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DEFENCE RESEARCH ESTABLISHMENT OTTAWA
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ABSTRACT

This report describes the results of the performance evaluation of a Honeywell GG1308 miniature Ring Laser Gyroscope (RLG). The tests include turn-on and cold start, bias drift, scale factor, scale factor linearity, thermal transients and effects of dither compensation.

The gyroscope demonstrated excellent high-rate performance although significant scale factor deviations were noted during temperature variations. Instrument design characteristics and areas of potential future investigation are also discussed.

RÉSUMÉ

Ce rapport décrit les résultats de l'évaluation du rendement d'un gyroscope à laser miniature, le modèle GG1308 de Honeywell. Les essais effectués incluent: la mise en marche initiale, la dérive de la polarisation, le facteur d'échelle, la linéarité du facteur d'échelle, les effets transitoires et les effets de la compensation des perturbations.

Le gyroscope a demontré un excellent rendement lors d'essais à haut taux de changement anulaire et ce, malgré les déviations importantes du facteur d'échelle observées lors de variations de température. Les caractéristiques de conception de l'instrument et les possibilités d'études futures sont aussi discutées.

EXECUTIVE SUMMARY

A Honeywell GG1308 miniature Ring Laser Gyroscope was evaluated in the DREO Inertial Navigation Laboratory for possible application in the design and development of a Low-Cost Attitude and Heading Reference System (LCAHRS) for drone/RPV and helicopter applications. The original LCAHRS concept was derived from a study conducted by Honeywell ATC in Canada for DREO. The purpose of the study was to investigate the AHRS requirements of several RPV's and other UAV's and, through simulation, evaluate the potential of the newly-developed Honeywell GG1308 gyroscope to meet these requirements. A GG1308 gyroscope was procured by DREO for in-house evaluation for comparison with predicted performance.

The Honeywell GG1308 is a single-axis Ring Laser Gyroscope (RLG) featuring an equilateral triangular glass block of 0.8 inch per leg (a total laser effective path length of 2.4 inches). The instrument construction employs simple, inexpensive techniques intended to produce a low performance instrument for stabilization and control applications where low cost and small size are required. A GG1308 gyroscope was delivered to DREO in mid-1990 and evaluations were carried out from November 1990 to April 1991.

Results of the testing showed that instrument performance at high angular rates was better than specifications although significant scale factor deviations were noted during temperature variations. This deviation may limit applications to lower-accuracy systems unless temperature compensation is employed. The gyroscope met most performance specifications over a rate range of ±1000 deg/sec.

Areas of future interest include characterization of low rate performance and performance in a vibration environment.

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1.0 INTRODUCTION

1.1 BACKGROUND

This report describes the results of the performance evaluation of a Honeywell GG1308 miniature Ring Laser Gyroscope (RLG). This instrument was developed for use in low-cost, non-precision applications. In particular, DREO was interested in the development of a Low-Cost Attitude and Heading Reference System (LCAHRS) for drone and Remotely Piloted Vehicle (RPV) applications. A paper study was conducted for DREO by Honeywell Advanced Technology Centre (ATC) in Canada investigating LCAHRS requirements for various vehicles. The Inertial Navigation Laboratory at DREO was then used to evaluate a GG1308 gyroscope to determine suitability for the LCAHRS application.

This report describes the gyroscope design, test facilities, test procedures and the results obtained.

1.2 THE HONEYWELL GG1308 GYROSCOPE

The Honeywell GG1308 miniature ring laser gyroscope (RLG) is a single-axis angle sensor consisting of a ring laser assembly, a dither motor and gyro-critical electronic circuitry all contained within a sealed housing. A drawing of the ring laser assembly is shown in Figure 1-1. [1]

It features an equilateral triangular glass block of 0.8 inch per leg (hence the Honeywell designation 1308; the last two digits being the leg length, in inches, of the laser cavity). On the glass block, made of a material designated BK-7, are mounted one path length control (PLC) transducer mirror, a readout wedge mirror and a curved mirror. In addition, there are three electrodes (two cathodes and one anode/fill tube) attached to the block with glass frit seals. The block cavity is filled with a mixture of Helium and Neon gases and is operated on the 0.6328 μm transition of Neon.

After cold-weld pinchoff of the fill tube electrode, a PLC driver is bonded to the transducer mirror, a PLC sensor is attached to the curved mirror and a readout sensor is attached to the readout wedge mirror. A microcircuit temperature sensor, a start-assisting, high-intensity light emitting diode and an interconnect Printed Wring Board (PWB) are mounted to the glass block. The ring laser assembly has an effective path length of 2.4 inches and is mechanically dithered about its input axis to minimize the non-linearities of lock-in at low input rates.

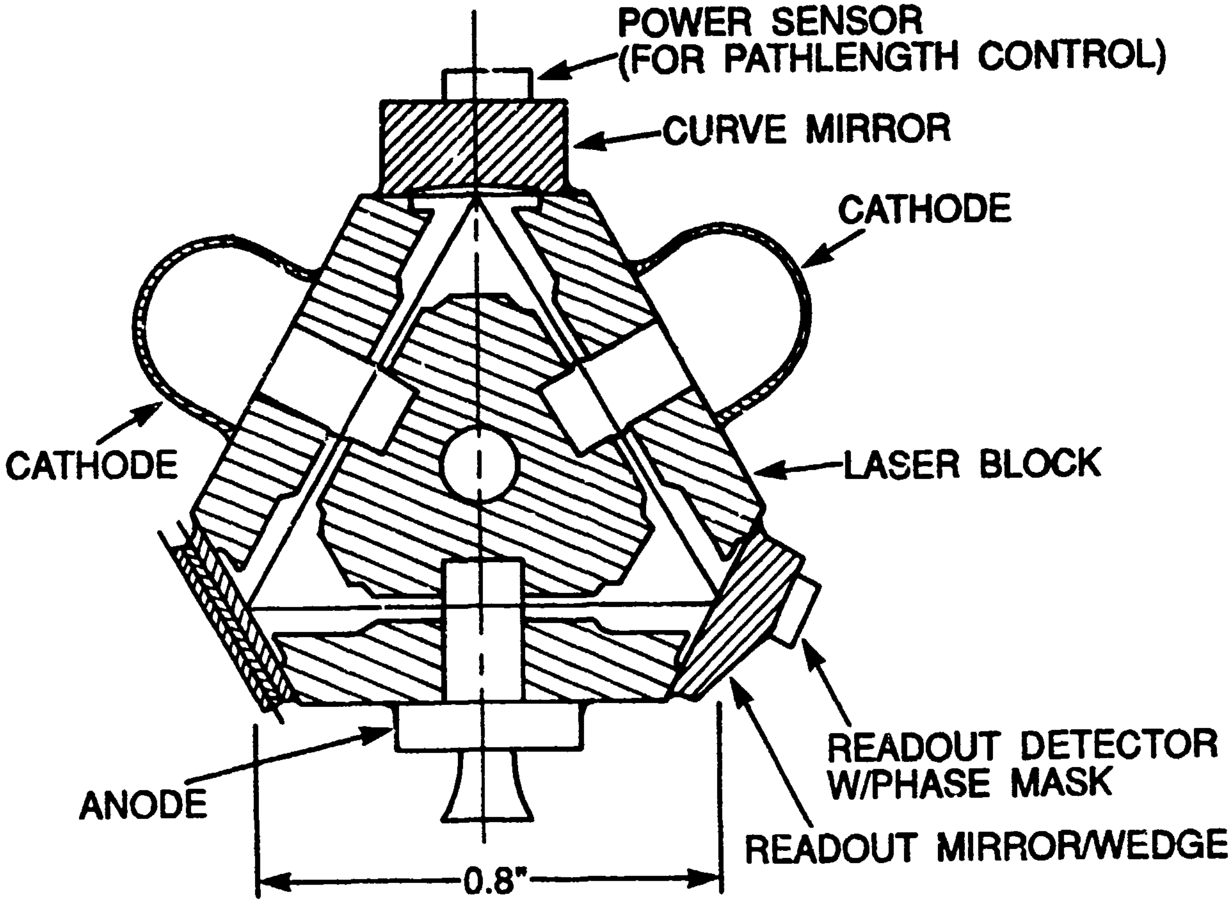

FIGURE 1-1 GG1308 RING LASER GYRO ASSEMBLY

The GG1308 gyroscope is unique in several ways in that it is a low performance instrument designed for stabilization and control applications where low cost and small size are required. The instrument design was totally cost-driven with the expressed intent of a final cost of less than $1,000 in production quantities. To achieve this, several innovative technologies have been employed and will be briefly described here because they impact upon the final performance of the gyroscope and results will be related back to these technologies later in this report.

In the past, gyro blocks have been made of a material with a very low coefficient of thermal expansion, such as Zerodur or Cervit glass ceramics, and components such as the mirrors and electrodes have been sealed to the block by precision polishing and bonding techniques.

The glass-frit technology permits small low-performance gyros to be made at far lower cost. Glass-frit bonding allows for the use of materials with large coefficients of thermal expansion. The frit process is used to seal the mirrors and electrodes to the solid BK-7 glass laser block. These parts are pasted to the glass block with a fine glass powder in a liquid or paste binder, and held mechanically in place. The assembly is then heated to a very high temperature. The binder evaporates and the glass powder melts, producing a strong vacuum-tight seal. As a result, a major concern is the performance of this gyro when it is subjected to temperature variations. The scale factor will vary with temperature because the gyro block expands as the temperature increases thus changing the laser path length. This effect is much larger in the GG1308 than in gyro models made of low-expansion materials. Resulting performance must be enhanced by thermal modelling and data compensation.

1.3 GG1308 PERFORMANCE SPECIFICATIONS

Performance specifications for the Honeywell GG1308 ring laser gyro are contained in Table 1-1. Note that the operating life, specified as ≥2000 hrs, is defined as "time during which the gyro is economically repairable"

A photograph of the gyroscope is shown in Figure 1-2.

1.4 SUPPORT ELECTRONICS

In addition to the gyroscope and it's internal electronics, a substantial amount of support electronics and data processing is required to obtain useable "inertial" data from the device.

Specification	
• Bias Stability:	1°/hour
• Random walk:	0.125°/$\sqrt{}$hour
• Resolution:	11.17 arc secs/pulse (2.79 arc secs/pulse available)
• Scale factor	
- Value:	116,000±200 pulses per revolution
- Error, all causes:	50 ppm (1σ)
• Input axis	
- Alignment:	2 mradians
- Repeatability:	50 μradians (1σ)
• Rate capability:	±1000°/second
• Bandwidth:	>500Hz
• Mechanical dither frequency:	900Hz min, 1550 Hz max
• Starting time:	<500 mseconds
• G-sensitive drift:	Inherently insensitive to acceleration effects
• Acceleration:	>100g sustained
• Operating temperature:	-65°F to +180°F
• Signal outputs:	Digital pulses for clockwise and counterclockwise rotation
• Shelf life:	>10 years
• Operating life:	≥2000 hrs*
Size, Weight and Power	
Ring Laser Gyro	
• Length:	1.5 inches
• Diameter:	1.6 inches
• Weight:	2.3 ounces
• Sensor power:	0.9 watts
Sensor electronics	single axis (packaged to requirements)
• Volume:	<2 cubic inches (typical)
• Board area (surface mount):	4 square inches
• Weight:	2.5 ounces (typical)
• Input power:	2.3 watts (including sensor)

* Repairable Life

TABLE 1-1 GG1308 PERFORMANCE SPECIFICATIONS [2]

FIGURE 1-2 HONEYWELL GG1308 RING LASER GYROSCOPE

A block diagram of the test concept, as designed by Honeywell Inc, is shown in Figure 1-3. Note that the GG1308 is connected directly to a Remote Interface Card which provides interface to the Gyro Run Box (the complete power supply) as well as to the Data Scan Box (DSB) through a breakout panel. The DSB provides all of the Honeywell-designed data signal manipulation to provide pulse count outputs from the gyroscope. It is significant to note that all of this additional support electronics is necessary to perform evaluation on the GG1308 gyroscope. User documentation is supplied by Honeywell but the user is intended to treat it all as a 'black box', the actual processing details being proprietary to Honeywell.

This resulted in several problems during testing and evaluation of the GG1308 and these will be described in the following sections since they are very significant to the test results.

Briefly, the function of each portion of the test set-up will first be described. The Remote Interface Card controls the high voltage for the gyro from the Gyro Run Box which acts as the turn-on/off controller. This card also contains the circuitry to condition the gyro signal prior to being input to the Data Scan Box. The Gyro Run Box also allows dither protection to be turned on or off as well as containing status indicator lights for operator monitoring. The Data Scan Box (DSB) is the most complex (and least understood) portion of the test system. The DSB act as a data station and is designed to measure the performance of the GG1308 gyro by accurately providing the accumulated gyro counts and corresponding time intervals. It also has the additional capability of reporting up to 15 analog voltage signals through an A/D converter for monitoring purposes. It consists of a 4 MHz Motorola 6809 microprocessor with an accumulator, A/D converter, precision oscillator, power supply and CRT terminal.

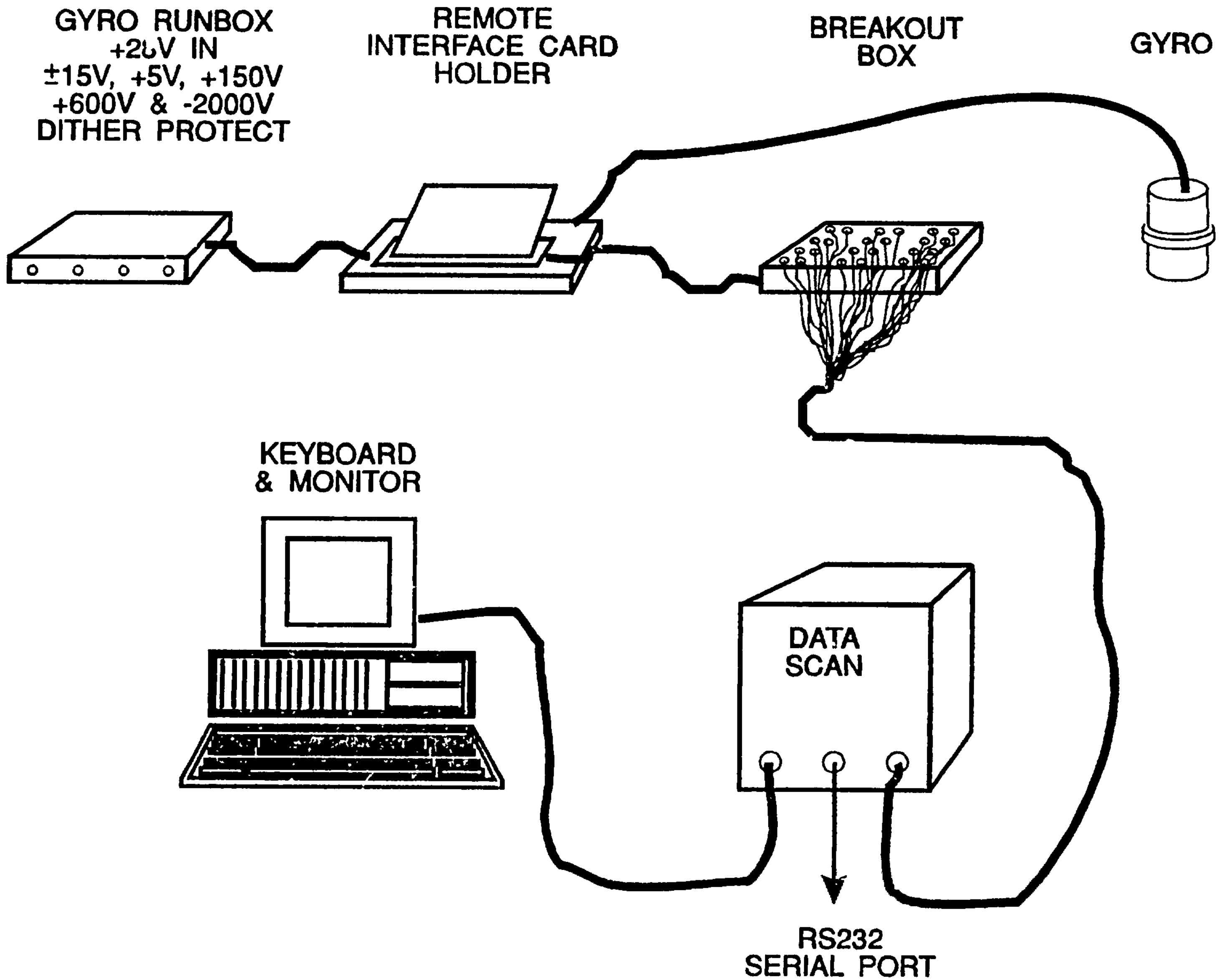

FIGURE 1-3 GG1308 GYRO TEST CONCEPT

2.0 GG1308 DATA OUTPUT DESCRIPTION

2.1 OUTPUT FORMAT

As previously illustrated in Fig 1-3, the RLG I/O is controlled via the Honeywell-designed remote electronics interface card and the Data Scan Box (DSB). [3] This configuration does not permit any user control over the RLG functional or processed data output other than what is allowed by the DSB firmware. This output data is then passed via the RS232-C interface to a video monitor and/or a host computer.

The data format as displayed by the monitor, Fig 2-1, is divided into five status areas. Line one at left provides time of day and at far right is the current RLG count for the invoked strobe format. The second area is labelled "AN:1 to AN:24" and provides up to 24 analog status signals for monitoring the RLG's operational performance. The five parameters typically displayed are:

a) Light Intensity Monitor - LIM,
b) Path Length Controller - PLC,
c) Laser Current - I/Ok,
d) Analog Dither Signal, and
e) Temperature in °K/100.

The next area is two command lines of user I/O for interactive communication with the DSB to provide the various test format configurations. The fourth area is eight lines of the most current strobed event time periods and RLG net count information. The final display line provides the current DSB configuration status.

An external strobe was established between the Contraves motion simulator (described in Section 3) and the DSB to provide RLG counts per revolution. The motion simulator TTL trigger pulse was used as an input to a differential line driver to yield this synchronization signal.

2.2 DATA RECORDING

A second RS232-C communications port on the DSB allows the time stamp, gyro count, and analog data sent to the monitor to be simultaneously transmitted to the host computer. If dither compensation is invoked, then the dither offset is included in this ASCII data string.

```
00:00:00          MODULAR  DATA  STATION  R 5.00          xxxxxxxxxx
--------------------------------------------------------------------
       CURRENT   MAX   MIN                    CURRENT   MAX   MIN
--------------------------------------------------------------------
AN  1:                        AN 13:
AN  2:                        AN 14:
AN  3:                        AN 15:
AN  4:                        AN 16:
AN  5:                        AN 17:
AN  6:                        AN 18:
AN  7:                        AN 19:
AN  8:                        AN 20:
AN  9:                        AN 21:
AN 10:                        AN 22:
AN 11:                        AN 23:
AN 12:                        AN 24:
--------------------------------------------------------------------
Press "ESC" to start a new command

--------------------------------------------------------------------
00:00:00.000000         0
00:00:10.000000         0
00:00:20.000000         0
00:00:30.000000         0
00:00:40.000000         0
00:00:50.000000         0
00:01:00.000000         0
00:01:10.000000         0
STROBE:  10.0 SECS, COM:LOC, CRT:96 HST:96, ANLGS:0, GYROS:1, DCOMP:OFF
```

FIGURE 2-1 SAMPLE DISPLAY

The host data was received by the Navlab PDP 11/73 computer via a 9600 baud serial link. A software routine called LOGRLG was established to handle the communication protocol and to parse the ASCII data string into a raw RLG data file logged on the hard disk. For further data reduction, the raw data files were moved to an IBM PC for processing.

A software routine called MODRLG was developed for the PC to provide preliminary data review. The data output was formatted to provide elapsed time, sample period, dither compensated sample period, dither offset, table rate, RLG net counts, and the five analog data channels discussed earlier. Also included is a brief data summary which includes maximum, minimum, range (peak to peak), mean, standard deviation, percent standard deviation, percent peak to peak deviation, and number of samples.

All further data reduction and plotting was carried out by the BBN software package RS/1. [4]

A brief explanation of data file names is necessary to minimize confusion when reviewing the data contained in this report. The generic code AA[A]DDDYYZ.EXT renders the basic format for the data file names. "A's" represents the alpha numeric characters of the data file types;

BD - bias drift,
SF - scale factor (cnts/rev, table triggered),
RS - rate stability (time base strobed),
SFL - scale factor linearity.

"D's" represent the Julian day of the year and "Y's" the year. "Z" is an alpha numeric character representing the number of experiments of that type executed on a given Julian day. The 'EXT' is the extension attached to a particular data file ie.. RLG, RL2, and RCA as it moves through the various data reduction routines.

2.3 GRAPHICAL REPRESENTATION

Figure 2-2 shows graphical representations of typical raw gyro outputs. The family of graphs (a) thru (e) illustrate the RLG counts and analog parameters for a bias drift test that includes local Earth rate with strobing at a nominal 10 seconds. The initial part of the traces show the RLG turn-on transient with a RLG Count settling time of approximately one minute. One should note that it takes more than five minutes for the temperature and the PLC controller to settle. Three PLC shifts occur during this turn-on temperature transient. Even though the RLG fixture is temperature controlled to better than 0.1°C it is shown in Fig. 2-2e that after turn-on the internal temperature of the RLG rises by 4 to 4.5°C before settling out.

Figure 2-2f is an example of RLG count stability at 50°C with an input rate of 100 degrees per second. The counts were strobed every 10 revolutions and the rate table was positioned to eliminate local Earth rate input. The data set shows an average relative scale factor deviation of 21 ppm with a standard deviation of ±9 ppm for this test period.

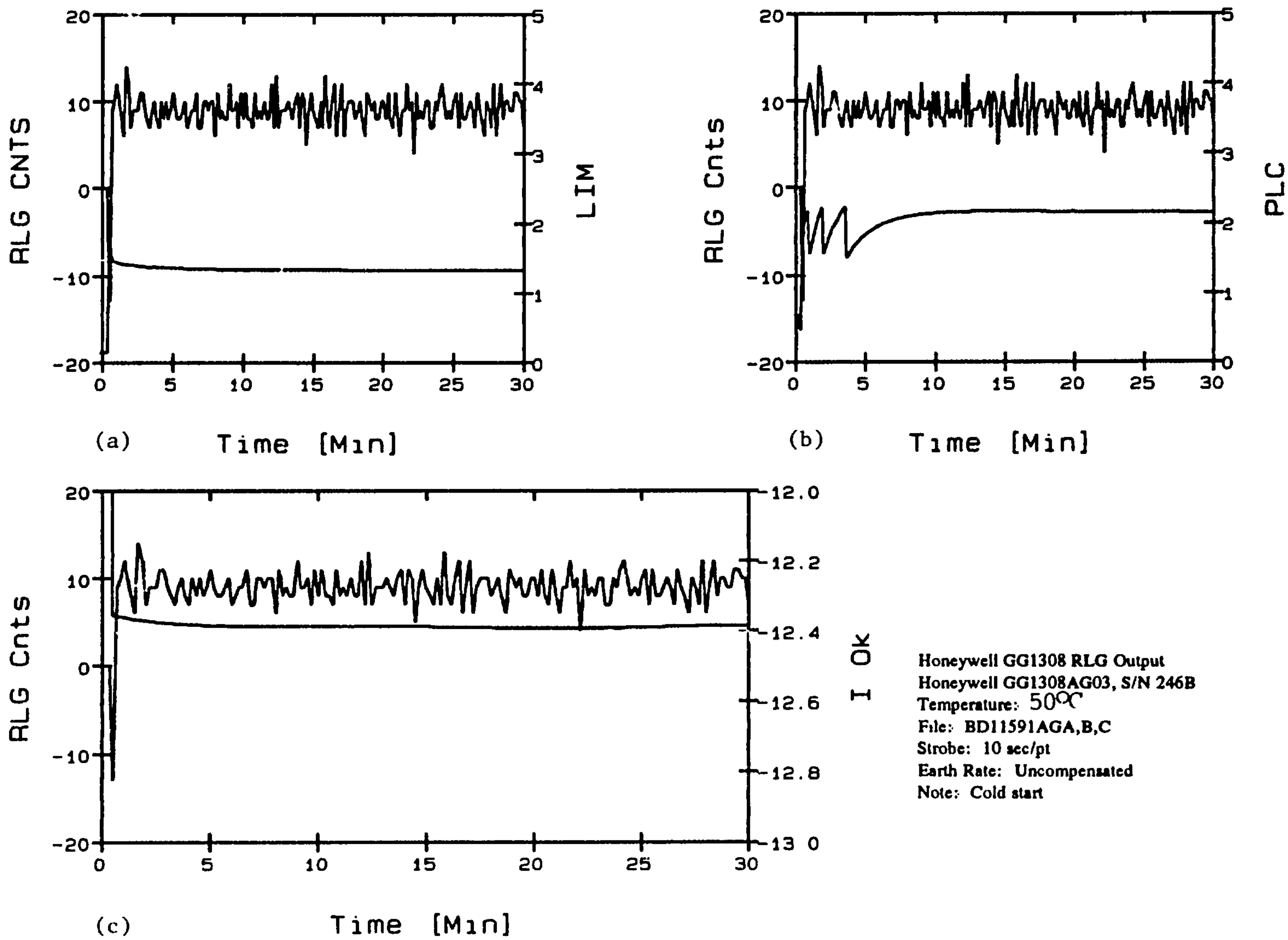

FIGURE 2-2 TYPICAL OUTPUT DATA

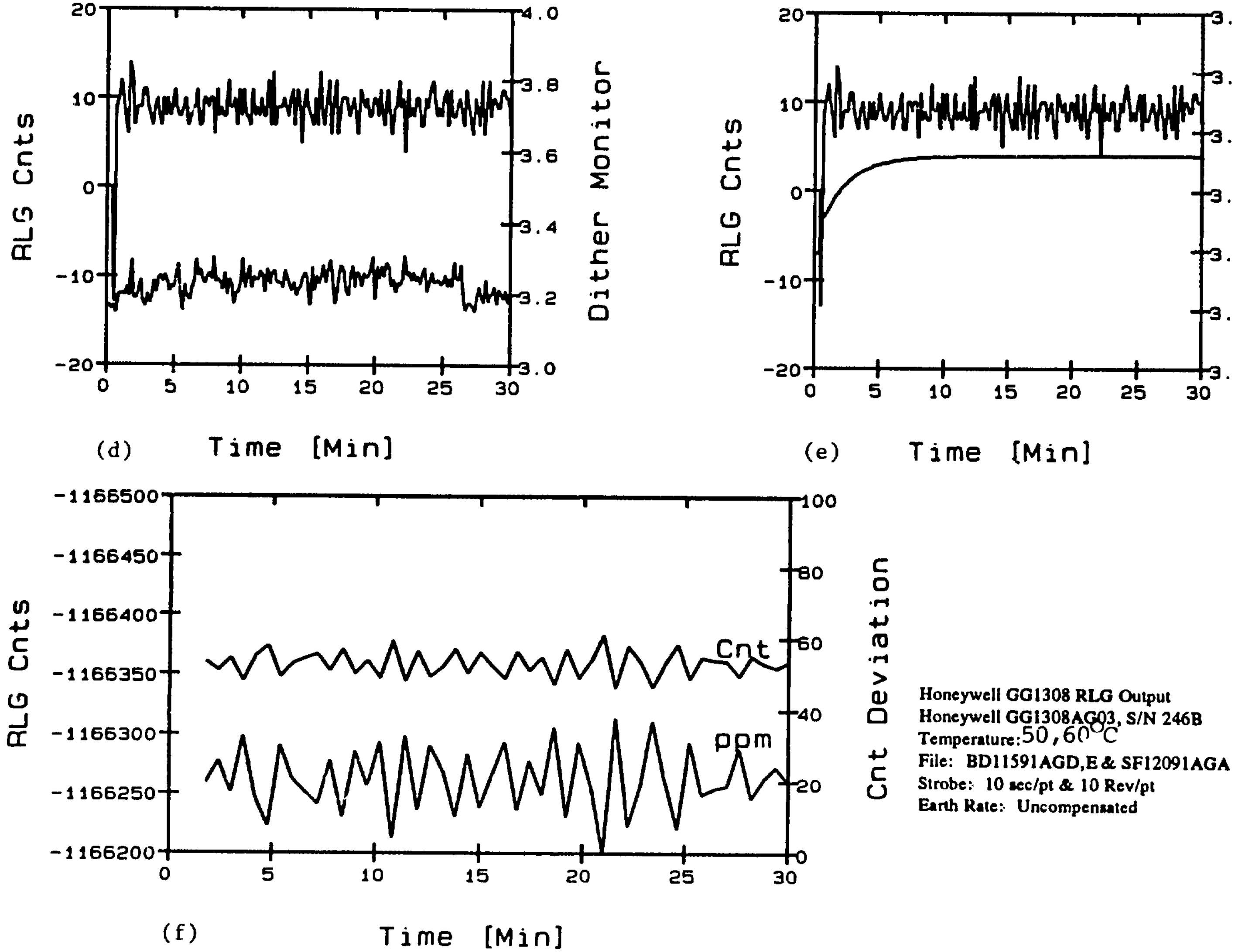

FIGURE [illegible] (continued)

3.0 DREO TEST FACILITY

3.1 DREO INERTIAL NAVIGATION LABORATORY

The DREO inertial navigation laboratory was designed to be a highly versatile and flexible facility for the evaluation and development of inertial components and systems. The core of the facility is a Contraves-Goerz Model 57CD 2-axis motion simulator capable of highly precise position, rate and acceleration about both axes. Maximum rates of ±1000 deg/sec are possible. Data acquisition and table control are accomplished through a PDP-11/73 computer via IEEE-488 interfaces to all instrumentation.

A photograph of the laboratory is shown in Figure 3-1.

Details on test equipment and laboratory capabilities are contained in DREO Report #825. [5]

3.2 TEST FIXTURING AND ALIGNMENT

Figure 3-2 shows the GG1308 in its mounting fixture with the top cover removed. This fixture contains heaters for precise temperature control. The circuit board behind the gyro is the Remote Interface Card with the table top breakout box in the foreground.

Figure 3-3 is a photograph of the table top configuration. Note the upper level table top which holds the Gyro Run Box. This second level was necessary due to lack of adequate table-top space on only one level.

The Data Scan Box was mounted in an instrument rack, remote from the table.

Gyroscope alignment was performed by a 'tip and tilt' fixture upon which the gyroscope fixture was mounted.

Temperature of the gyroscope was controlled to ±0.1° Celsius.

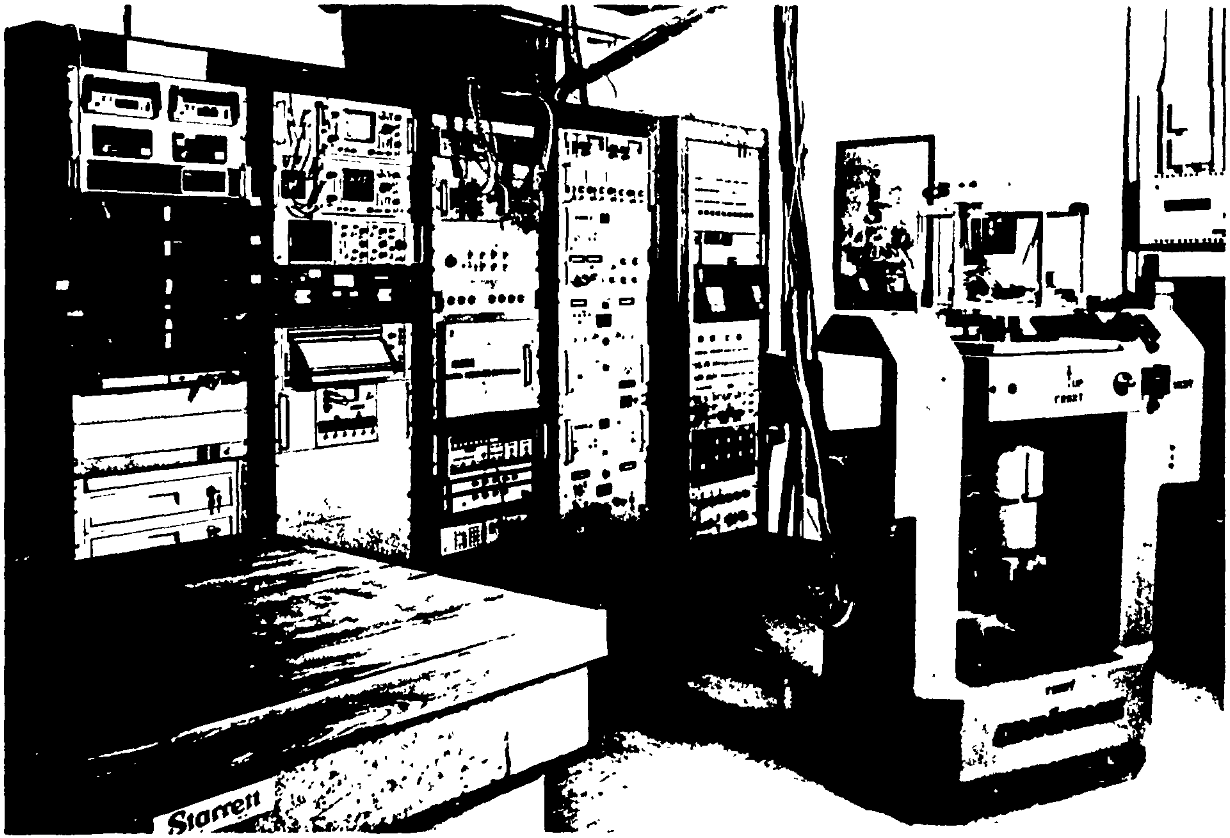

FIGURE 3-1 DREO INERTIAL NAVIGATION LABORATORY

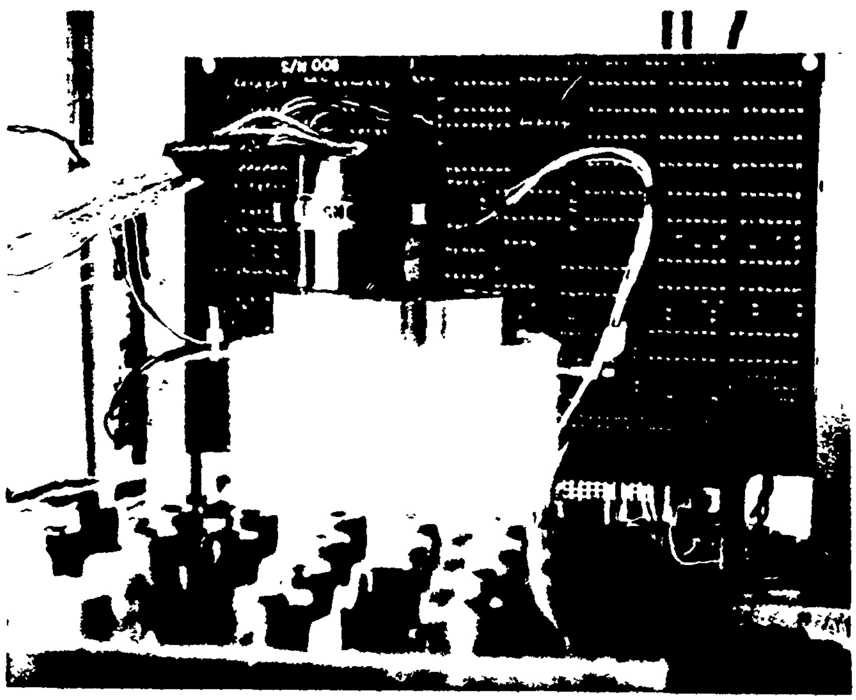

FIGURE 3-2 GG1308 MOUNTED IN TEST FIXTURE

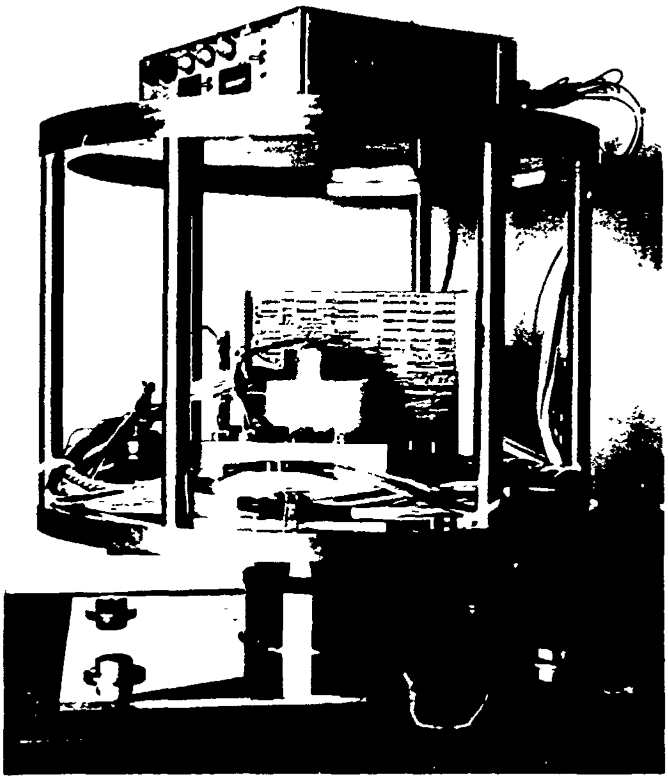

FIGURE 3-3 GG1308 TABLE TOP CONFIGURATION

4.0 TEST PROGRAM

4.1 HISTORICAL

A formal test program was planned and organized for the Honeywell RLG GG1308, S/N 173B. The program included turn-on, cold start, scale factor stability and linearity, repeatability, thermal transient, and dither compensation tests. These terms are defined by the IEEE Standard Specification Format Guide and Test Procedure for Single-Axis Laser Gyros (IEEE Std 647-1981). Procedures are as defined in Section 4.2. Even though this test program was completed, a large portion of the data was compromised by a hardware configuration error discovered on the remote interface card. The board was delivered with the pseudo random noise generator shorted out. This circuit assists the dither motor amplitude signal in providing an improved compensation for laser lock-in at very low RLG input rates. Portions of the data acquired from these tests are, however valid, particularly high rate tests, and are included in the results.

Eventual failure of RLG S/N 173B caused a restructuring of the test program using another gyroscope obtained from Honeywell under a lease agreement for a limited time period. This was RLG S/N 246B. With the time available a reduced test program format was arranged and executed on the new instrument as per table 4.1.

4.2 TEST PROCEDURES

4.2.1 Turn-On/Cold Start

The turn-on discussed here is for the laser only, as indicated by the RLG count output. The "gyro run box" 28 VDC input is on (500 mA) and stabilized. The RLG output is initiated by laser turn-on (850 mA). The turn-on time is the time taken for the RLG output to reach the stabilized mean for the test type, i.e. bias drift or scale factor.

Cold start is defined as the time required for the RLG to reach operational temperature from a given ambient condition.

4.2.2 Bias Drift

Bias drift was determined by recording the RLG static output strobed at 10 second intervals over periods ranging from 2 to 8 hours. These measurements were made both with

GG1308AG003 Test Summary
Serial No. 246B

File Name	Temp °C	Smp Rate	No. of Smp	ER Status	Notes
BD08691A	40	10 s/Pt	2880	LER	
BD10091A	40	5 s/Pt	250	LER	
BD10091B	30.5	10 s/Pt	2880	Zero ER	
BD10191A	25.6	10 s/Pt	2880	LER	
BD11291A	40	10 s/Pt	1440	LER	
BD11491A	40	60 s/Pt	240	LER	
BD11591A*	40	10 s/Pt	1080	LER	
BD11991A	40	10 s/Pt	1440	Zero ER	
BD11991B	50	10 s/Pt	1440	Zero ER	
BD12091A	60	10 s/Pt	720	Zero ER	
BD12091B	41	10 s/Pt	1440	LER	
DIT08791A	40	Pt/1000 cyc	180	LER	A = 11 Cnts
DIT10091A	40	Pt/10000 cyc	30	LER	A = 49 Cnts
DIT11491A	40	Pt/10000 cyc	80	LER	A = 56 Cnts
DIT12191A	41.2	Pt/10000 cyc	60	LER	A = 49 Cnts
SF08791A	40	Pt/10 Rev	20	LER	+100 D/S
SF10191A	25.3	Pt/10 Rev	100	LER	+100 D/S
SF10191B	25.4	Pt/10 Rev	100	LER	-100 D/S
SF11591A	40	Pt/100 Rev	160	LER	+100 D/S
SF11691A*	40	Pt/3 Rev	1080	LER	+100 D/S
SF12091A	50	Pt/10 Rev	720	Zero ER	+100 D/S
SF12091B	60	Pt/10 Rev	200	Zero ER	+100 D/S
SFL11291A	40	Pt/Rev	40	LER	±1 to 100 D/S
SFL11391A	40	Pt/10 Rev	10	LER	± 100 to 1000 D/S
SFL11391B	40	Pt/10 Rev	20	LER	± 560 to 740 D/S
SFL11391C	40	Pt/Rev	40	LER	± 1 to 100 D/S
SFL11491A	40	1/Rev	40	LER	± 1 to 100 D/S
SFL11591A+	40	Pt/10 Rev	16	LER	± 100 to 1000 D/S
SFL11691A	40	Pt/Rev	40	LER	± 0.25 to 16 D/S
S/N 246B#	RT			Zero ER	± 100 to 1000 D/S

Legend:
* Cold start
\+ Exp't set up to repeat 3 times.
\# Honeywell data
LER Local Earth Rate

TABLE 4-1

and without local earth rate input. For reference purposes, all tests were carried out at least once with the RLG fixture/case temperature controlled at 40.0°C (the nominal operating temperature).

4.2.3 **Scale Factor**

The scale factor was resolved from data accumulated during logging of the RLG output as a function of the motion table rotation. The motion table furnishes a trigger pulse at each revolution which is used as an external strobe for the DSB. One data point per 10 revolutions was collected at a rate of 100 degrees per second to provide the raw data to calculate the RLG scale factor.

4.2.4 **Scale Factor Linearity**

Scale factor linearity is a programmed series of scale factor tests over a specified rate range. The rate range was divided into three areas for this test plan, ±0.25 to 16, ±1 to 100 and ±100 to 1000 degrees per second (o/s).

Using the ±100 to 1000°/s rate range as an example, the test format is as follows: The strobe is set to give a data point per 10 revolutions and a minimum of 10 data points are collected at each rate. Data for the "even" clockwise rates is measured up to 1000°/s followed by the "odd" clockwise rates and repeated in the same manner for the counter clockwise rates. This unique stepping format is used to insure that there is no systematic or hystereris error. A delay greater than twice the sample time for a data point is programmed to ensure the data collected has been stabilized at the appropriate test rate.

4.2.5 **Thermal Transient**

The RLG and fixture are thermally stabilized at a given temperature with a minimum of 30 minutes of data collected before the temperature controller is set for the next thermal plateau. Data logging via the DSB continues during the temperature transient and for a minimum of 30 minutes afterwards. This procedure is valid for both static, bias drift, and dynamic, or rate type, tests.

4.2.6 **Dither Compensation**

A brief description of dither and dither compensation is necessary. The RLG is maintained in constant motion by a piezo electric dither motor. This device provides a sinusoidal rotational input to the laser assembly to keep the counter-rotating light beams from phase locking at low rates. The rotation or dither frequency for this instrument is ≈ 1250 Hz. (period = 800 microseconds) with an amplitude of ≈ 600 arc seconds. This implies that the dither-induced RLG counts will cancel if the event strobe is synchronized to a reference point on the dither cycle. The synchronizing is accomplished by delaying the strobe event to the next positive zero crossing of the dither cycle. To compensate, the time stamp for each strobe event is adjusted for the dither-induced delay. The time adjustment is a function of the dither period, 1 to 800 micro seconds.

For this test the RLG output is stabilized for one hour in a drift or rate mode. Then by selecting the dither function, as furnished by the DSB firmware, the setting is fixed to "on" or "off" to illustrate the appropriate case.

4.3 DATA REDUCTION

The in house software routine MODRLG manipulates the DSB time stamp to provide a sample period and dither compensated sample period. With the external table strobe invoked, the sample period thus generated is used as an independent calculation of table rate.

For a static input, the dither-compensated sample period is used to calculate RLG counts per unit time. By then applying the gyro scale factor (ArcS/Cnt), the drift is determined in ArcS/Sec or Deg/Hr. Depending on table position, the local earth rate correction is applied to resolve the RLG bias drift.

Basic statistical mean and standard deviation are used to represent the bias drift or scale factor determinations for a given test set.

Scale factor deviation in parts per million (ppm) is calculated by subtracting the minimum scale factor value from the data set then dividing by the data set's mean, and finally multiplying by one million. The data set thus provided is normalized and relative only to its self.

5.0 TEST RESULTS

5.1 HONEYWELL TEST DATA

Test data provided by Honeywell for both gyroscopes was fairly limited; bias drift and scale factor measurements had been made but there was insufficient data to draw conclusions regarding repeatability and stability. In addition, instrument performance at lower rates (1 to 100 deg/sec) was also of interest to us as discussed previously but no data in this range was available from Honeywell.

Table 5-1 summarizes the data as provided by Honeywell. It should be noted that Bias Drift temperature sensitivity is very small, clearly observable only under very large temperature changes (>30°C).

Parameter	Gyro Serial Number	
	S/N 173B	S/N 246B
Gyro Scale Factor	116440.618	116615.664 counts/rev
Bias Drift	-3.525	-1.728 deg/hr
Bias Stability	0.656	--- deg/hr
Dither Frequency	1211	--- Hz
Dither Amplitude	63	--- counts p-p
Bias Drift Temp. Sensitivity	<.04	--- deg/hr/°F

TABLE 5-1 HONEYWELL TEST DATA

5.2 DREO TEST RESULTS

The tests, as described in Chapter 4.0, were performed between December 1990 and April 1991 on gyro serial numbers 173B and 246B. Prelimary tests included measurement of dither frequency and amplitude.

5.2.1 Turn-On Transient/Cold Start

Figure 5-1 contains two views of a turn-on transient test performed at 40°C. Figure 5-1a is an expanded view of the first 10 minutes after gyro turn-on showing gyro bias drift. The settling time is approximately 40 seconds. Figure 5-1b shows the entire 180 minutes of bias drift and indicates no further settling time from a cold start.

Figure 5-2 illustrates the gyro warm-up time, approximately 8 minutes after turn-on, during which the gyro internal temperature rises 4°C before settling. Instrument bias drift does not change appreciably over this temperature. This 4°C temperature change was observed consistently in all tests after gyro turn-on. The one transient noted on the SFD trace is due to a PLC change caused by the temperature rise.

5.2.2 **Bias Drift**

Figure 5-3 is a 4 hour bias drift test performed at 40°C. Bias drift is -1.80 deg/hr with a standard deviation of 2.3 deg/hr. Over the test period of several weeks, bias drift on this instrument shifted by approximately 1 deg/hr. This is most likely due to instrument aging.

Table 5-2 lists results from several bias drift tests. Note that temperature variations of 10 to 20°C had little effect on bias drift.

No.	File	Temp °C	Strobe Sec/Pt	No. of Points	B-Drift Deg/Hr	Std Dev +/-
1	BD10091A	40.0	5	250	-1.70	3.8
2	BD10091B	30.5	10	2880	-2.20	2.4
3	BD10191A	25.6	10	2880	-1.60	3.3
4	BD11291A	40.0	10	1440	-1.80	2.3
5	BD11491A	40.0	60	240	-1.20	0.5
6	BD11591A	40.0	10	1080	-0.59	2.0
7	BD11991A	40.0	10	1440	-0.87	1.9
8	BD11991B	50.0	10	1440	-0.57	2.0
9	BD12091A	60.0	10	720	-0.61	2.1
10	BD12091A	41.0	10	1440	-0.95	1.9

TABLE 5-2 BIAS DRIFT TESTS

5.2.3 **Scale Factor**

Figure 5-4 is a plot of scale factor and scale factor deviation versus time at a table rate of 100 deg/sec for gyro SIN 246B. Scale factor is 11662F.1 counts/revolution or 11.1125 arc-sec/pulse. The scale factor stability over the three hout test is 143 ppm peak to peak.

The very high noise level for this test has been attributed to the approaching "failure" of this gyro during the test plan. This is discussed at the end of the test results.

5.2.4 **Scale Factor Deviation**

Scale factor deviation over the rate range of zero to 1000 deg/sec was evaluated. The tests were broken into three rate ranges; ±0.25-16 deg/sec (low rate), ±1-100 deg/sec (mid rate) and ±100-1000 deg/sec (high rate) to control the size of accumulated data files.

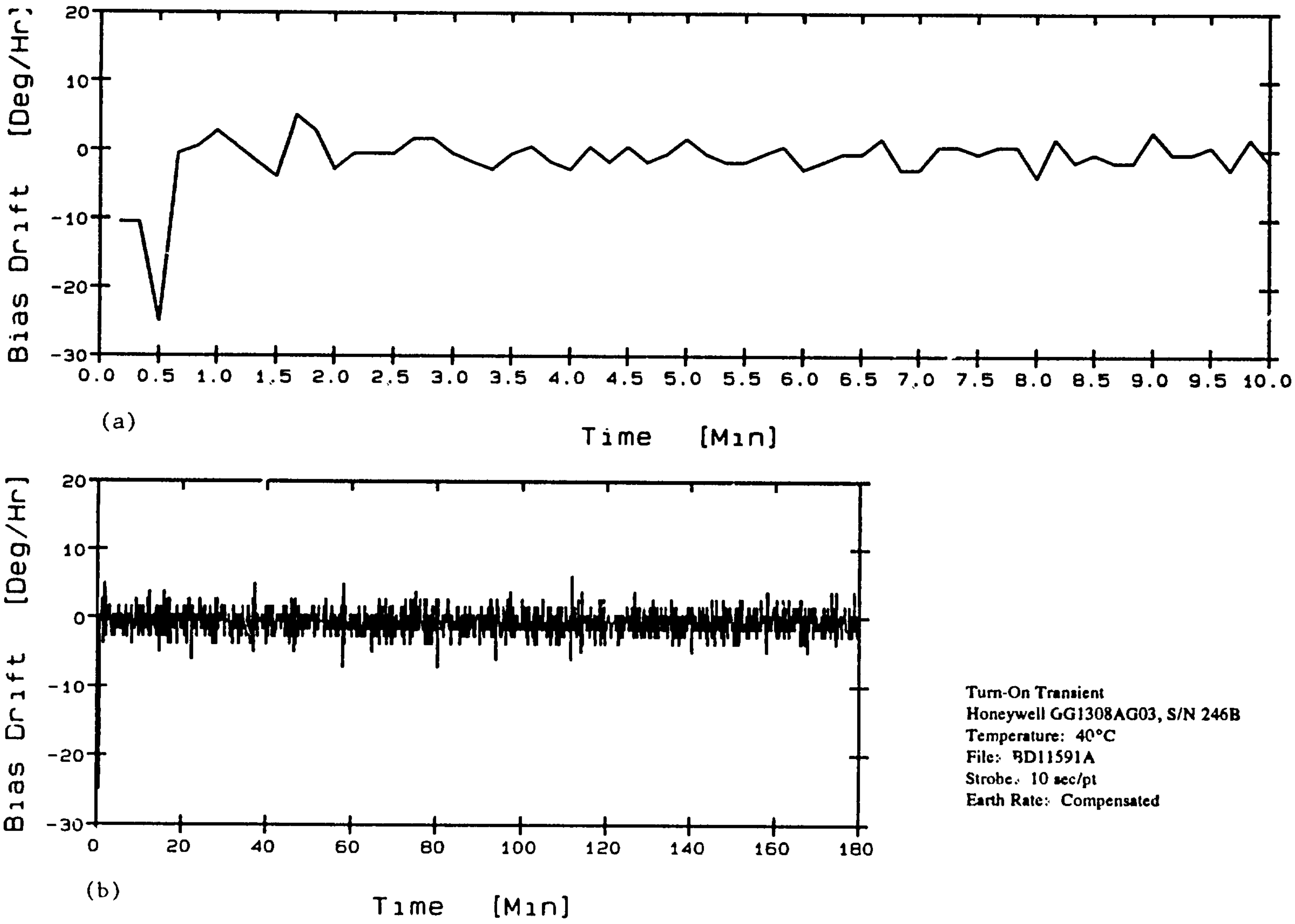

FIGURE 5-1 TURN-ON TRANSIENT/COLD START

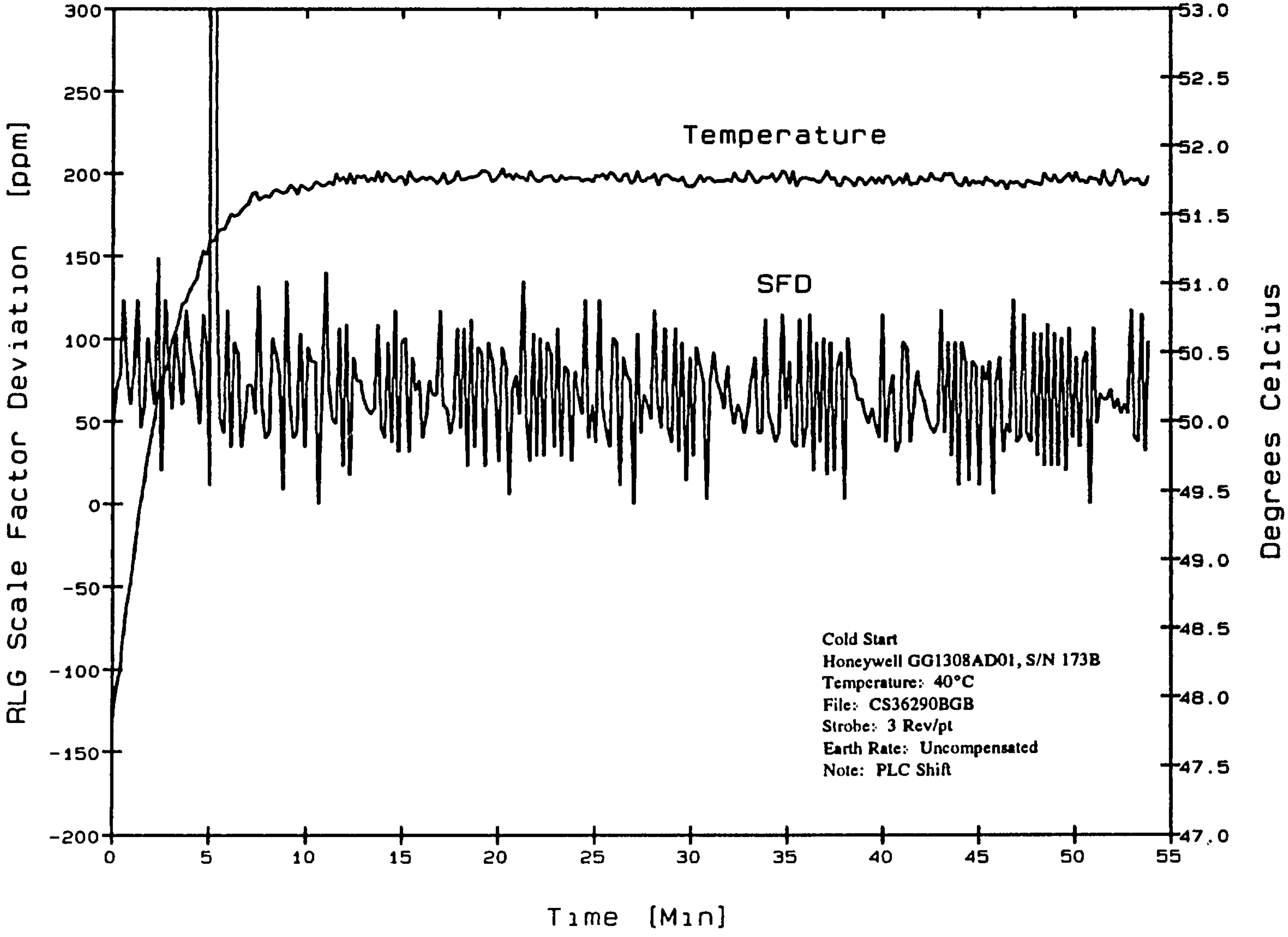

FIGURE 5-2 WARM-UP TIME

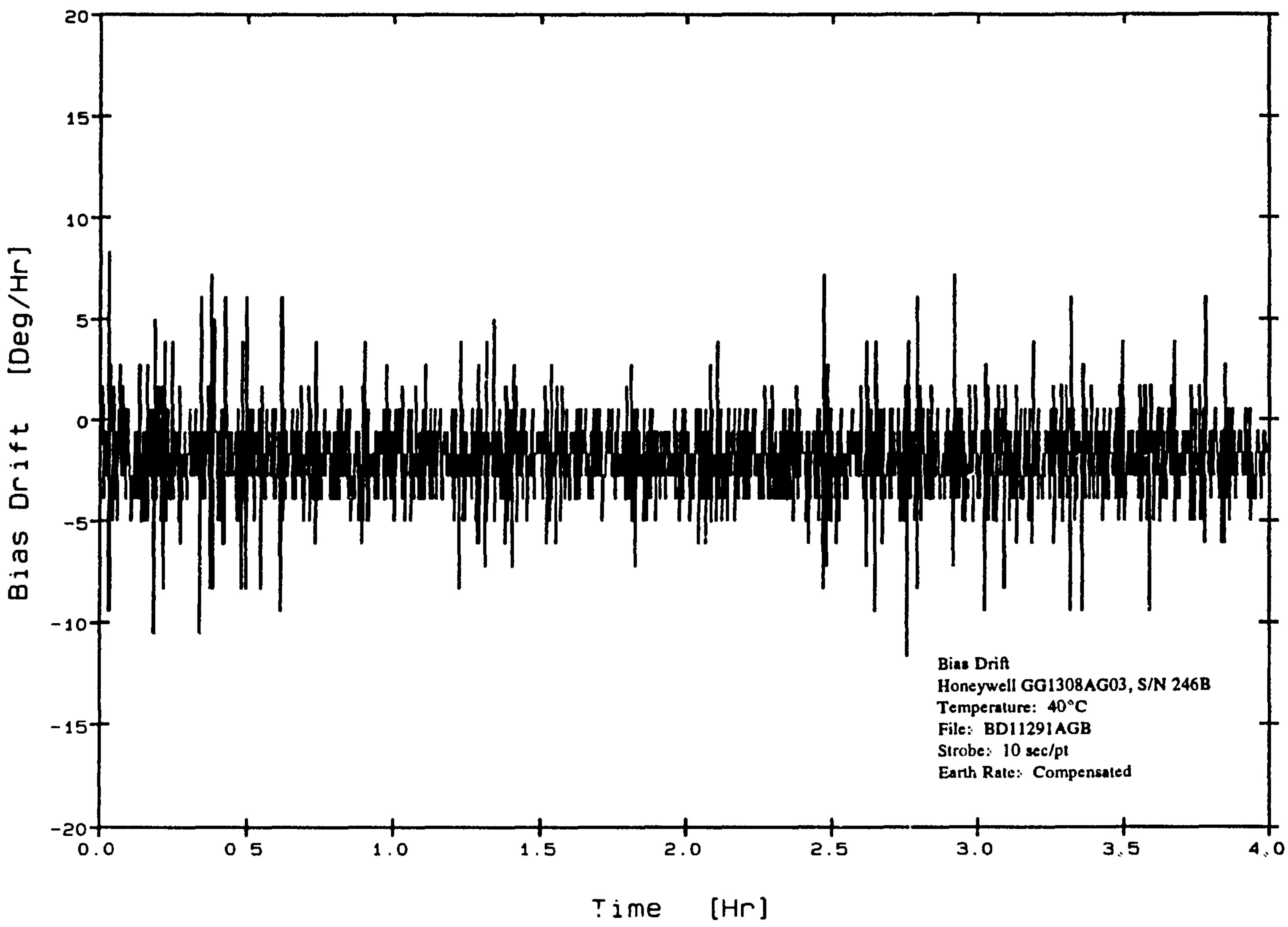

FIGURE 5-3 BIAS DRIFT TEST

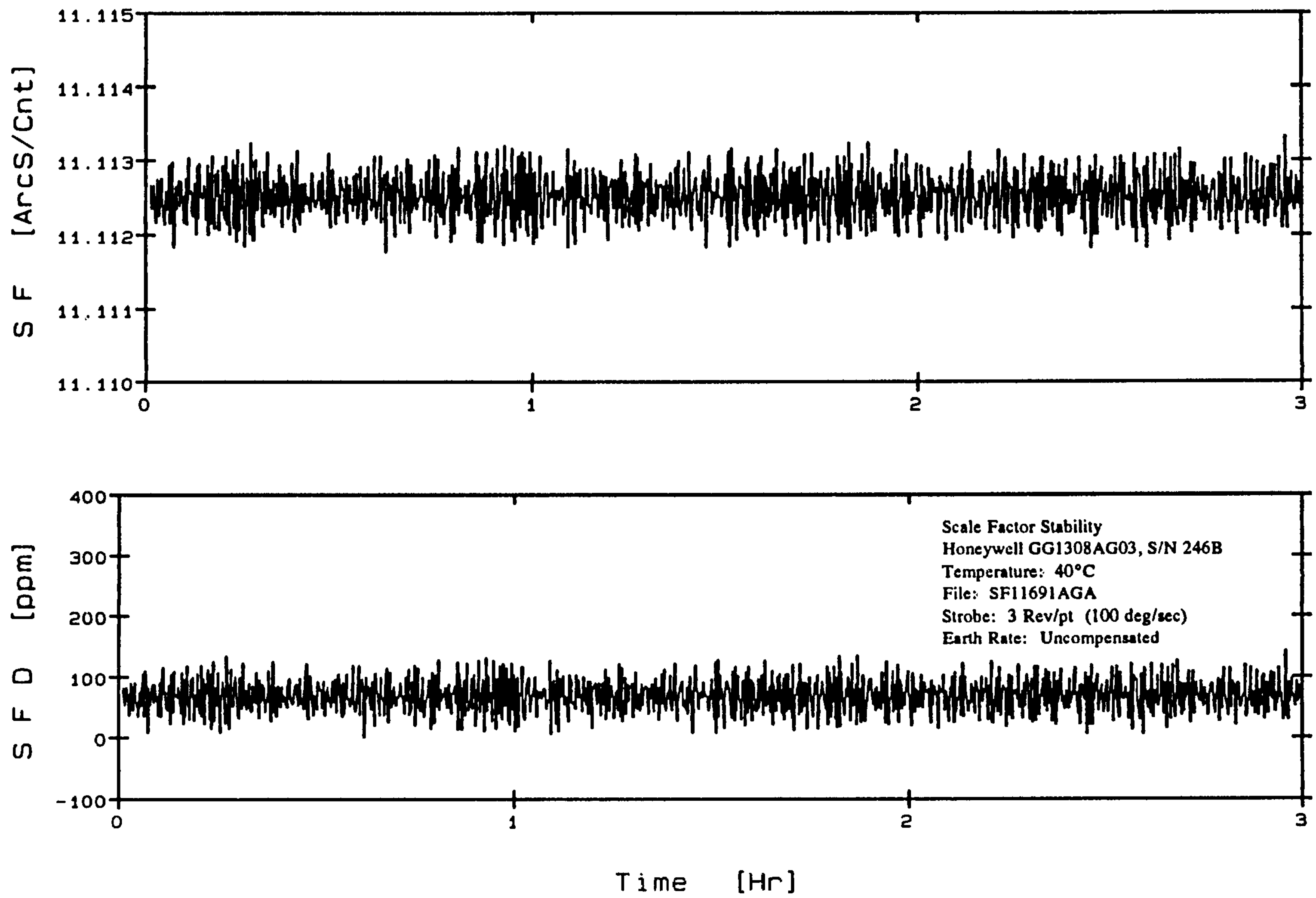

FIGURE 5-4 SCALE FACTOR VS TIME

Figure 5-5 illustrates SFD for the rate ranges of $\pm$ 0.25 to 16 deg/sec and $\pm$ 20 to 100 deg/sec. The 60 ppm maximum deviation at very low rates (0 to 4 o/s) is attributable to dither motor noise, inadequate dither compensation, and misalignment, while the balance of the rate range is stable at ≈ 20 ppm.

Figure 5-6 combines the results of the rate tests for all three ranges. Discontinuity between the rate ranges is due to turn-on to turn-on repeatability of the scale factor; approximately 50 ppm. Scale factor deviation over the range of 100 to 1000 deg/sec is 35 ppm peak to peak. At rates greater than 5 deg/sec, scale factor repeatability is better than 50 ppm. The "dep" observed at 700 o/s will be discussed later in the paper.

Figure 5-7 is a comparison between the Honeywell-supplied data and DREO data for scale factor deviation over the range of 100-1000 deg/sec. There is a ≈100 ppm offset between the scale factor values derived, but the scale factor deviation tracks very closely over the entire range. This offset is most likely attributed to misalignment (different alignments at Honeywell and DREO facilities).

The 'dip' in scale factor deviation at 700 deg/sec in Fig 5-7 and 650 deg/sec in Fig 5-8 illustrates the modulation at the first harmonic of the mechanical dither frequency and results in a significant scale factor deviation. This is typical of all mechanically dithered RLG's. The data illustrated here in for two different RLG's, thus the different rates and magnitude of the "dip".

5.2.5 **Thermal Transients**

The effects of a thermal transient are illustrated in Figures 5-9 to 5-13 which are a family of curves relating changes in RLG net counts and the analog monitor signals to a temperature transient of 20°C (from 64 to 44°C).

Note the deviation 'spikes' in the scale factor in Figure 5-9 which correspond to the Path Length Control (PLC) shifts in Figure 5-10. The PLC compensates for the change in laser path length due to the temperature change causing expansion and contraction of the block. From the PLC shifts in Figure 5-10 and supporting RLG count transients in Figure 5-9 a calculation of 2.22°C (4.0°F) per shift can be made.

The scale factor deviation for a 20°C temperature change is 120 ppm, or 6 ppm/°C (SIN 173B).

5.2.6 **Temperature**

The operating temperature has previously been shown to have little effect on the bias drift of the GG1308 gyroscope.

The scale factor, on the other hand shows significant sensitivity to block temperature as illustrated in Figure 5-14 where a 20°C change in temperature results in a 175 ppm change in scale factor, or 9 ppm/°C (SIN 246B).

The quietness of the 40°C trace in Fig 5-14 as compared with the 50 or 60°C traces can be explained by the averaging executed by the different sample rates (100 Ref/pts vs 10 Rev/pt).

The scale factor thermal sensitivity of better than 10 ppm/°C is further supported by the fact that the determination was made by two GG1308 gyros in two different experimental formats.

5.2.7 **Dither Compensation**

The effect of employing dither compensation is illustrated in Figure 5-15 where scale factor stability between dither-on and dither-off degrades by 20 ppm peak-to-peak.

Dither compensation is 'user-selectable' on this gyroscope since the compensation technique is only one of several which could theoretically be employed and, as such, one can compare performance of the instrument with and without the compensation.

5.2.8 **Summary**

The two GG1308 gyroscopes, S/N's 173B and 246B, were run for a total of 1244.5 hours and 250 hrs, respectively.

As explained, S/N 173B appeared to degrade after ≈600 hrs of running time. This failure was not analyzed in detail due to lack of time but data was supplied to Honeywell for their examination. Gyro S/N 246B performed uneventfully for the entire duration of the tests.

Similar evaluations performed by other agencies [6] lead us to believe that the useful lifetime of this gyro is of the order of 300-400 hours and that as a result, we probably 'wore-out' gyro S/N 173B. This is supported by other work which has shown that smaller ring laser

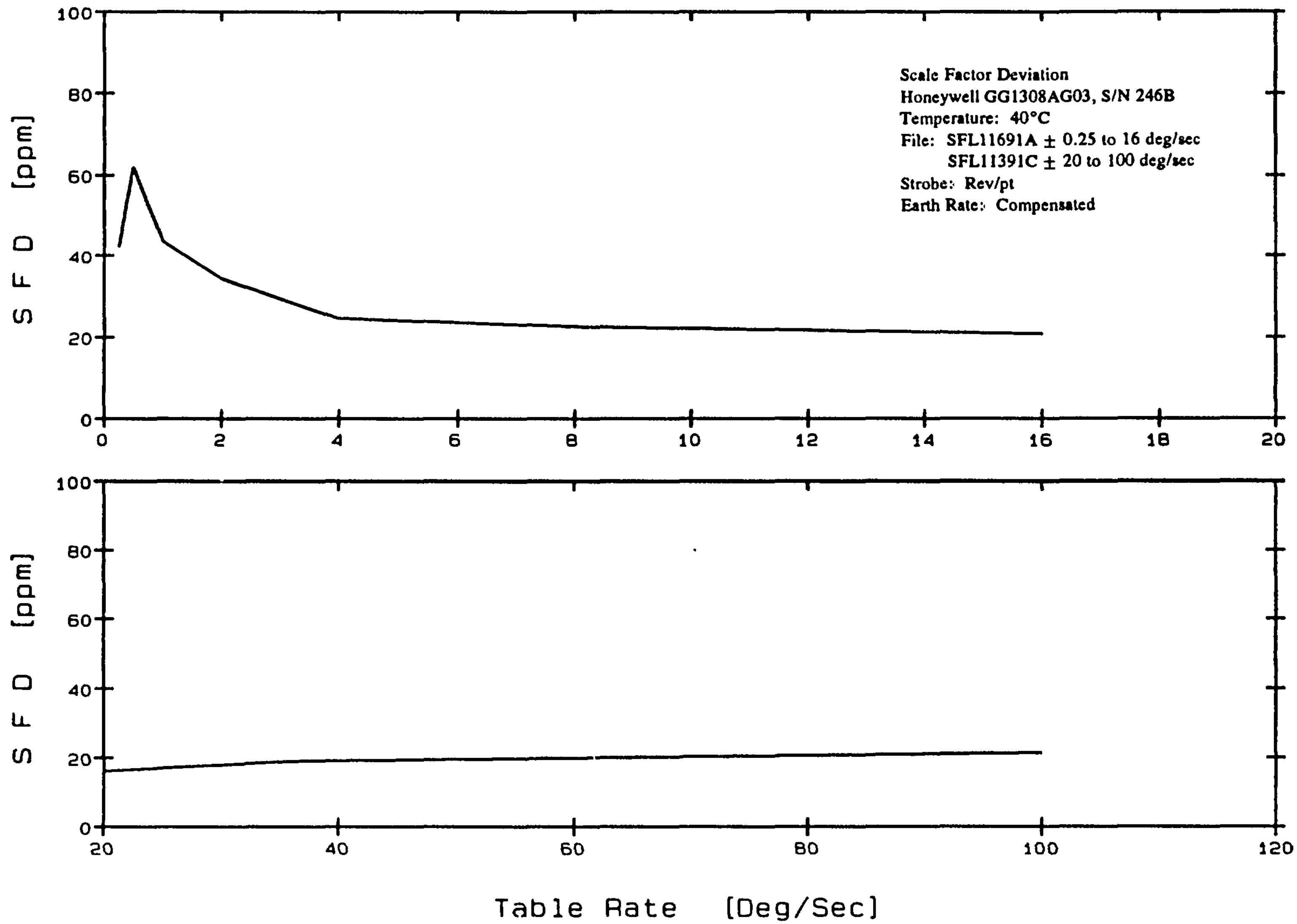

FIGURE 5-5 SCALE FACTOR DEVICATION, LOW RATE

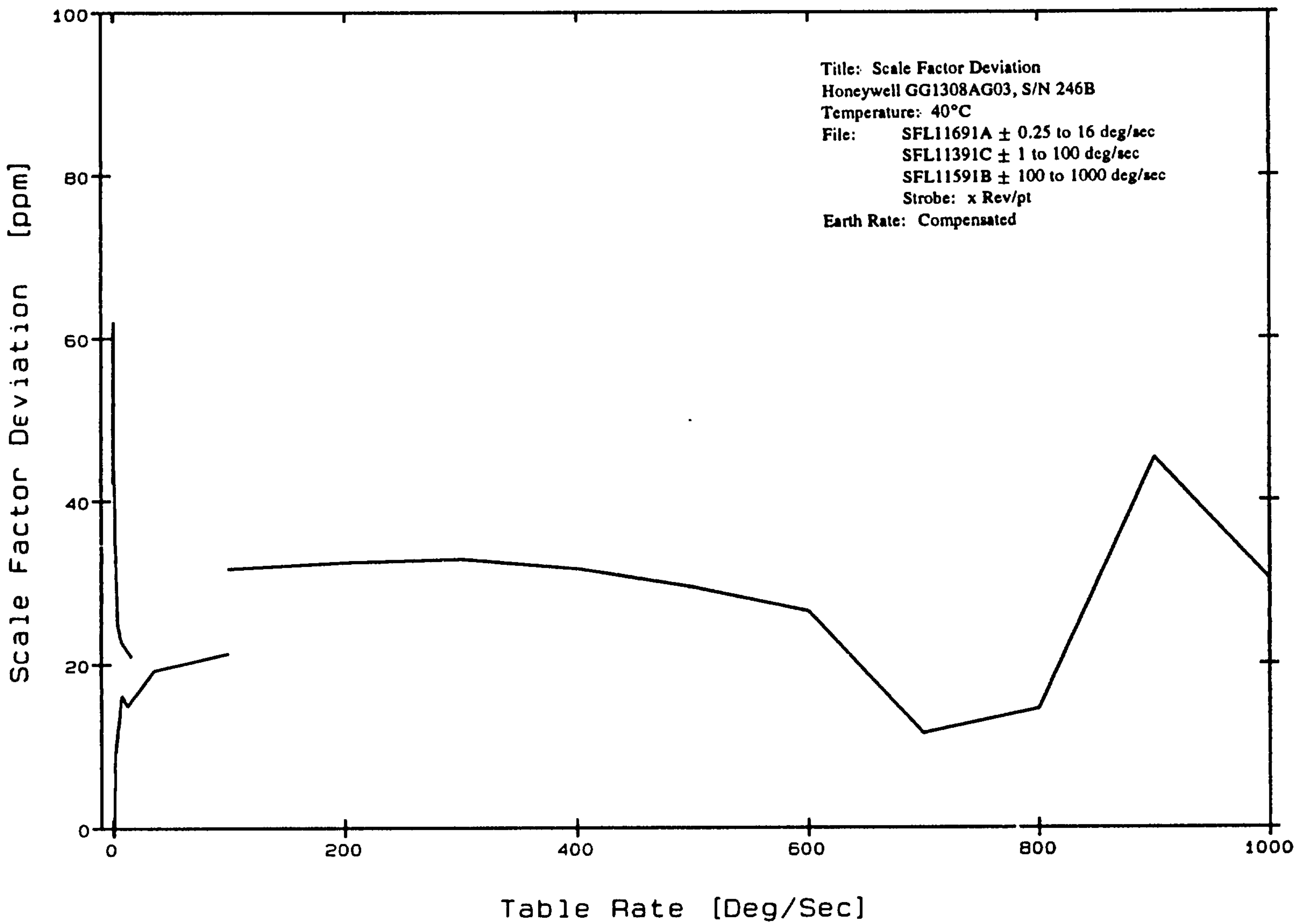

FIGURE 5-6 SCALE FACTOR DEVIATION, 0.25-1000 DEG/SEC

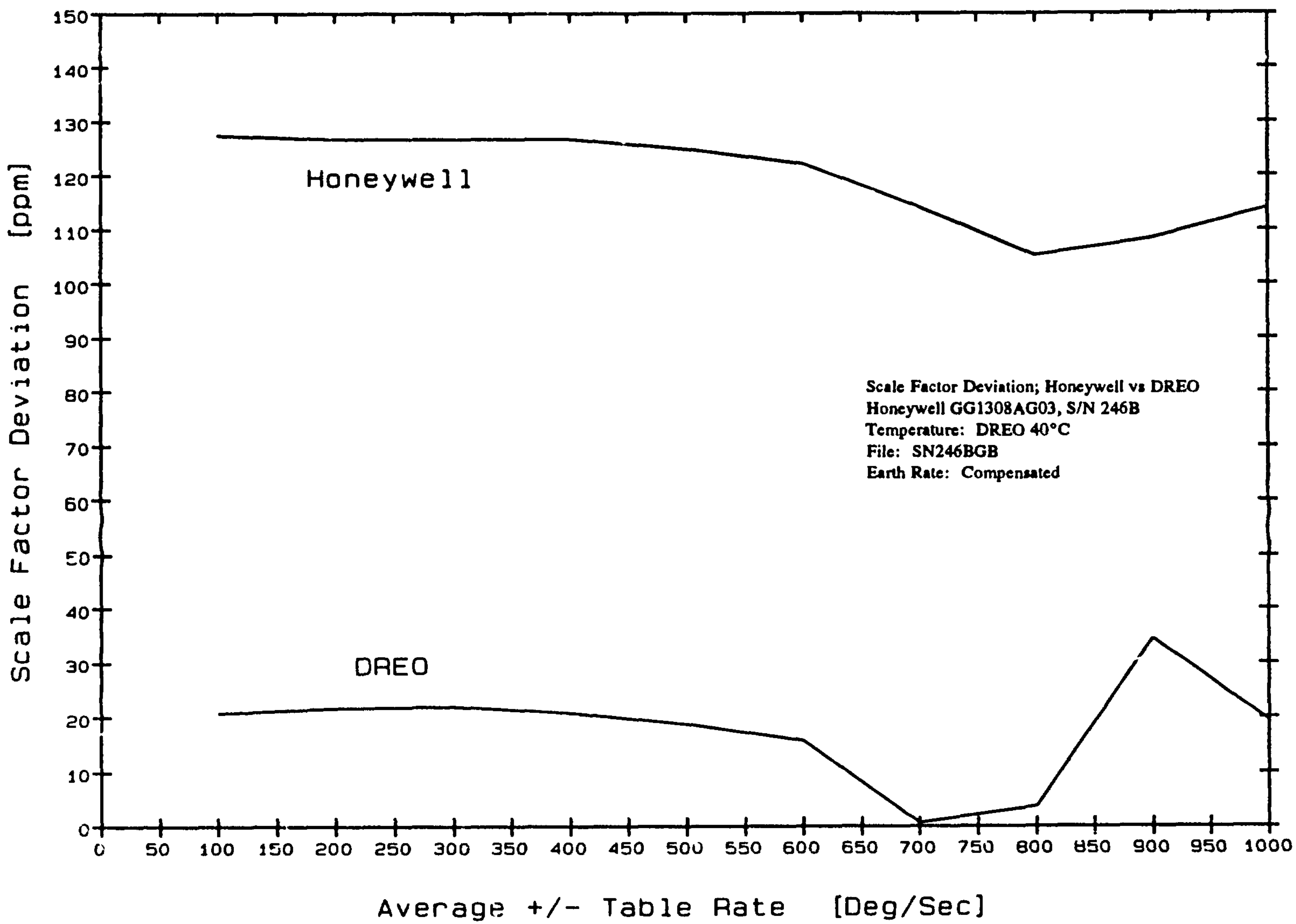

FIGURE 5-7 SCALE FACTOR DEVIATION; HONEYWELL VS DREO

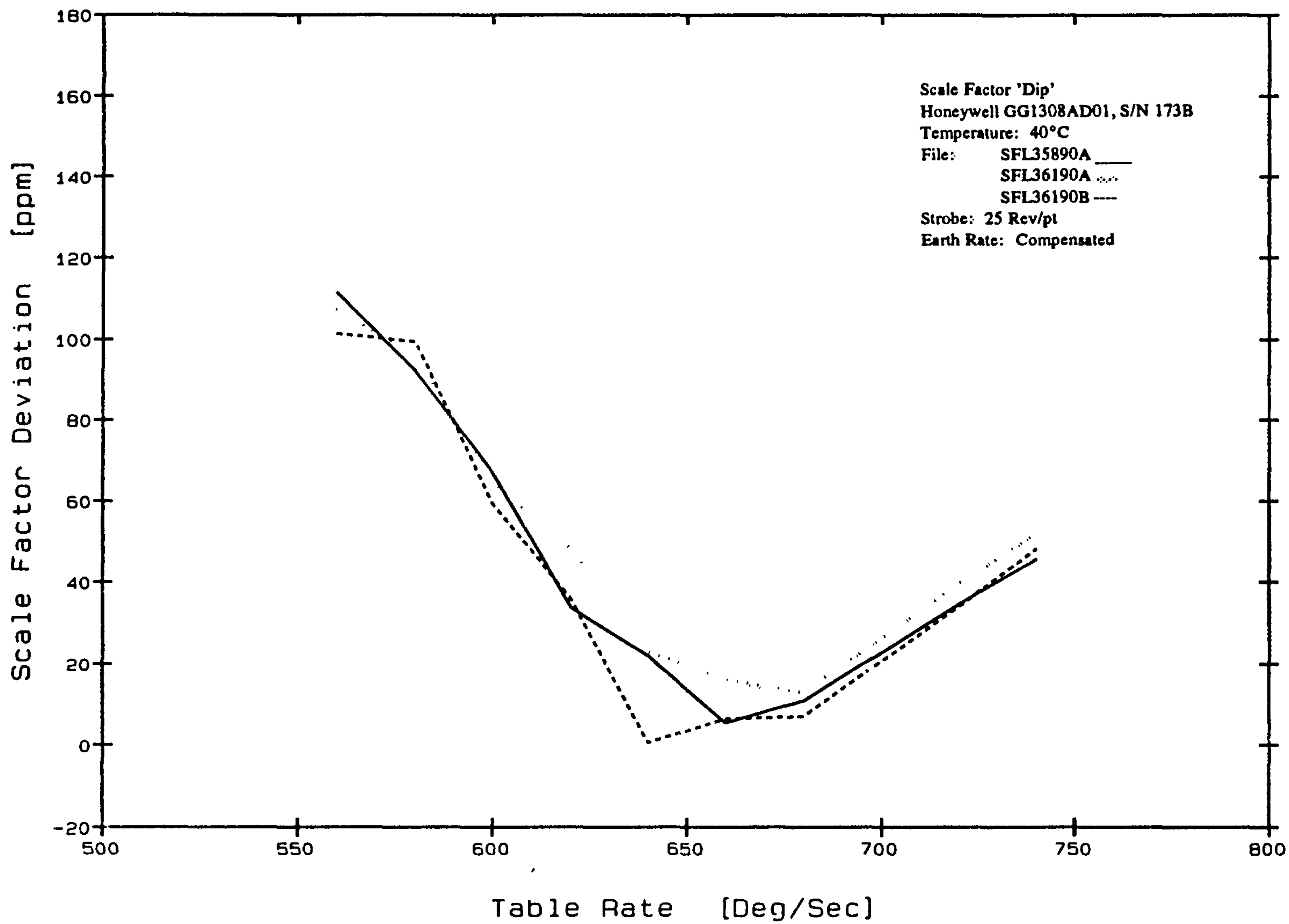

FIGURE 5-8 SCALE FACTOR 'DIP'

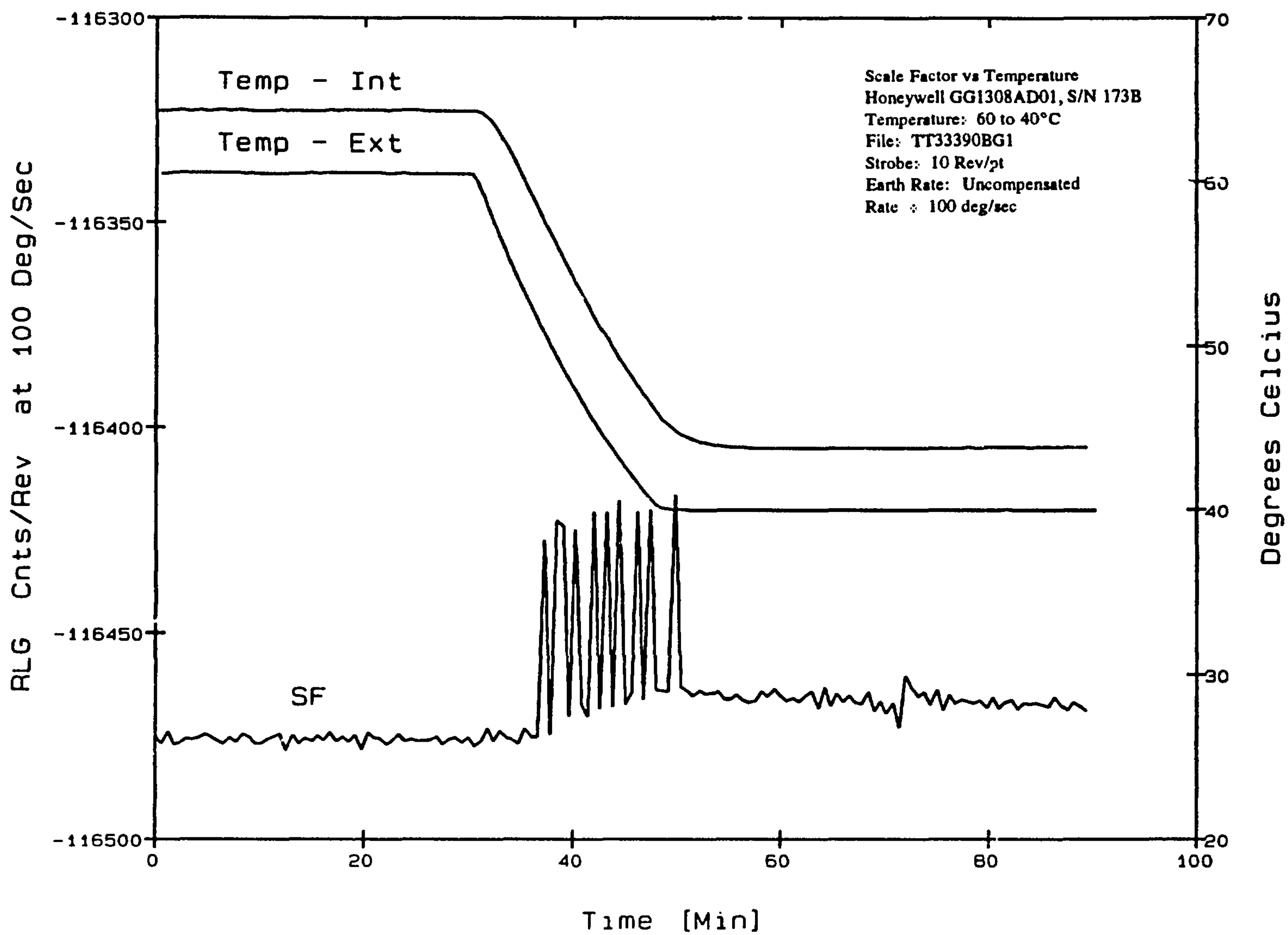

FIGURE 5-9 SCALE FACTOR VS TEMPERATURE CHANGE

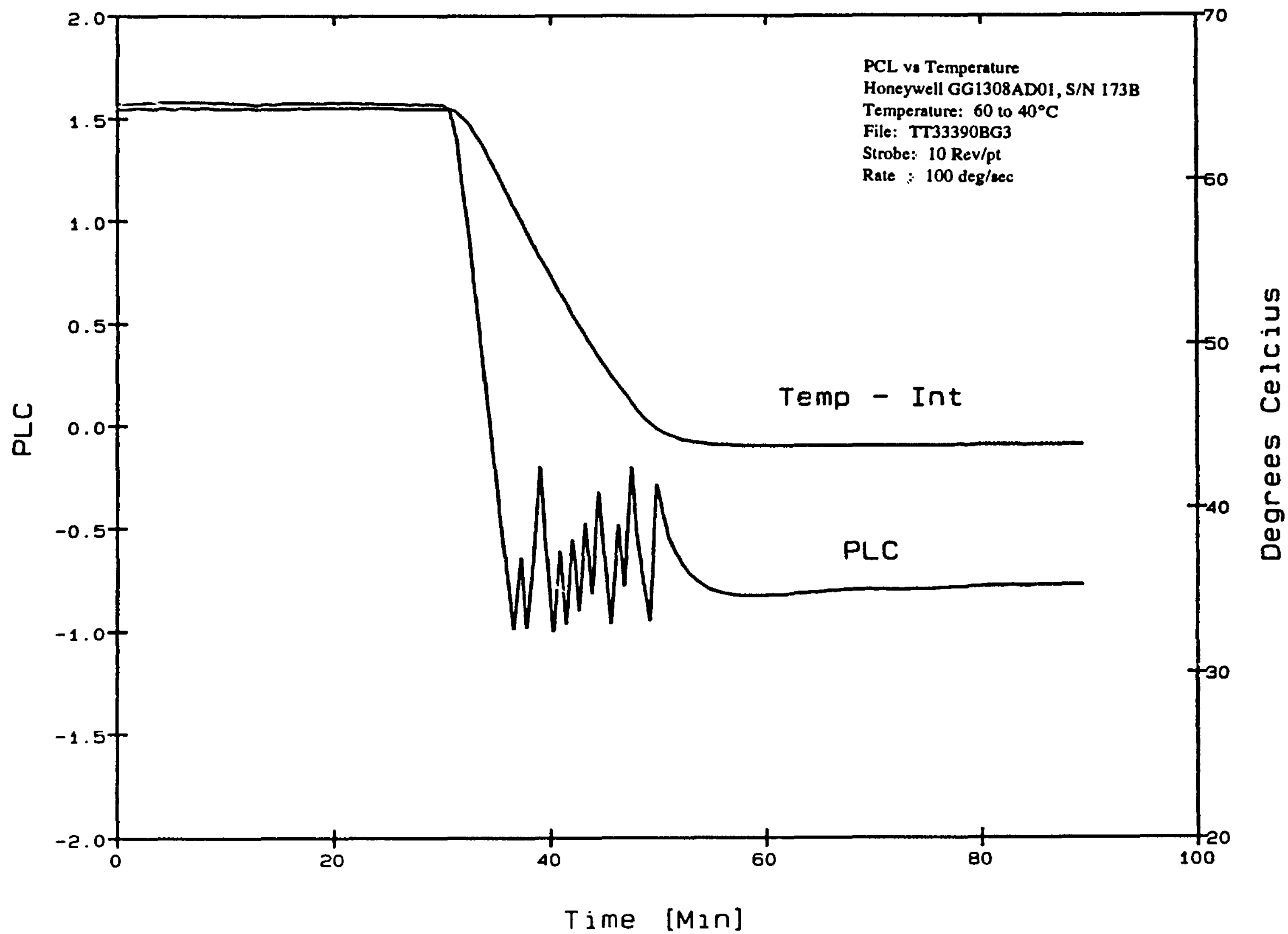

FIGURE 5-10 PLC VS TEMPERATURE CHANGE

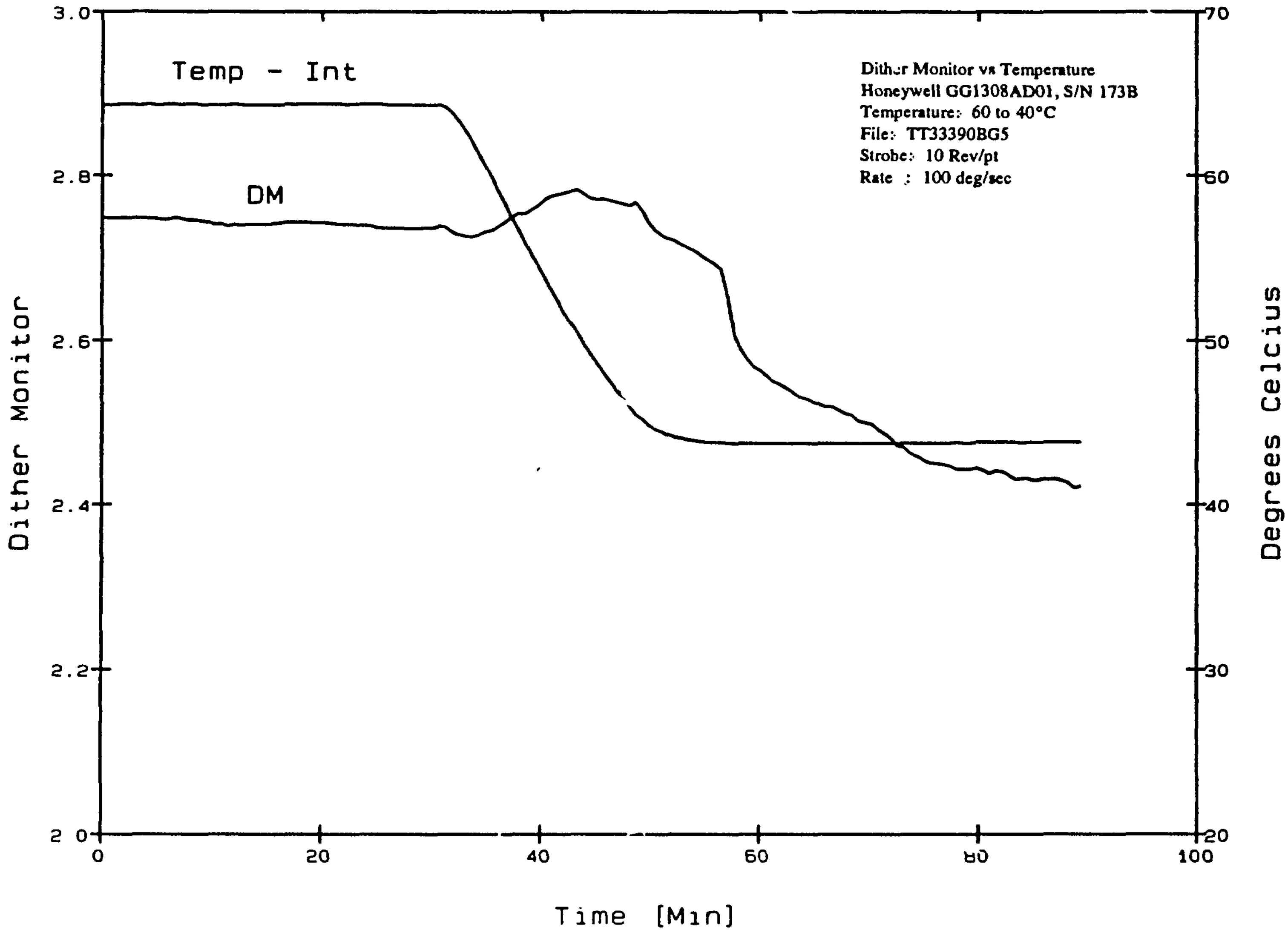

FIGURE 5-11 DITHER MONITOR VS TEMPERATURE CHANGE

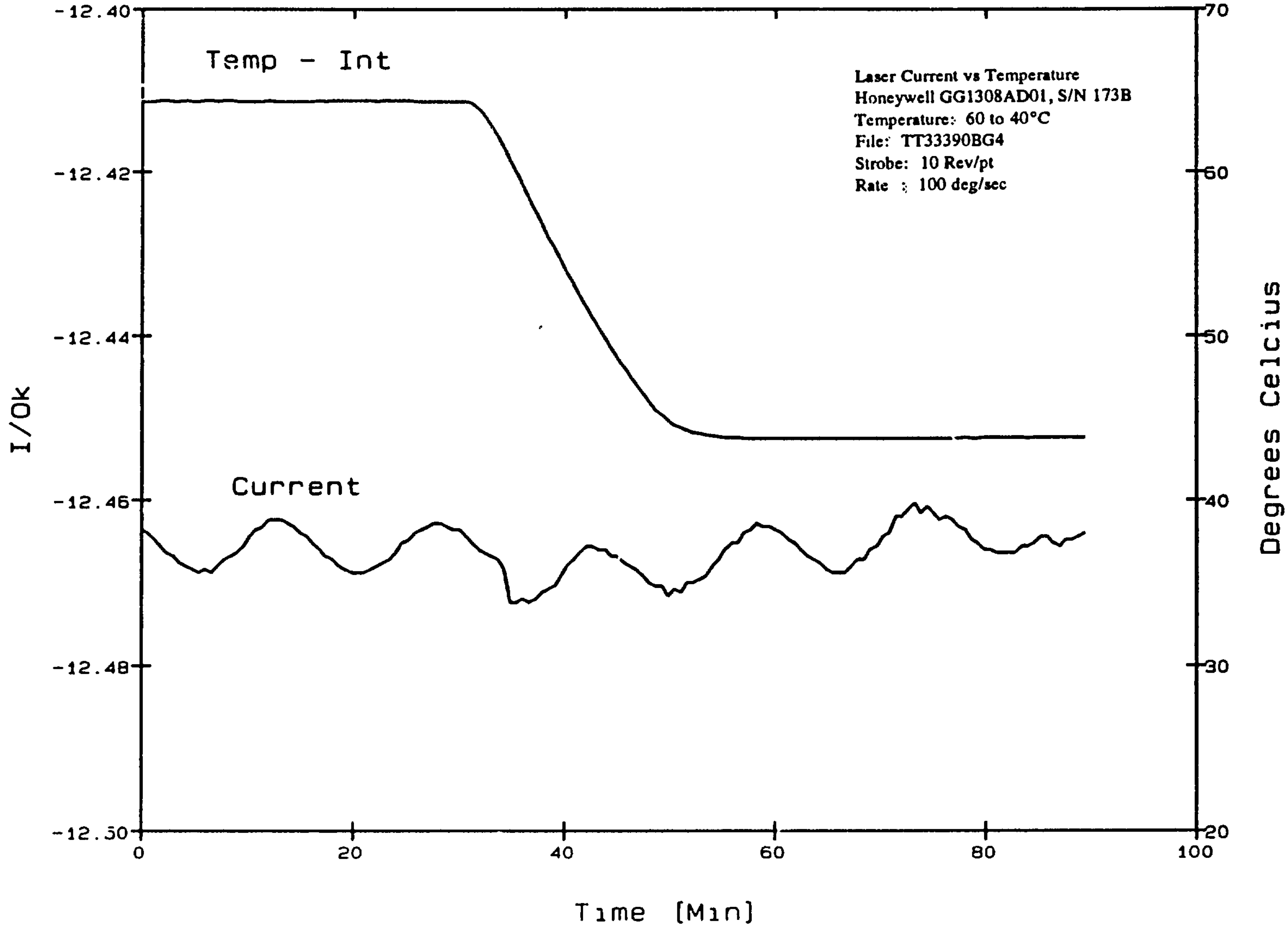

FIGURE 5-12 LASER CURRENT VS TEMPERATURE CHANGE

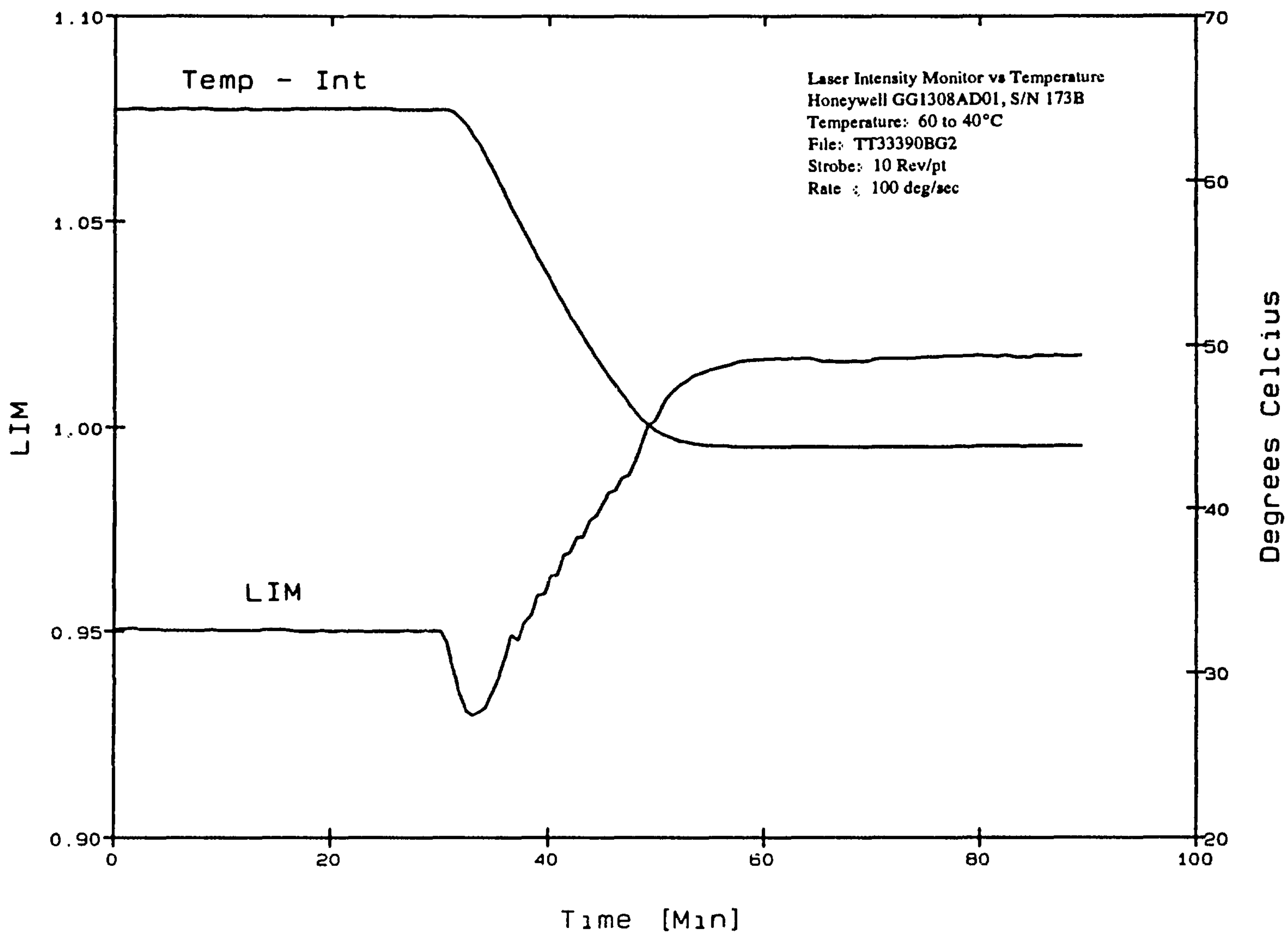

FIGURE 5-13 LASER INTENSITY MONITOR VS TEMPERATURE CHANGE

gyroscopes exhibit short operating lifetimes possibly due to the relatively high current required to operate the unit which causes the gas to be pumped out of the system [7].

The more signi' -t test results are summarized in Table 5-3.

	GG1308 S/N 246B	
Parameter	DREO	UNITS
Scale Factor (at 100 deg/sec)	11.11265	Arc S/Cnt
Scale Factor Repeatability Std Dev/1δ	±.00001	Arc S/Cnt
Scale Factor Deviation P to P	8	ppm
Scale Factor Temp. Sensitivity	10	PPM/°C
Bias Drift	-1.8	deg/hr
Bias Drift Stability (1δ)	2.3	deg/hr
Dither Frequency	1380	Hz
Dither Amplitude	56	Counts
Turn-on Time	40	Sec

TABLE 5-3 SUMMARY OF TEST RESULTS

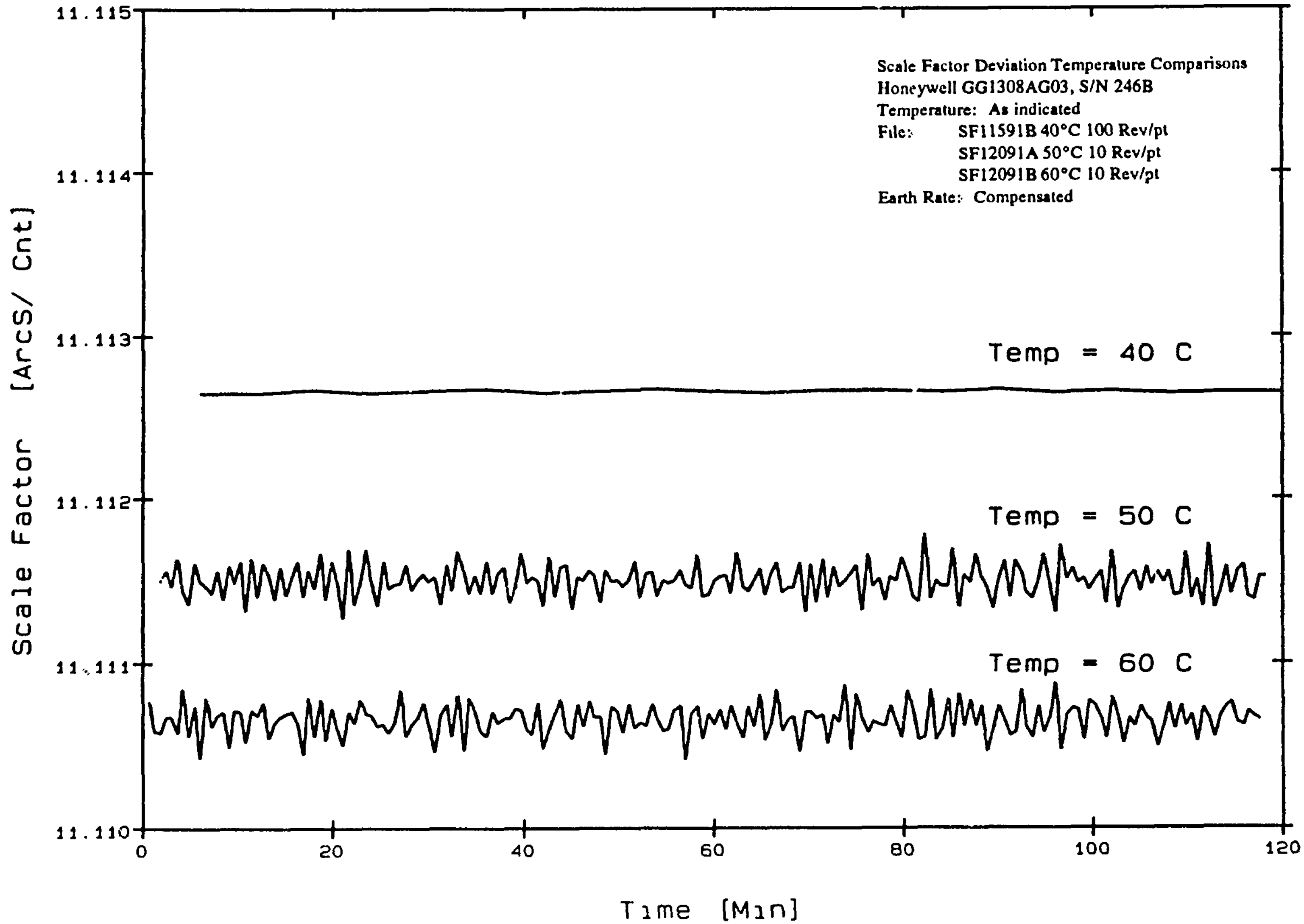

FIGURE 5-14 SCALE FACTOR AT VARIOUS TEMPERATURES

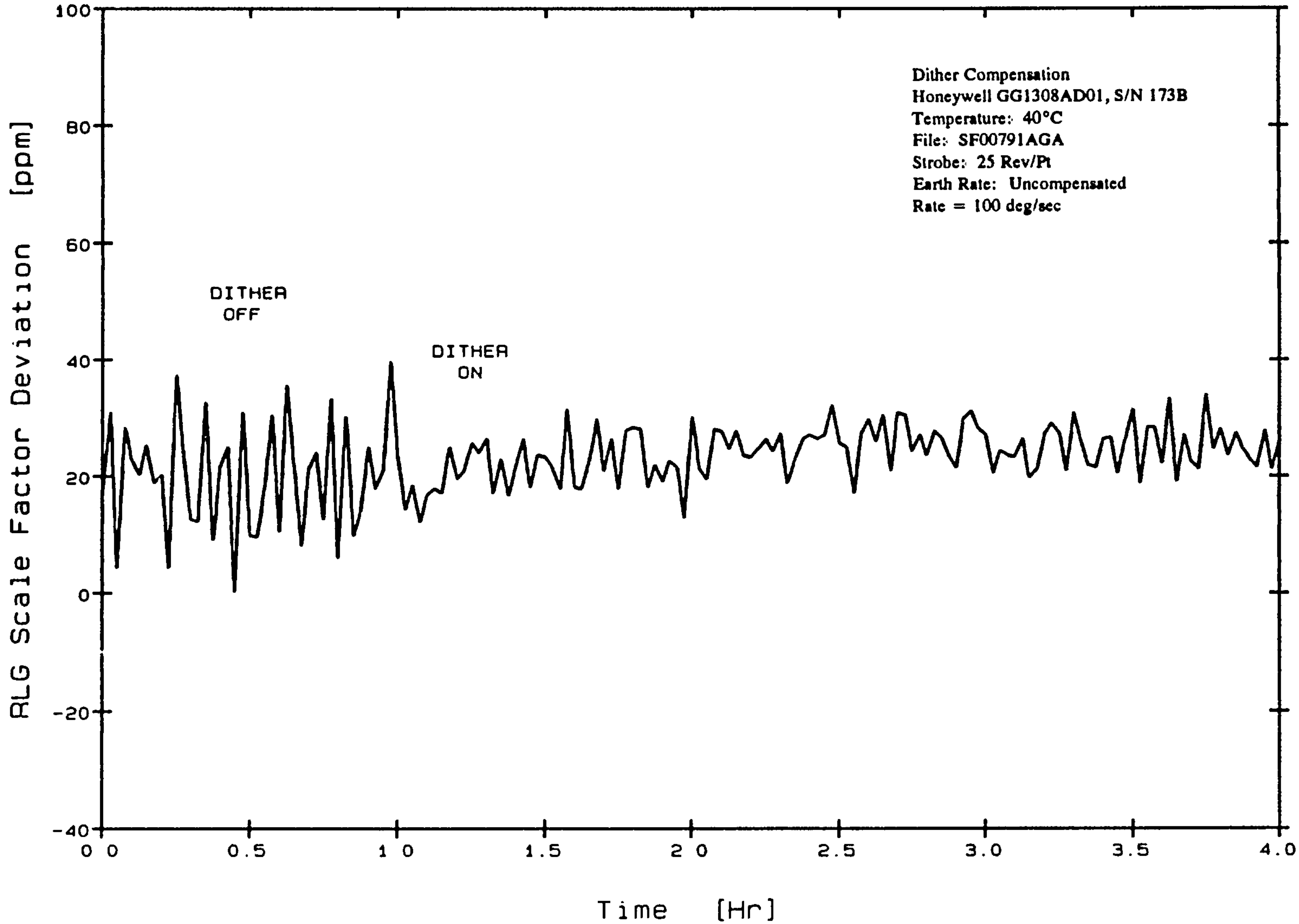

FIGURE 5-15 EFFECT OF DITHER COMPENSATION ON SCALE FACTOR STABILITY

6.0 CONCLUSIONS

6.1 EVALUATION OF RESULTS

In general instrument performance approaches Honeywell specifications over the entire rate range of the gyroscope. An exact comparison of test results as provided by Honeywell with those obtained at DREO is difficult due to insufficient Honeywell data. Bias drift appears to change over a period of time; probably a result of instrument aging. This was noticed on both gyroscopes and agrees with tests performed by other agencies [6]. Scale factor repeatability is very good as is scale factor deviation over the entire rate range of ±1000 deg/sec. Modelling of scale factor deviation with temperature would permit fairly simple compensation in a system application since the effect appears nearly linear.

6.2 GENERAL COMMENTS

The test instrumentation 'package' (gyroscope, DSB, interface card, etc.), as provided by Honeywell functions very reliably. Documentation on controls such as dither compensation is lacking and this results in some confusion when performing data analysis as well as an inability to pinpoint performance weaknesses or provide recommendations or suggestions for improvement.

Gyroscope life expectancy appears to be the limiting factor in consideration for use in AHRS applications where the vehicle must be recovered and used again but, for truly low-cost applications, the GG1308 would appear to be an ideal candidate.

Areas of future interest, which have not been evaluated in detail for this instrument include characterization of low rate performance (± 5 deg/sec) and the effects of vibration such as that caused by small RPV/drone type aircraft.

REFERENCES

1. 'GG1308AD01' Ring Laser Gyro Critical Item Development Specification', Spec. #DS33359-01, Part I, Honeywell Military Avionics Division, Minneapolis, MN, 1989.

2. 'Test Specification Ring Laser Gyroscope - GG1308AD01', Spec #DS33359-01, Part II, Honeywell Military Avionics Division, Minneapolis, MN, 1989.

3. 'GG1308 Operational Manual', Honeywell document ED5486.

4. BBN Software Products Corp., Cambridge, MA.

5. 'The DREO Inertial Navigation Laboratory: Development and Test Capabilities', M. Vinnins, DREO Report #895, June 1984.

6. 'Tactical Ring Laser Gyro Test', 6585th Test Group, Guidance Test Division, Holloman AFB, New Mexico, August 1986, Final Report.

7. 'Fiber Optic Sensors: An Introduction for Engineers and Scientists', E. Udd, John Wiley and Sons, Inc. 1991.

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This report describes the results of the performance evaluation of a Honeywell GG1308 miniature Ring Laser Gyroscope (RLG). The tests include turn-on and cold start, bias drift, scale factor, scale factor linearity, thermal transients and effects of dither compensation.

The gyroscope demonstrated excellent high-rate performance although significant scale factor deviations were noted during temperature variations. Instrument design characteristics and areas of potential future investigation are also discussed.

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Navigation