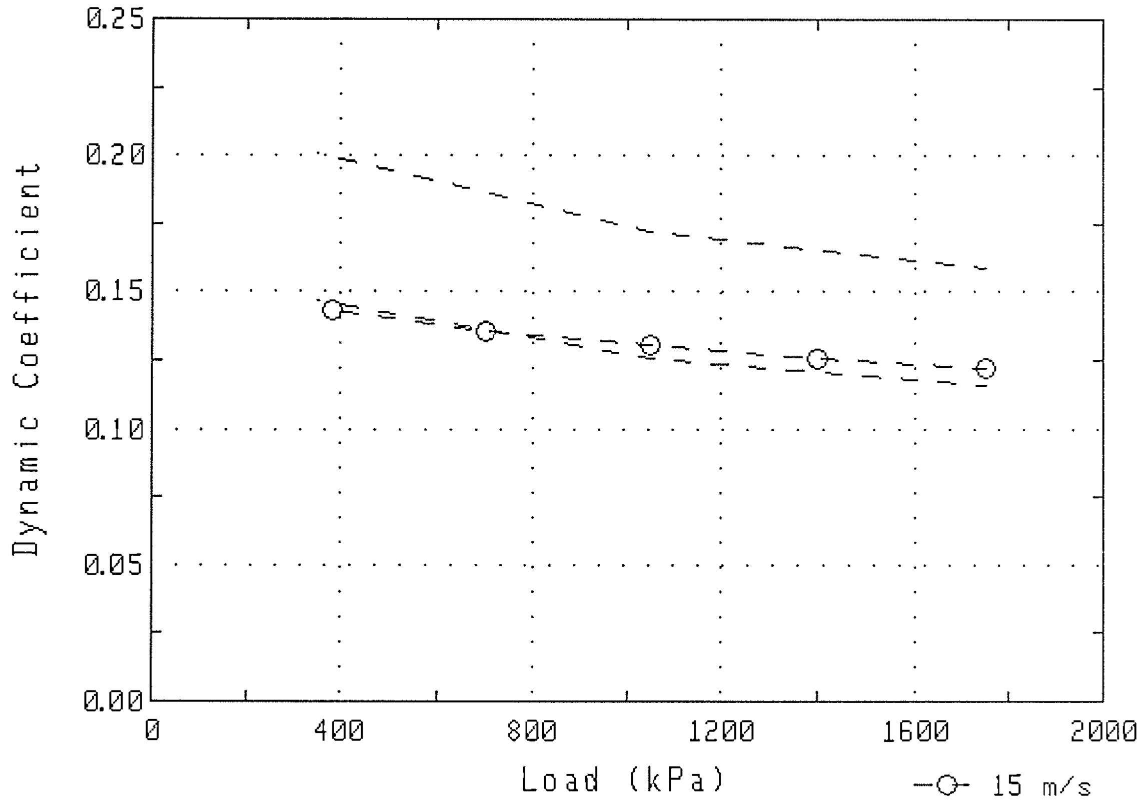


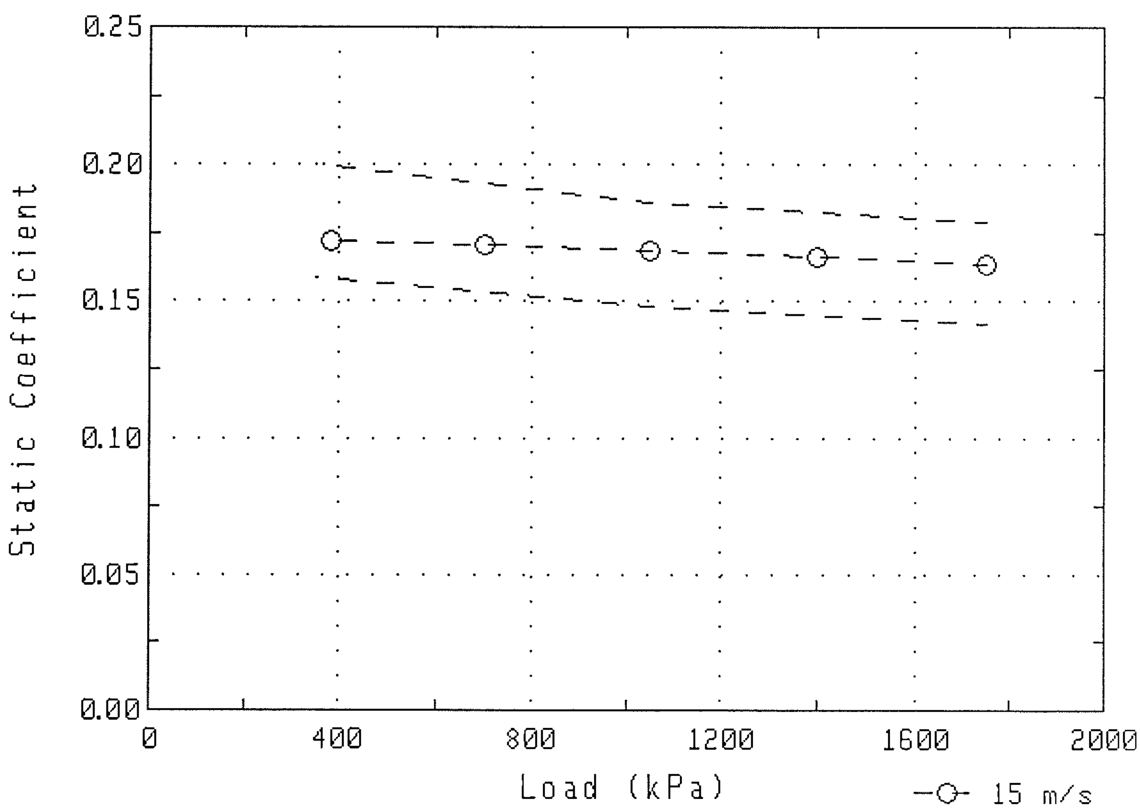

1Y0711 DISC
THICKNESS

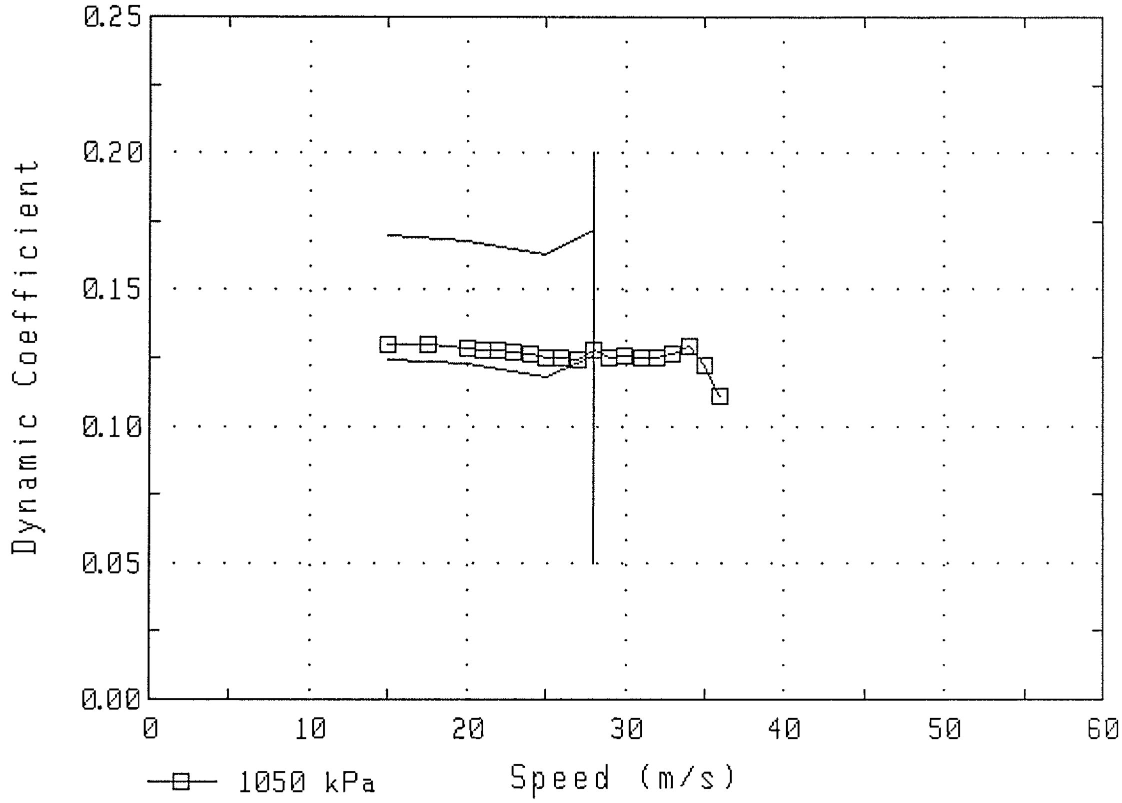
| Loc | Outer Diameter M1 | Outer Diameter M2 | Outer Diameter M3 | Inner Diameter M1 | Inner Diameter M2 | Inner Diameter M3 |
|---|---|---|---|---|---|---|
| 1 | 4.92 | 4.89 | 4.88 | 4.91 | 4.89 | 4.88 |
| 2 | 4.89 | 4.86 | 4.86 | 4.88 | 4.86 | 4.85 |
| 3 | 4.89 | 4.86 | 4.86 | 4.89 | 4.87 | 4.86 |
| 4 | 4.90 | 4.87 | 4.87 | 4.90 | 4.87 | 4.87 |
| 5 | 4.89 | 4.87 | 4.87 | 4.89 | 4.87 | 4.87 |
| 6 | 4.91 | 4.88 | 4.88 | 4.91 | 4.88 | 4.88 |
| Avg | 4.90 | 4.87 | 4.87 | 4.90 | 4.87 | 4.87 |

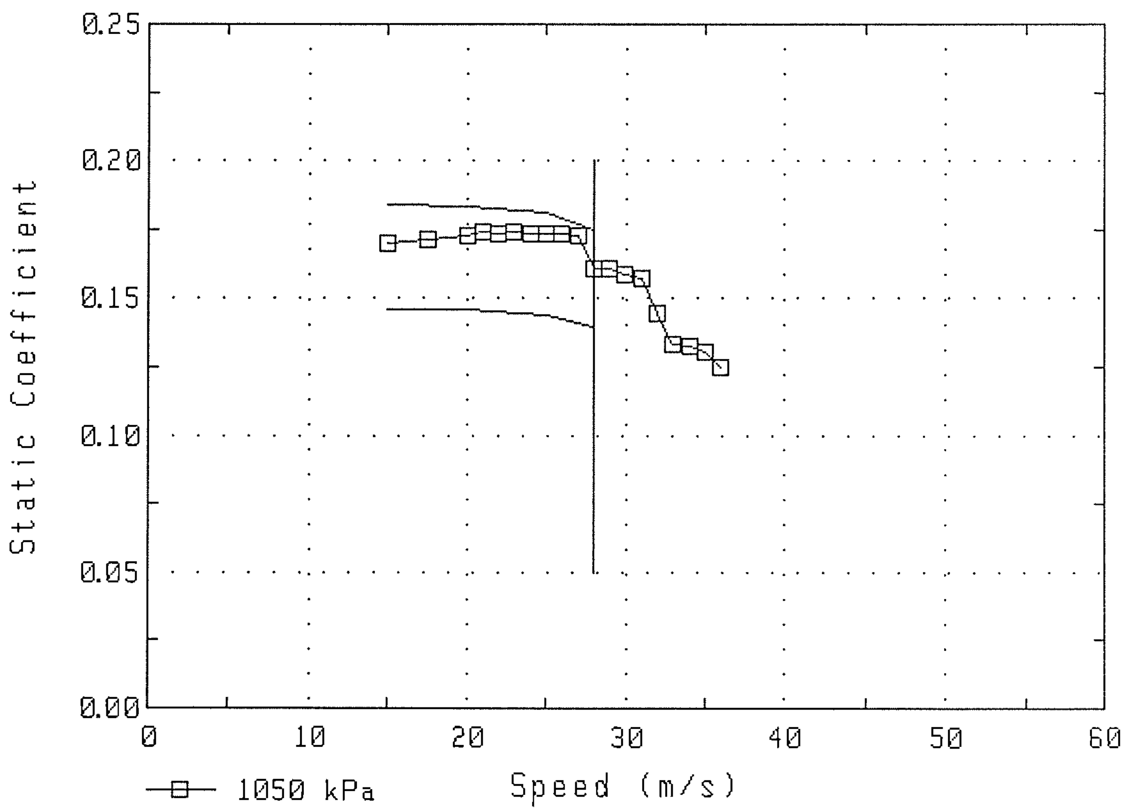
Compression set average wear: 0.026
M2 - M3 average Wear: 0.003

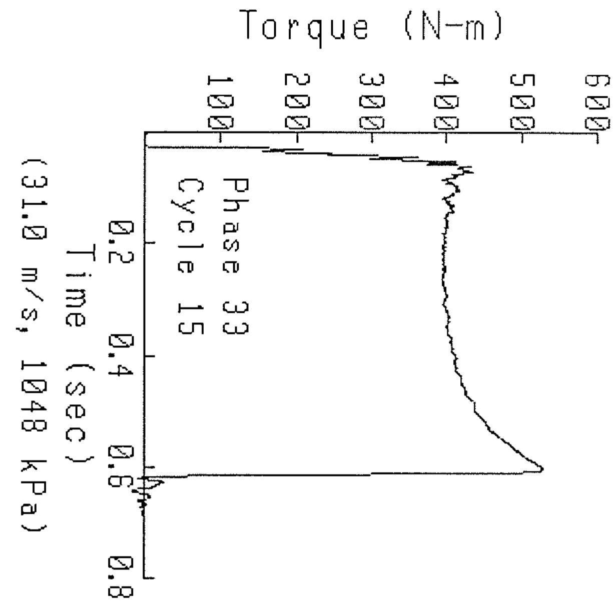
Total Wear (all measurements in mm): 0.029

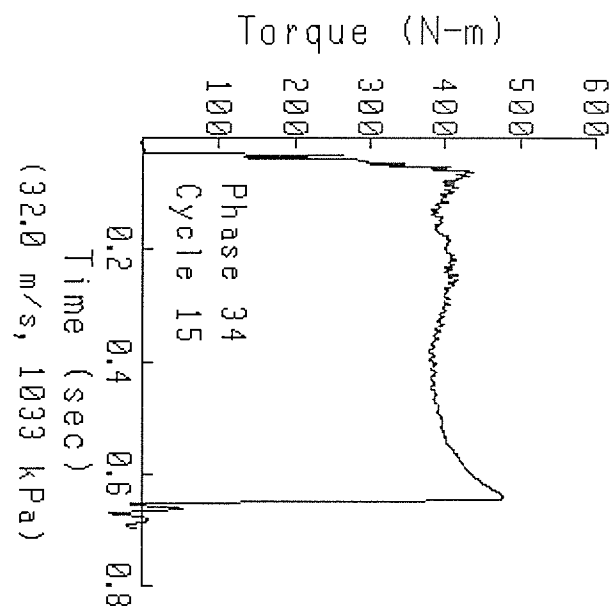

0.25
0.20
0.15
0.10
0.05
0.00
Dynamic Coefficient
0
400
800
1200
1600
2000
Load (kPa)
15 m/s

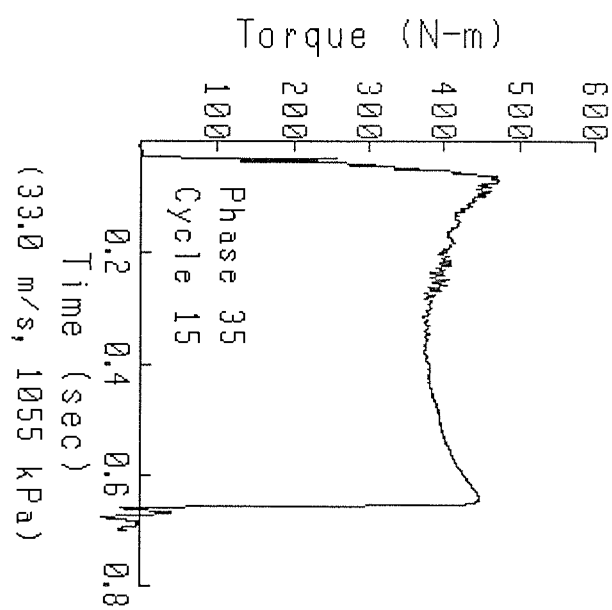

0.25
0.20
0.15
0.10
0.05
0.00
Static Coefficient
0
400
800
1200
1600
2000
Load (kPa)
15 m/s

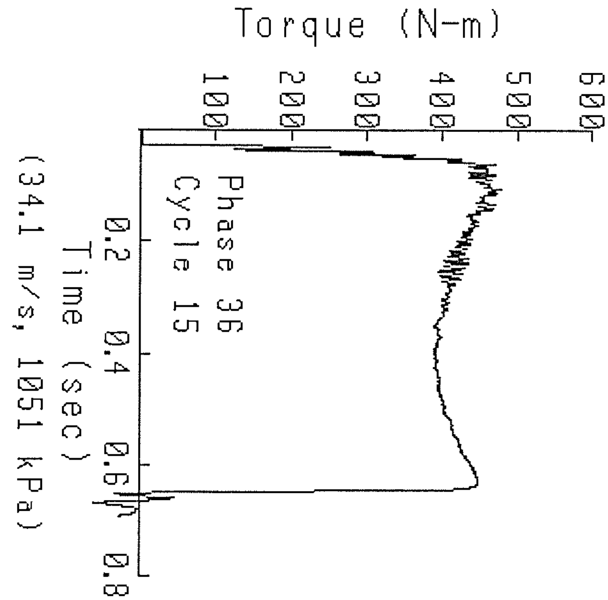

0.25
0.20
0.15
0.10
0.05
0.00
Dynamic Coefficient
0
10
20
30
40
50
60
Speed (m/s)
1050 kPa

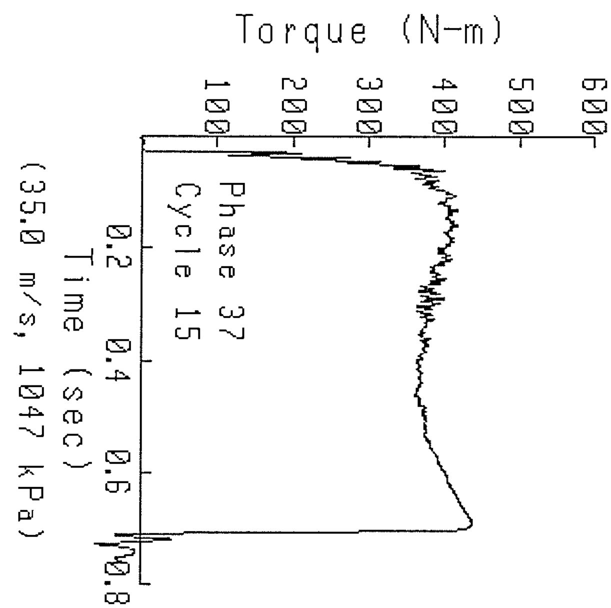

0.25
0.20
0.15
0.10
0.05
0.00
Static Coefficient
0
10
20
30
40
50
60
Speed (m/s)
1050 kPa

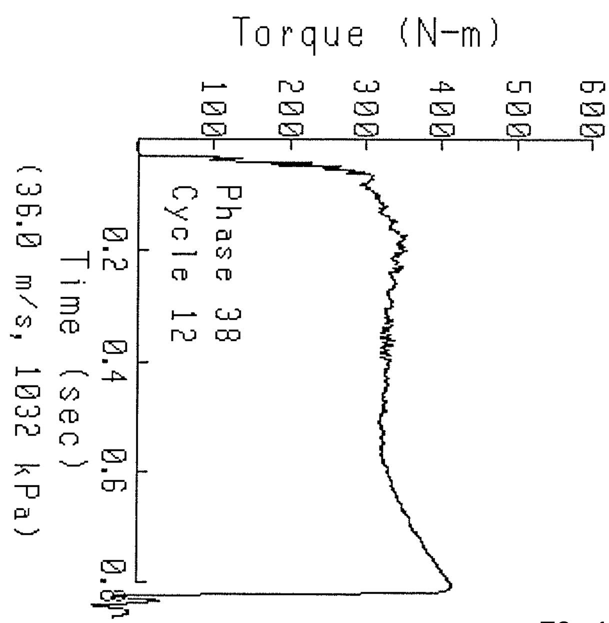

Torque (N-m)
100 200 300 400 500 600
Phase 33
Cycle 15
0.2 0.4 0.6 0.8
Time (sec)
(31.0 m/s, 1048 kPa)


Torque (N-m)
100 200 300 400 500 600
Phase 34
Cycle 15
0.2 0.4 0.6 0.8
Time (sec)
(32.0 m/s, 1033 kPa)


Torque (N-m)
100 200 300 400 500 600
Phase 35
Cycle 15
0.2 0.4 0.6 0.8
Time (sec)
(33.0 m/s, 1055 kPa)


Torque (N-m)
100 200 300 400 500 600
Phase 36
Cycle 15
0.2 0.4 0.6 0.8
Time (sec)
(34.1 m/s, 1051 kPa)


Torque (N-m)
100 200 300 400 500 600
Phase 37
Cycle 15
0.2 0.4 0.6 0.8
Time (sec)
(35.0 m/s, 1047 kPa)


Torque (N-m)
100 200 300 400 500 600
Phase 38
Cycle 12
0.2 0.4 0.6 0.8
Time (sec)
(36.0 m/s, 1032 kPa)

# APPENDIX – F1

# JOHN DEERE JDQ-96
# PERFORMED USING 1400 SERIES AXLE

# LO268869

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

**John Deere JDQ-96**
**Performed using 1400 Series Axle**

Conducted for

**U.S. Army TARDEC Fuels and Lubricants Research Facility**

**LO268869**

**Test Number**
**11843**

**November 23, 2011**

Submitted by:

Brian Decker
Engineer
Specialty & Driveline Fluid Evaluations

The results of this report relate only to the items tested.
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## John Deere JDQ-96 Performed using 1400 Series Axle

### General Information

| Oil Code: LO268869 | E.O.T. Date: November 23, 2011 |
|---|---|

### Purpose

The purpose of this test was to evaluate the anti-chatter properties of this oil on the brakes of a 1400 series John Deere Inboard Planetary Axle.

### Test Procedure

The test was performed as specified by John Deere Product Engineering. The only changes made to the Deere procedure were those necessary to compensate for a different spiral bevel gear ratio. This procedure is proprietary to Deere and Company.

### Data Interpretation

The capacity for each engagement is the average torque during the middle of the engagement. The torque variation is the greatest difference between the maximum and minimum torque recorded during any 0.2-second portion of the engagement. The SwRI variation is the sum of all differences between the maximum torque and minimum torque for each engagement. It is obtained by summing all torque variations of each 0.2-second time block of all engagements.

### Test Number

The run number listed on this report is a random number and is not sequential. Only SwRI® can link this run number to JDQ-96, LO268869, November 23, 2011.

## John Deere JDQ-96 Performed using 1400 Series Axle

## Results

| Oil Code: LO268869 | E.O.T. Date: November 23, 2011 |
|---|---|

The candidate results can be compared to the baseline reference average. Pass or fail decisions are only made by John Deere Product Engineering. The current reference baseline average is the average of the five most recent tests.

| Current Reference Baseline Average (N · m) | | | | | |
|---|---|---|---|---|---|
| | **1,000 Cycles** | **10,000 Cycles** | **20,000 Cycles** | **30,000 Cycles** | **TOTAL** |
| Relative Capacity | 330,753 | 340,749 | 339,241 | 341,212 | 1,351,955 |
| Torque Variation | 171,228 | 148,851 | 144,908 | 139,005 | 603,993 |

| Results From Test Candidate LO268869 | | | | | |
|---|---|---|---|---|---|
| | **1,000 Cycles** | **10,000 Cycles** | **20,000 Cycles** | **30,000 Cycles** | **TOTAL** |
| Relative Capacity | 335,125 | N/A | N/A | N/A | 335,125 |
| Torque Variation | 206,202 | N/A | N/A | N/A | 206,202 |

Table 1 of the Appendix contains chatter test results from 1,000. Table 2 contains results of the five current baseline reference tests. Table 3 contains the history of tests conducted on reference oil and a graphic presentation of 1000-cycle reference results on LO268869.

Figures 1 and 2 are graphic presentations of candidate oil performance compared to baseline reference data.

**John Deere JDQ-96 Performed using 1400 Series Axle**

| | |
|---|---|
| **Oil Code:** LO268869 | **E.O.T. Date:** November 23, 2011 |

**Appendix**

1. Table 1 – Durability results 1,000 cycles Candidate Oil
2. Table 2 – Reference Data Compared to Candidate Data
3. Table 3 – History of tests conducted on reference oil & graphic presentation of 1000 cycle reference results & Candidate
4. Figure 1 & Figure 2 - Torque Variation & Relative Capacity Chart

**TABLE 1: JDQ-96 DURABILITY TEST RESULTS 1,000 CYCLES**
Electrically Powered Test Stand

Sponsor Oil Code LO268869 Date November 23, 2011

| Axle Speed (rpm) | Brake Press. (kPa) | TORQUE VARIATION TEST RESULTS (TORQUE and VARIATION in Nm) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Oil Temp. 32°C | | | Oil Temp. 49°C | | | Oil Temp. 60°C | | | Oil Temp. 71°C | | |
| | | Torque | Variation | Temp. | Torque | Variation | Temp. | Torque | Variation | Temp. | Torque | Variation | Temp. |
| 8 | 3831 | 4335 | 2220 | 21 | 4201 | 1427 | 47 | 4067 | 1413 | 59 | 4228 | 1241 | 68 |
| 10 | 3831 | 4369 | 2423 | 21 | 4192 | 1811 | 47 | 4043 | 1645 | 59 | 4199 | 1570 | 68 |
| 15 | 3831 | 4364 | 2865 | 21 | 4140 | 2316 | 46 | 4026 | 2242 | 58 | 4127 | 2257 | 67 |
| 20 | 3831 | 4312 | 2864 | 21 | 4117 | 2807 | 47 | 3977 | 2826 | 58 | 4104 | 2573 | 67 |
| 25 | 3831 | 4240 | 3226 | 22 | 4059 | 2858 | 47 | 3930 | 2818 | 59 | 4057 | 2842 | 68 |
| 30 | 3831 | 4178 | 2967 | 22 | 4001 | 2800 | 48 | 3875 | 2618 | 59 | 4003 | 2718 | 68 |
| 35 | 3831 | 4123 | 2750 | 23 | 3950 | 2513 | 48 | 3829 | 2665 | 59 | 3960 | 2701 | 68 |
| 40 | 3831 | 4077 | 2731 | 24 | 3896 | 2575 | 48 | 3784 | 2533 | 59 | 3919 | 2631 | 68 |
| 45 | 3831 | 4023 | 2741 | 25 | 3852 | 2587 | 48 | 3736 | 2507 | 59 | 3859 | 2375 | 68 |
| 50 | 3831 | 3959 | 2557 | 27 | 3810 | 2427 | 48 | 3697 | 2625 | 59 | 3833 | 2557 | 68 |
| 55 | 3831 | 3909 | 2551 | 28 | 3773 | 2300 | 49 | 3661 | 2480 | 60 | 3795 | 2309 | 69 |
| 60 | 3831 | 3864 | 2441 | 29 | 3732 | 2367 | 50 | 3622 | 2411 | 61 | 3768 | 2595 | 70 |
| 15 | 1532 | 1584 | 2400 | 30 | 1621 | 2369 | 50 | 1625 | 2296 | 61 | 1606 | 2331 | 70 |
| 15 | 2300 | 2477 | 2452 | 30 | 2465 | 2525 | 49 | 2483 | 2402 | 60 | 2452 | 2485 | 69 |
| 15 | 3065 | 3324 | 2718 | 30 | 3312 | 2501 | 45 | 3348 | 2531 | 60 | 3289 | 2435 | 69 |
| 15 | 3831 | 4211 | 2691 | 30 | 4150 | 2748 | 45 | 4173 | 2524 | 60 | 4151 | 2595 | 68 |
| 15 | 4598 | 5033 | 2872 | 30 | 4979 | 2680 | 46 | 4808 | 2604 | 60 | 4937 | 2520 | 68 |
| 15 | 5364 | 5862 | 3257 | 30 | 5767 | 3184 | 46 | 5717 | 2913 | 59 | 5676 | 2799 | 68 |
| 15 | 6130 | 6120 | 3467 | 30 | 6080 | 2995 | 46 | 6538 | 3211 | 59 | 6461 | 3218 | 68 |
| 15 | 7050 | 7614 | 3027 | 31 | 7482 | 3180 | 46 | 7048 | 3106 | 59 | 7157 | 2894 | 67 |

| Temp (°C) | Relative Capacity (Nm) | Torque Variation (Nm) | SwRI Variation (Nm) |
|---|---|---|---|
| 32 | 85,978 | 55,218 | 896,035 |
| 49 | 83,577 | 50,970 | 822,720 |
| 60 | 81,987 | 50,368 | 795,669 |
| 71 | 83,584 | 49,645 | 784,552 |
| TOTAL | 335,125 | 206,202 | 3,298,976 |

## TABLE 2: JDQ-96 Electric Initial Test Stand REFERENCE DATA

Candidate Oil Code : LO268869 EOT Date: November 23, 2011
Reference Oil Code : 69X31111M

| | Cycles | Relative Capacity | Torque Variation | SwRI Variation | Average Facing Thickness (millimeters) |
|---|---|---|---|---|---|
| First Reference Run | | | | | |
| 11279 | 1,000 | 329,975 | 160,449 | 2,530,213 | 7.45 |
| | 10,000 | 336,719 | 115,287 | 1,647,685 | 7.23 |
| | 20,000 | 334,984 | 119,314 | 1,755,276 | 7.03 |
| | 30,000 | 335,508 | 119,149 | 1,592,586 | 6.78 |
| | Total | 1,337,186 | 514,198 | 7,525,760 | |
| Second Reference Run | | | | | |
| 11852 | 1,000 | 327,258 | 172,283 | 2,624,608 | 7.42 |
| | 10,000 | 336,696 | 208,440 | 2,732,636 | 7.24 |
| | 20,000 | 339,033 | 152,391 | 2,143,494 | 7.08 |
| | 30,000 | 333,213 | 147,746 | 2,127,478 | 6.94 |
| | Total | 1,336,201 | 680,859 | 9,628,216 | |
| Third Reference Run | | | | | |
| 11663 | 1,000 | 325,464 | 179,529 | 2,696,409 | 7.43 |
| | 10,000 | 340,089 | 146,169 | 2,145,968 | 7.23 |
| | 20,000 | 330,568 | 145,948 | 2,016,724 | 7.07 |
| | 30,000 | 332,713 | 148,011 | 2,001,514 | 6.88 |
| | Total | 1,328,834 | 619,656 | 8,860,614 | |
| Fourth Reference Run | | | | | |
| 11922 | 1,000 | 325,990 | 179,251 | 2,596,844 | 7.46 |
| | 10,000 | 334,464 | 156,902 | 2,185,176 | 7.31 |
| | 20,000 | 333,886 | 183,892 | 2,437,145 | 7.18 |
| | 30,000 | 339,695 | 147,072 | 2,033,787 | 7.07 |
| | Total | 1,334,036 | 667,118 | 9,252,951 | |
| Fifth Reference Run | | | | | |
| 11175 | 1,000 | 345,076 | 164,630 | 2,569,506 | 7.46 |
| | 10,000 | 355,779 | 117,458 | 1,636,195 | 7.26 |
| | 20,000 | 357,736 | 122,993 | 1,721,073 | 7.09 |
| | 30,000 | 364,928 | 133,050 | 1,799,847 | 6.84 |
| | Total | 1,423,519 | 538,132 | 7,726,620 | |
| Candidate oil | | | | | |
| LO268869 | | 335,125 | 206,202 | 3,298,976 | |

**Table 3: History of 1000 cycle reference tests**

Candidate Oil Code: LO268869 EOT Date: November 23, 2011

| Oil Code | Comments | Torque Variation 1000 cycles |
|---|---|---|
| 69X31111M | new piston and backing plate | 160,449 |
| 69X31111M | new piston and backing plate | 172,283 |
| 69X31111M | new piston and backing plate | 179,529 |
| 69X31111M | new piston and backing plate | 179,251 |
| 69X31111M | new piston and backing plate | 164,630 |
| 69X31111M | new piston and backing plate | 194,668 |
| 69X31111M | new piston and backing plate | 183,301 |
| LO268869 | new piston and backing plate | 206,202 |

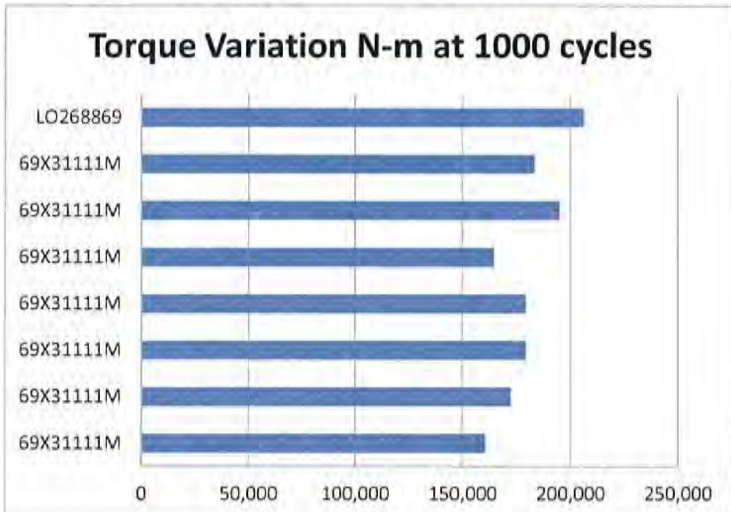


Figure 1

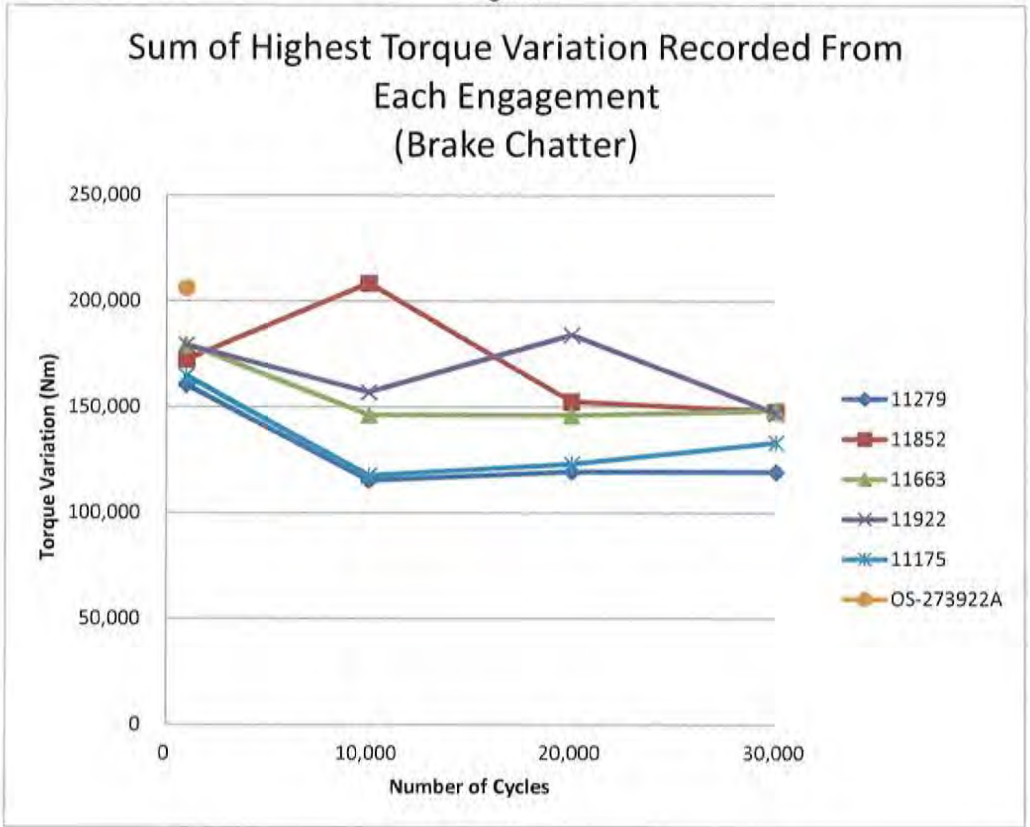
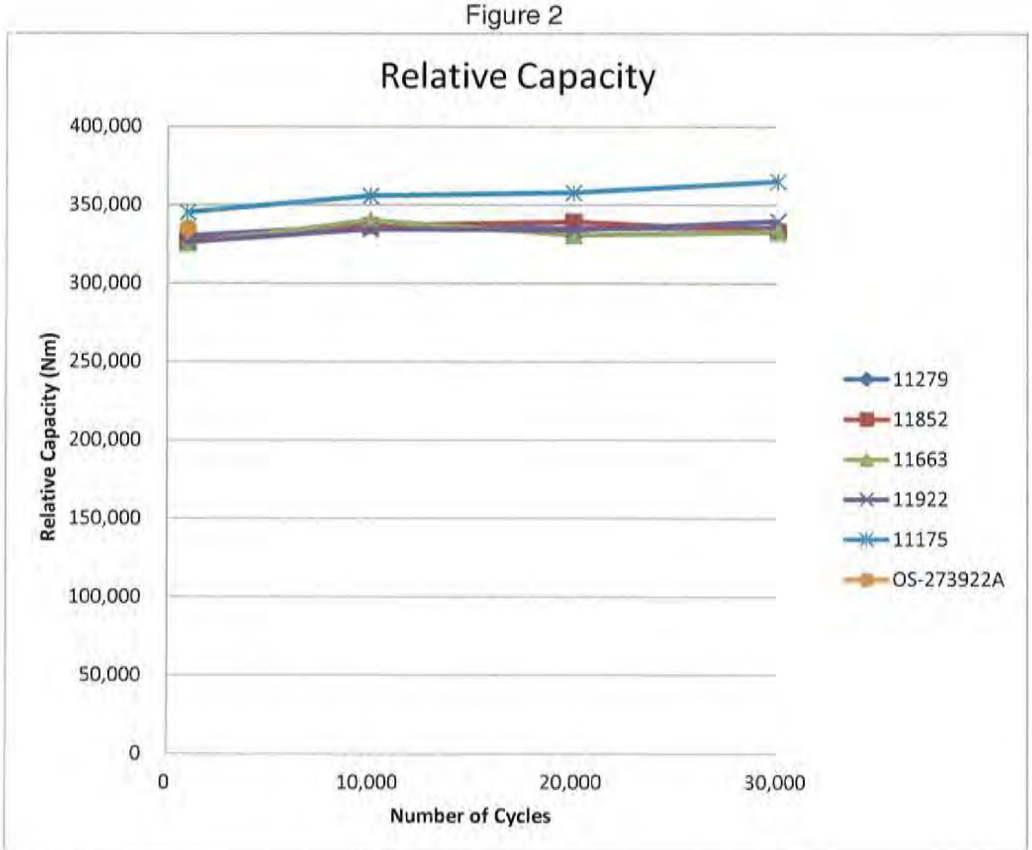



Figure 2



# APPENDIX – F2

# JOHN DEERE JDQ-96
# PERFORMED USING 1400 SERIES AXLE

# LO271510

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

**John Deere JDQ-96**
**Performed using 1400 Series Axle**

Conducted for

**U.S. Army TARDEC Fuels and Lubricants Research Facility**

**LO271510**

**Test Number**
**11114**

**December 1, 2011**

Submitted by:

Brian Decker
Engineer
Specialty & Driveline Fluid Evaluations

The results of this report relate only to the items tested.
This report shall not be reproduced, except in full, without the written approval of Southwest Research Institute®.

## John Deere JDQ-96 Performed using 1400 Series Axle

### General Information

| Oil Code: LO271510 | E.O.T. Date: December 1, 2011 |
|---|---|

### Purpose

The purpose of this test was to evaluate the anti-chatter properties of this oil on the brakes of a 1400 series John Deere Inboard Planetary Axle.

### Test Procedure

The test was performed as specified by John Deere Product Engineering. The only changes made to the Deere procedure were those necessary to compensate for a different spiral bevel gear ratio. This procedure is proprietary to Deere and Company.

### Data Interpretation

The capacity for each engagement is the average torque during the middle of the engagement. The torque variation is the greatest difference between the maximum and minimum torque recorded during any 0.2-second portion of the engagement. The SwRI variation is the sum of all differences between the maximum torque and minimum torque for each engagement. It is obtained by summing all torque variations of each 0.2-second time block of all engagements.

### Test Number

The run number listed on this report is a random number and is not sequential. Only SwRI® can link this run number to JDQ-96, LO271510, December 1, 2011.

## John Deere JDQ-96 Performed using 1400 Series Axle

### Results

| **Oil Code:** LO271510 | **E.O.T. Date:** December 1, 2011 |
|---|---|

The candidate results can be compared to the baseline reference average. Pass or fail decisions are only made by John Deere Product Engineering. The current reference baseline average is the average of the five most recent tests.

| Current Reference Baseline Average (N · m) | | | | | |
|---|---|---|---|---|---|
| | **1,000 Cycles** | **10,000 Cycles** | **20,000 Cycles** | **30,000 Cycles** | **TOTAL** |
| Relative Capacity | 330,753 | 340,749 | 339,241 | 341,212 | 1,351,955 |
| Torque Variation | 171,228 | 148,851 | 144,908 | 139,005 | 603,993 |

| Results From Test Candidate LO271510 | | | | | |
|---|---|---|---|---|---|
| | **1,000 Cycles** | **10,000 Cycles** | **20,000 Cycles** | **30,000 Cycles** | **TOTAL** |
| Relative Capacity | 392,229 | N/A | N/A | N/A | 392,229 |
| Torque Variation | 264,603 | N/A | N/A | N/A | 264,603 |

Table 1 of the Appendix contains chatter test results from 1,000 cycles. Table 2 contains results of the five current baseline reference tests. Table 3 contains the history of tests conducted on reference oil and a graphic presentation of 1000-cycle reference results on LO271510.

Figures 1 and 2 are graphic presentations of candidate oil performance compared to baseline reference data.

| Oil Code: LO271510 | E.O.T. Date: December 1, 2011 |
|---|---|

## Appendix

### Tables

**TABLE 1: JDQ-96 DURABILITY TEST RESULTS 1,000 CYCLES**
Electrically Powered Test Stand

SwRI Oil Code LO-271510 Sponsor Oil Code LO271510

| Axle Speed (rpm) | Brake Press. (kPa) | TORQUE VARIATION TEST RESULTS (TORQUE and VARIATION in Nm) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Oil Temp. 32°C | | | Oil Temp. 49°C | | | Oil Temp. 60°C | | | Oil Temp. 71°C | | |
| | | Torque | Variation | Temp. | Torque | Variation | Temp. | Torque | Variation | Temp. | Torque | Variation | Temp. |
| 8 | 3831 | 4548 | 2429 | 20 | 5010 | 1890 | 47 | 5021 | 1884 | 59 | 4914 | 1931 | 68 |
| 10 | 3831 | 4597 | 2484 | 21 | 4978 | 2213 | 47 | 4964 | 2215 | 58 | 4878 | 2240 | 68 |
| 15 | 3831 | 4679 | 3085 | 21 | 4981 | 2819 | 46 | 4976 | 2908 | 58 | 4888 | 2943 | 67 |
| 20 | 3831 | 4727 | 3692 | 21 | 4949 | 3679 | 47 | 4932 | 3797 | 58 | 4842 | 3854 | 67 |
| 25 | 3831 | 4738 | 4244 | 21 | 4919 | 4248 | 47 | 4887 | 4409 | 59 | 4819 | 4462 | 68 |
| 30 | 3831 | 4700 | 4171 | 22 | 4853 | 4830 | 48 | 4834 | 4915 | 59 | 4809 | 4918 | 68 |
| 35 | 3831 | 4645 | 3250 | 23 | 4748 | 4079 | 48 | 4772 | 5334 | 60 | 4808 | 5170 | 68 |
| 40 | 3831 | 4593 | 3081 | 24 | 4687 | 3026 | 48 | 4701 | 3010 | 60 | 4802 | 3101 | 68 |
| 45 | 3831 | 4534 | 2982 | 25 | 4683 | 3176 | 49 | 4714 | 3407 | 60 | 4808 | 3248 | 69 |
| 50 | 3831 | 4520 | 2916 | 27 | 4682 | 2930 | 49 | 4719 | 3259 | 61 | 4778 | 3135 | 69 |
| 55 | 3831 | 4471 | 2972 | 28 | 4680 | 3284 | 50 | 4704 | 3040 | 62 | 4742 | 3044 | 70 |
| 60 | 3831 | 4426 | 2926 | 30 | 4671 | 3236 | 51 | 4695 | 2947 | 63 | 4702 | 3110 | 71 |
| 15 | 1532 | 1793 | 2591 | 30 | 1860 | 2639 | 47 | 1918 | 2498 | 58 | 1888 | 2637 | 71 |
| 15 | 2300 | 2700 | 2778 | 30 | 2817 | 2947 | 45 | 2885 | 2635 | 58 | 2828 | 2919 | 64 |
| 15 | 3065 | 3659 | 3147 | 30 | 3834 | 3126 | 45 | 3892 | 2661 | 58 | 3801 | 3231 | 64 |
| 15 | 3831 | 4587 | 3329 | 30 | 4823 | 3393 | 46 | 4742 | 3085 | 58 | 4827 | 3521 | 64 |
| 15 | 4598 | 5586 | 3676 | 30 | 5754 | 3918 | 46 | 5463 | 3293 | 58 | 5794 | 3744 | 65 |
| 15 | 5364 | 6524 | 4234 | 30 | 6697 | 4163 | 46 | 6328 | 3495 | 58 | 6798 | 4170 | 65 |
| 15 | 6130 | 7416 | 3859 | 31 | 7161 | 3855 | 47 | 7029 | 3689 | 58 | 7235 | 4059 | 65 |
| 15 | 7050 | 7888 | 3332 | 31 | 8420 | 2543 | 47 | 8291 | 2731 | 58 | 8262 | 2786 | 65 |

| Temp (°C) | Relative Capacity (Nm) | Torque Variation (Nm) | SwRI Variation (Nm) |
|---|---|---|---|
| 32 | 95,330 | 65,176 | 1,067,069 |
| 49 | 99,208 | 65,992 | 1,057,131 |
| 60 | 98,467 | 65,211 | 1,079,366 |
| 71 | 99,223 | 68,224 | 1,088,670 |
| TOTAL | 392,229 | 264,603 | 4,292,236 |

## TABLE 2: JDQ-96 Electric Initial Test Stand REFERENCE DATA

Candidate Oil Code : LO271510 EOT Date: December 1, 2011
Reference Oil Code : 69X31111M

| | Cycles | Relative Capacity | Torque Variation | SwRI Variation | Average Facing Thickness (millimeters) |
|---|---|---|---|---|---|
| First Reference Run | | | | | |
| 11279 | 1,000 | 329,975 | 160,449 | 2,530,213 | 7.45 |
| | 10,000 | 336,719 | 115,287 | 1,647,685 | 7.23 |
| | 20,000 | 334,984 | 119,314 | 1,755,276 | 7.03 |
| | 30,000 | 335,508 | 119,149 | 1,592,586 | 6.78 |
| | Total | 1,337,186 | 514,198 | 7,525,760 | |
| Second Reference Run | | | | | |
| 11852 | 1,000 | 327,258 | 172,283 | 2,624,608 | 7.42 |
| | 10,000 | 336,696 | 208,440 | 2,732,636 | 7.24 |
| | 20,000 | 339,033 | 152,391 | 2,143,494 | 7.08 |
| | 30,000 | 333,213 | 147,746 | 2,127,478 | 6.94 |
| | Total | 1,336,201 | 680,859 | 9,628,216 | |
| Third Reference Run | | | | | |
| 11663 | 1,000 | 325,464 | 179,529 | 2,696,409 | 7.43 |
| | 10,000 | 340,089 | 146,169 | 2,145,968 | 7.23 |
| | 20,000 | 330,568 | 145,948 | 2,016,724 | 7.07 |
| | 30,000 | 332,713 | 148,011 | 2,001,514 | 6.88 |
| | Total | 1,328,834 | 619,656 | 8,860,614 | |
| Fourth Reference Rur | | | | | |
| 11922 | 1,000 | 325,990 | 179,251 | 2,596,844 | 7.46 |
| | 10,000 | 334,464 | 156,902 | 2,185,176 | 7.31 |
| | 20,000 | 333,886 | 183,892 | 2,437,145 | 7.18 |
| | 30,000 | 339,695 | 147,072 | 2,033,787 | 7.07 |
| | Total | 1,334,036 | 667,118 | 9,252,951 | |
| Fifth Reference Run | | | | | |
| 11175 | 1,000 | 345,076 | 164,630 | 2,569,506 | 7.46 |
| | 10,000 | 355,779 | 117,458 | 1,636,195 | 7.26 |
| | 20,000 | 357,736 | 122,993 | 1,721,073 | 7.09 |
| | 30,000 | 364,928 | 133,050 | 1,799,847 | 6.84 |
| | Total | 1,423,519 | 538,132 | 7,726,620 | |
| Candidate oil | | | | | |
| LO271510 | 1,000 | 392,229 | 264,603 | 4,292,236 | |

**Table 3: History of 1000 cycle reference tests**

Canidate Oil Code: LO271510 EOT Date: December 1, 2011

| Oil Code | Comments | Torque Variation 1000 cycles |
|---|---|---|
| 69X31111M | new piston and backing plate | 160,449 |
| 69X31111M | new piston and backing plate | 172,283 |
| 69X31111M | new piston and backing plate | 179,529 |
| 69X31111M | new piston and backing plate | 179,251 |
| 69X31111M | new piston and backing plate | 164,630 |
| 69X31111M | new piston and backing plate | 194,668 |
| 69X31111M | new piston and backing plate | 183,301 |
| LO271510 | new piston and backing plate | 264,603 |

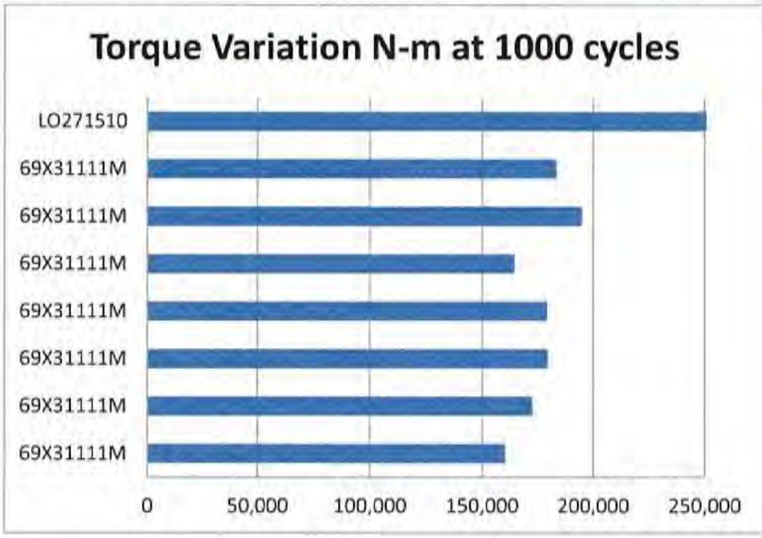


Figure 1

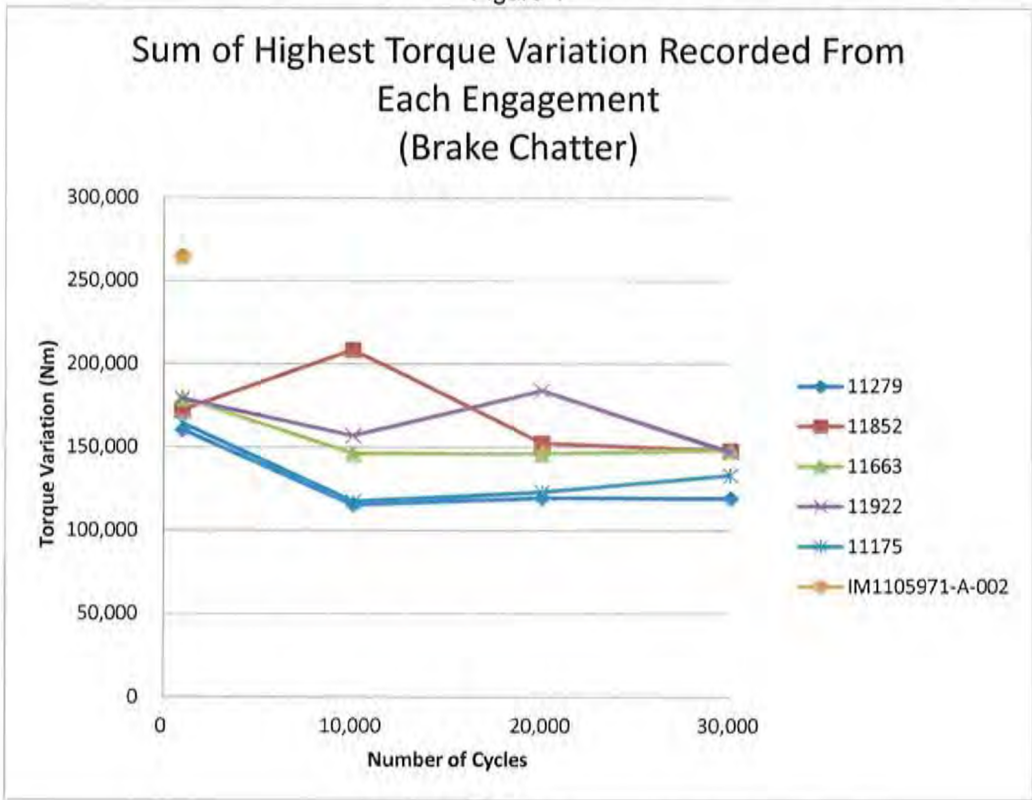
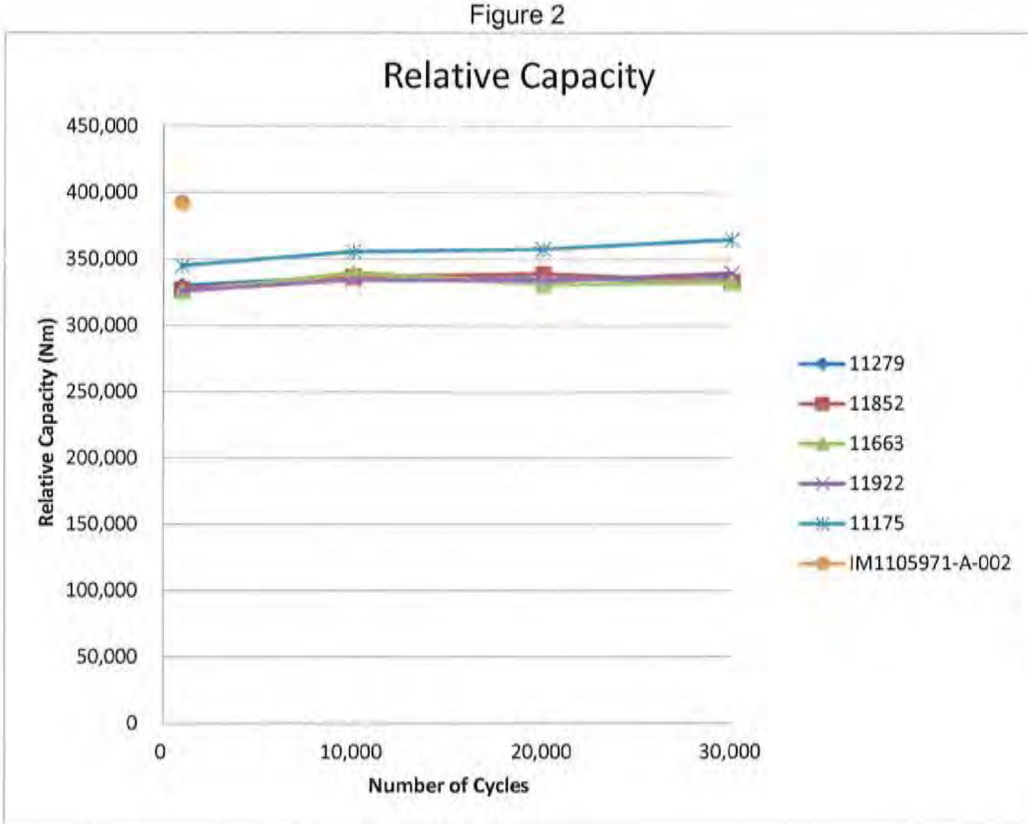



Figure 2



# APPENDIX G
# GEP 6.5L(T) TEST FUEL

**Test Fuel Description:**

Fuel used for engine durability testing was blended on site from commercially available Jet-A. To ensure that fuel lubricity impacts would have a minimized role on fuel system degradation resulting in reduced engine performance, a double max treat rate of lubricity additive DCI-4A was used during blending. The remaining two additives utilized in JP8, anti-icing and anti-static, were not used in the test fuel blend, as they have little to no impact on the fuel used in this application. Table G1 below shows the certificate of analysis (COA) for the Jet-A as purchased for blending. Table G2 shows the resulting fuel lubricity values after the double max treat rate of DCI-4A was successfully blended into the test fuel.

**Table G1 – JET-A Certificate of Analysis**

Alcor PetroLab, L.L.P.

20 Laboratory Road, Floresville, Texas 78114 Telephone 830-216-3113 www.alcorpetrolab.com

NuStar
San Antonio Products Terminal
P. O. Box 241017
San Antonio, Texas 78224-1017

February 22, 2010

Sample Type: Jet A
Tank Number.: 103
nt @ 1600 02/21/10 pu @ 0600 02/22/10

Sample Date: 02/22/10
Sample Time: 630

| **Volatility** | **Method** | **Specification** | | **Result** |
|---|---|---|---|---|
| Initial Boiling Point (°F) | D 86 | | | **320.0** |
| Distillation 10% Rec (°F) | | 400 | max | **334.4** |
| Distillation 50% Rec (°F) | | Report | | **365.9** |
| Distillation 90% Rec (°F) | | Report | | **415.4** |
| Distillation 95% Rec (°F) | | Report | | **433.4** |
| Distillation Final BP (°F) | | 572 | max | **459.5** |
| Distillation Recovery (vol %) | | | | **98.9** |
| Distillation Residue (vol %) | | 1.5 | max | **0.9** |
| Distillation Loss (vol %) | | 1.5 | max | **0.2** |
| Flash Point, Tag Closed (°F) | D 56 | 100 | min | **121.0** |
| API Gravity @ 60 (°F) | D 1298 | 37.0 / 51.0 | | **45.8** |
| Cetane Index | D 4737 | 40.0 | min | **41.3** |
| Particulate Matter Mgs/Gal | D 2276 | 3.0 | max | **0.8** |
| Sulfur Wt % | D 7220 | 0.30 | max | **0.0001** |
| Copper Strip | D130 | No. 1 | max | **1A** |
| Existent Gum Mgs / 100 Mls. | D381 | 7 | max | **<1.0** |
| **Fluidity** | | | | |
| Freezing Point (°F) | D 2386 | -41.0 | max | **-76.9** |
| **Contaminants** | | | | |
| Color (Saybolt) | D 156 | +15 | min | **+30** |
| Appearance | D4176 | clear/bright | pass/fail | **Pass** |
| Water Reaction: Change | D 1094 | 2.0 | max | **0** |
| Water Reaction: Interface Rating | D 1094 | 2 | max | **1** |
| Water Reaction: Separation Rating | D 1094 | 2 | max | **1** |
| MSEP | D 3948 | 85 | min | **99** |

This Product Conforms to ASTM D1655 for the Above Tests: XX YES ____ NO

Reviewed and submitted by,

Chris Taylor CEO

Report Number: P022210A

**Table G2 – JET-A Lubricity Test Results**

| Property | ASTM | Result |
|---|---|---|
| Scuffing Load BOCLE | D6078 | 3450 |
| BOCLE | D5001 | 0.5 |
| HFFR | D6079 | 0.69 |