Wheel Force Transducer Research and Development

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14. ABSTRACT

This document forms the third progress report on the development of a concept wheel force transducer that can measure the forces and moments between a tire and a road on a HMMWV driven under off-road conditions. This concept development is part of a project that endeavors to develop, validate and calibrate cost effective field test equipment for measuring tire characteristics on vehicles whilst driving off-road. The proposed wheel force transducer is an important step in a renewed research effort that aims to correct the gap in current tire testing and modeling knowledge to ensure that future off-road vehicle models and simulation efforts are conducted with confidence.
The report briefly describes the fatigue testing performed on material samples as well as manufacturing and progress with fatigue testing of the first prototype.

15. SUBJECT TERMS

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Scientific Work done during reporting period

Abstract

This document forms the third progress report on the development of a concept wheel force transducer that can measure the forces and moments between a tire and a road on a HMMWV driven under off-road conditions. This concept development is part of a project that endeavors to develop, validate and calibrate cost effective field test equipment for measuring tire characteristics on vehicles whilst driving off-road. The proposed wheel force transducer is an important step in a renewed research effort that aims to correct the gap in current tire testing and modeling knowledge to ensure that future off-road vehicle models and simulation efforts are conducted with confidence.

The report briefly describes the fatigue testing performed on material samples as well as manufacturing and progress with fatigue testing of the first prototype.

1. Problem statement

Obtaining tire characteristics on off-road terrain for use in tire models, as well as suitable tire models represent a significant research challenge. A first, but extremely important step in this research is to develop suitable tire test equipment. Due to the difficulty of simulating off-road terrain under laboratory conditions, field test equipment, that can determine tire characteristics on vehicles whilst driving over these terrains, is required.

2. Objectives

In order to obtain tire characteristics over off-road terrain, cost-effective field test equipment is required. The proposal therefore has four main objectives [1,2]:

a) Develop a prototype 6-component wheel force transducer to measure tire forces and moments on a vehicle whilst driving
b) Develop mathematical models of the wheel force transducer
c) Validate and calibrate the wheel force transducer
d) Manufacture a set of four wheel load cells for fitment to a vehicle.

This report describes part of the design validation stage of the wheel force transducer required under point c) above. Special emphasis is placed on fatigue testing of the flanges, load cells and load cell pins. Several design improvements, aimed at reducing stress concentrations and ensuring acceptable fatigue life are discussed and implemented.

3. Design validation testing

The concept design of the wheel force transducer, where the space envelope, layout, basic dimensions and expected load was determined, was discussed in the first interim report [3]. Apart from finalizing the dimensions and layout, the detail design[4] addressed two aspects namely sealing and strength.

In the final sealing arrangement, V-ring seals are used to seal the spaces between the different parts of the wheel force transducer to prevent foreign objects from entering the transducer.

Strength was analyzed by performing a Finite Element Analysis (FEM) on two load cases that are considered to be worst case. The applied load in each case was 50 kN (or 5 000 kg) which means that the vehicle can land with the full vehicle weight on one wheel and that only one of the six load cells in the wheel force transducer can carry the entire dynamic load. This resembles an extreme load case. Finite element analysis results indicated that the stresses in the areas of possible failure are below 200 MPa. This means that the load cell flanges can be manufactured from Aluminium 7075 alloy in the T651 heat treatment condition. This material has a yield strength in excess of 400 MPa which is around double the maximum stress expected during this extreme load case.

Material test specimens were manufactured from the off cut material used for the first flange. An example of a test specimen is indicated in Figure 1. The specimens all had a 10x10 mm test cross section and initially had a radius of 10 mm based on the machining radius in the flange design. The specimens were tested “as machined” and were not polished. Figure 2 indicates a test specimen in the tension-compression tester just after failure and Figure 3 indicates several failed specimens.

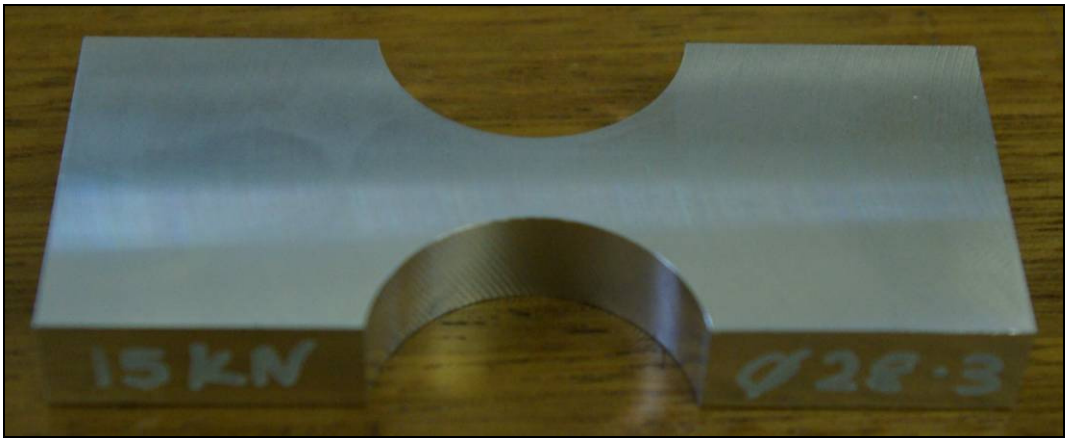

Figure 1 - Material test samples

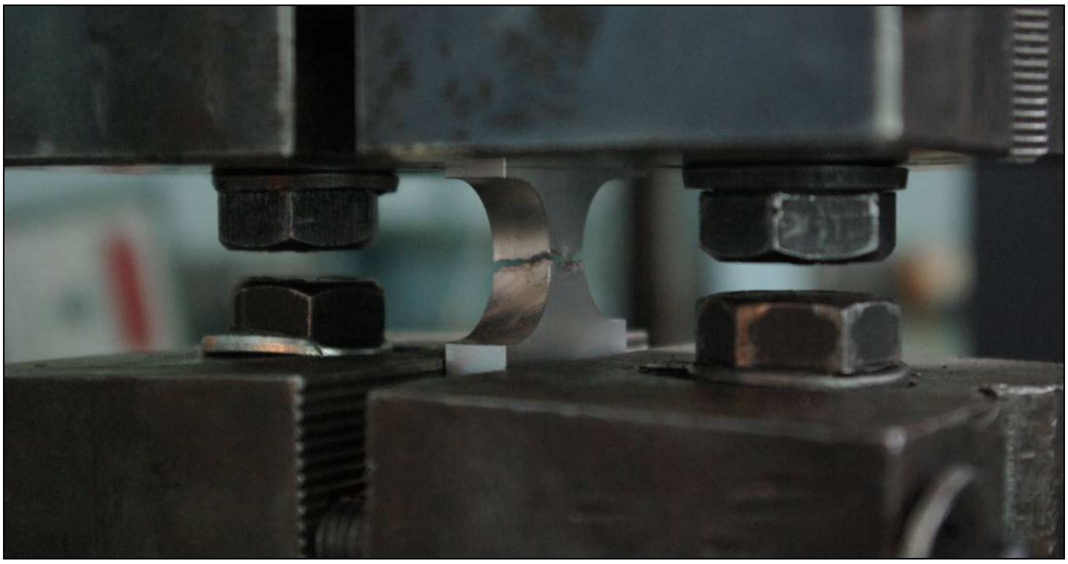

Figure 2 – Fatigue testing of specimens

Figure 3 – Fatigue test specimens after failure

Specimens were tested at different fully-reversed tension-compression force values and the number of cycles until failure were counted. The resulting S-N (Stress vs. number of cycles) curve is indicated in Figure 4. Also indicated in Figure 4 is data published by NASA[5] for smooth polished specimens as well as Alcoa[6] for notched specimens. Our test data corresponds well to that of the notched Alcoa specimens. The test specimen at 50 MPa (red square) hasn't failed yet after completing 1 million cycles. Test results at 150 MPa are also indicated for specimens with an increased radius (14 mm instead of 10 mm) as well as a polished specimen. Both the increased radius and polishing significantly increases the fatigue life. The results do however indicate that to achieve life of more than 1 million cycles, the stress should be less than 50 MPa. The original flange design, indicated in Figure 5, was modified to reduce the stress concentration at the critical point by increasing the radius and adding more material. The surface will also now be polished after machining. The modified design is indicated in Figure 6. Finite element analysis results for the original design (Figure 7) and the modified design (Figure 8) indicates a reduction in stress, at the critical point, from 140 to 94 MPa.

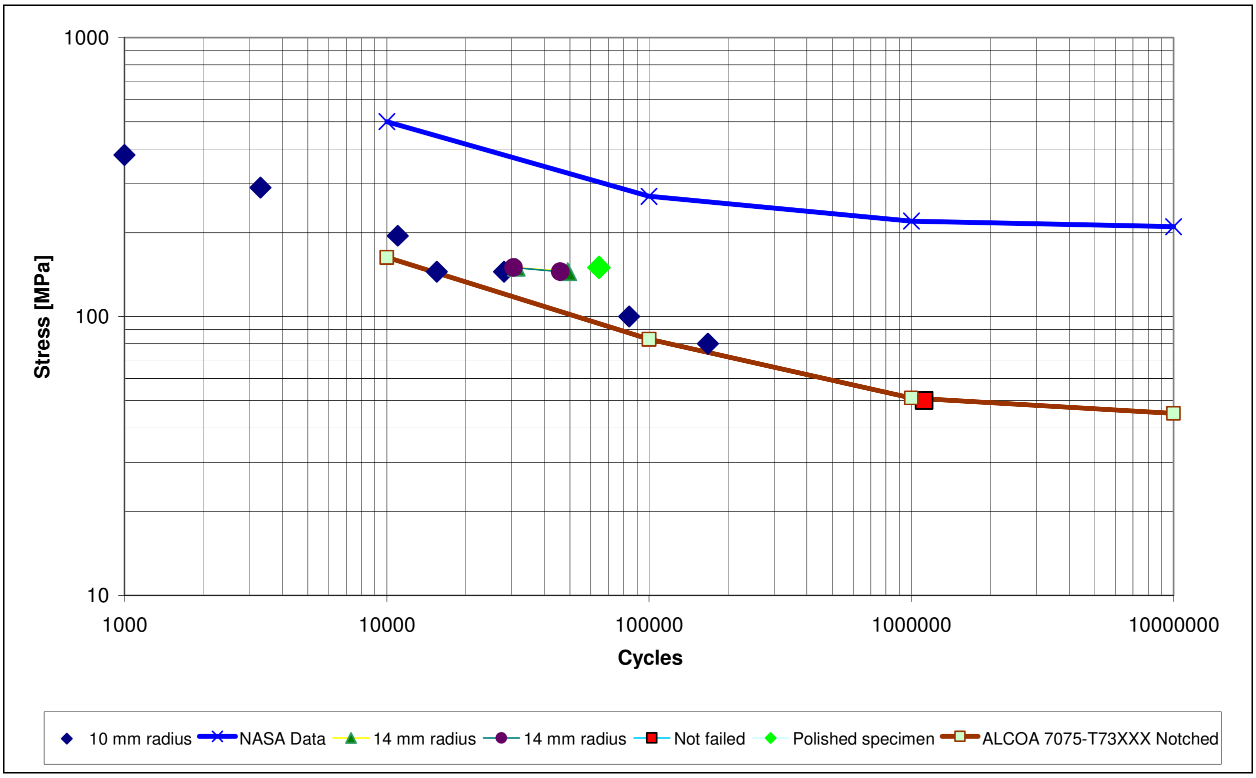

Figure 4 – Results of fatigue tests on specimens

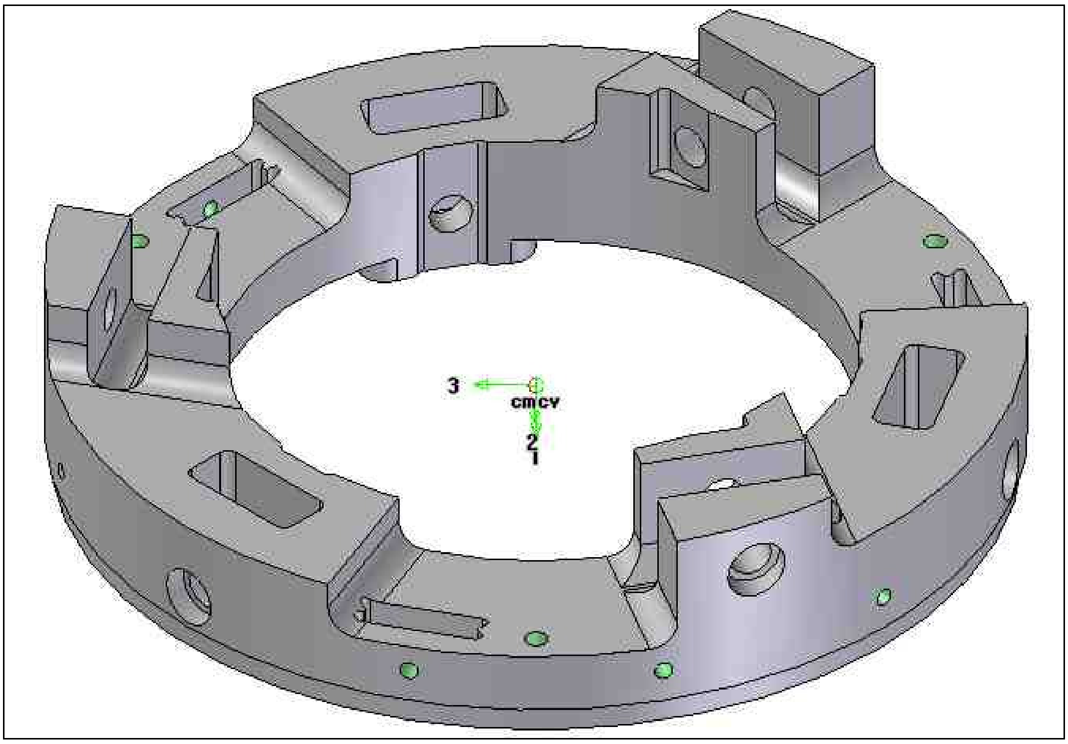

Figure 5 – Original flange design

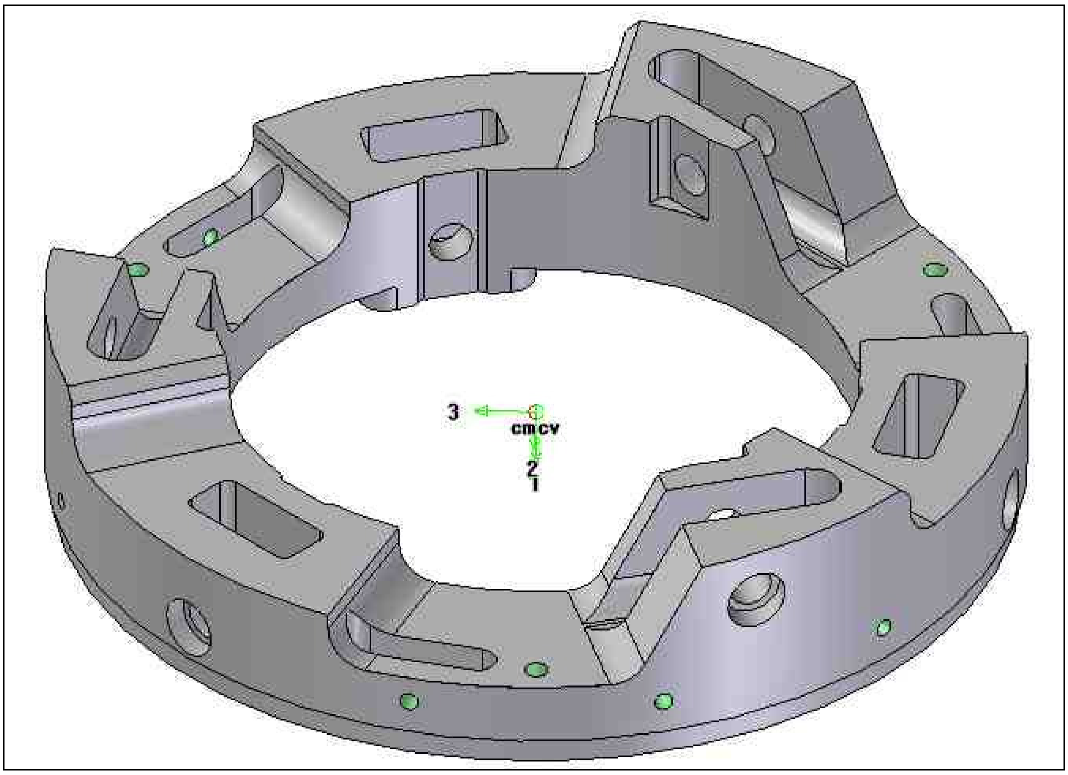

Figure 6 – Improved flange design

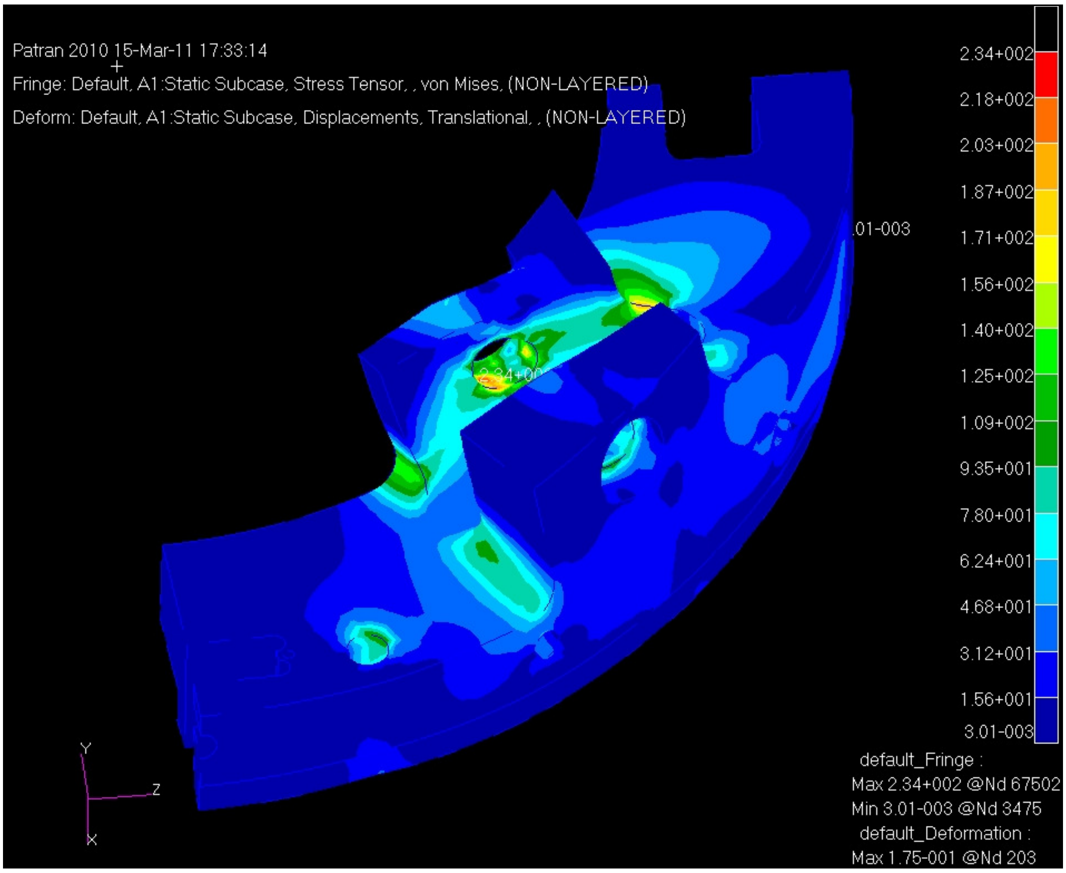

Figure 7 – Finite element analysis of original flange

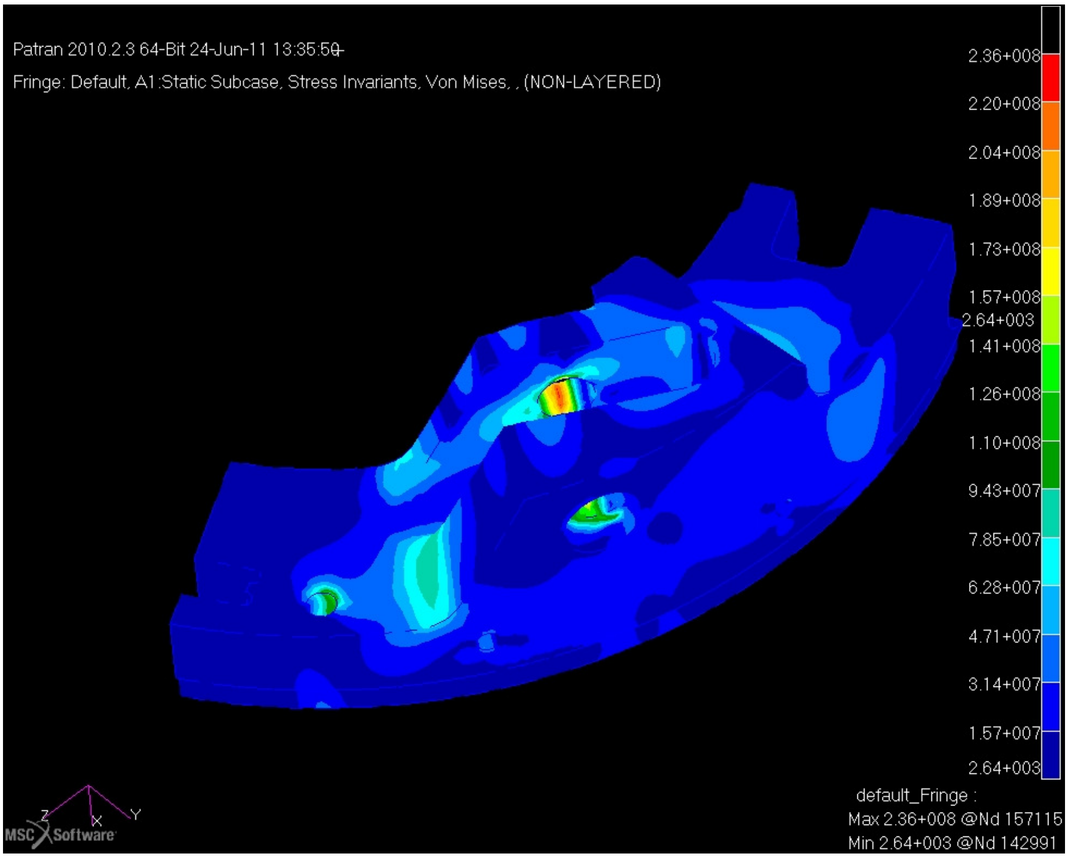

Figure 8 – Finite element analysis of improved flange design

The extreme applied load case in the initial design was 50 kN (or 5 000 kg) which means that the vehicle can land with the full vehicle weight on one wheel. It was also assumed at that stage that only one of the six load cells in the wheel force transducer may carry the entire load. Test results, measured during calibration of our first prototype design for the Land Rover, are indicated in Figure 9. These results show that any single load cell will only see a maximum of 65% of the load applied to the wheel. If the maximum wheel load is 5000 kg, then each individual load cell will only see 3250 kg. Scaling the stresses from the finite element analysis accordingly results in a maximum stress of 0.65*94 MPa or 61 MPa. The flanges are therefore expected to have a life of around 1 million cycles at this extreme load case. Given the HMMWV wheel diameter of 0.9 m, this represents a circumference of 2.8 m and a distance of around 2800 km at this extreme loading case.

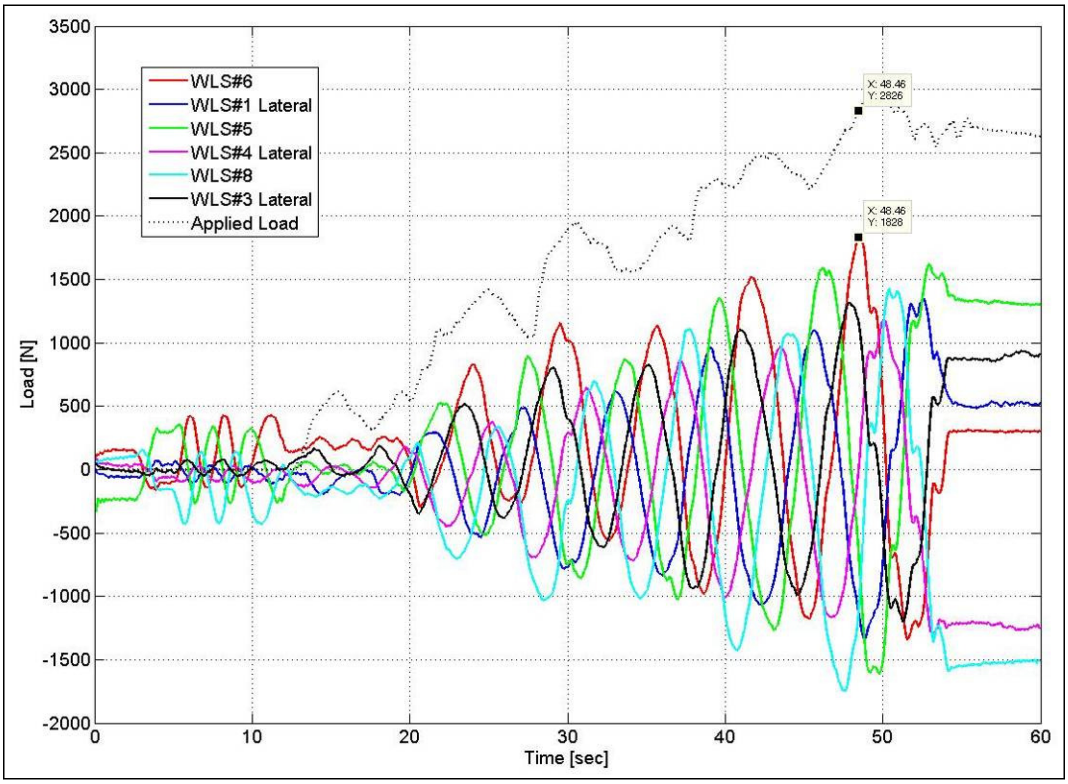

Figure 9 – Test results on Land Rover prototype

The manufactured flange is indicated in Figure 11. The flange was cut into three sections for fatigue testing. Initial fatigue testing at 50 kN force (Figure 11) indicated that the load cells and load cell pins are not strong enough. The load cell pin diameter was subsequently increased from 12 mm to 17 mm and the shoulder in the initial pin design was removed to eliminate the stress concentration. The 12 mm diameter spherical bearings were replaced with 17 mm bearings. The load cell design was changed to reduce stress concentrations and the load bearing area was increased.

Fatigue testing on the test rig, as indicated in Figure 12, is currently in progress. Fatigue testing is also now performed at a load of 30 kN according to the argument set out above. At the time of writing the report, the top aluminium test piece in Figure 12 has completed 459 000 cycles (around 1 500 km) and the bottom aluminium test piece completed 527 000 cycles (around 1 800 km) without any visible cracks. Testing will continue until failure or until 1 000 000 cycles are reached. The current life is however already considered more than adequate as this means that the vehicle can drive with the full vehicle load on a single wheel for more than 1 500 km. As the wheel force transducer is a piece of test equipment, that will only be used under controlled conditions for dedicated tests, this life is more than acceptable. The load cell pins seem to be the weak point currently. This is good as this is the least expensive part in the load cell and can therefore be checked and replaced each time the load cells are removed for calibration.

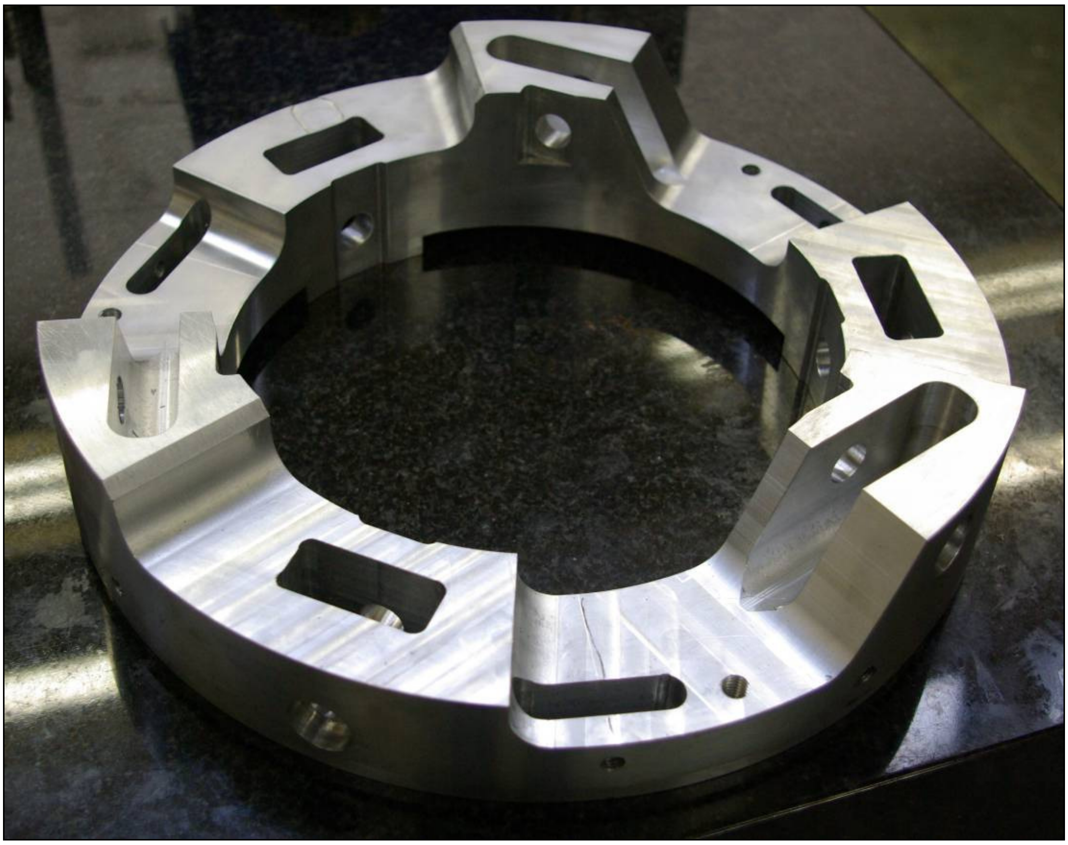

Figure 10 – Manufactured improved flange

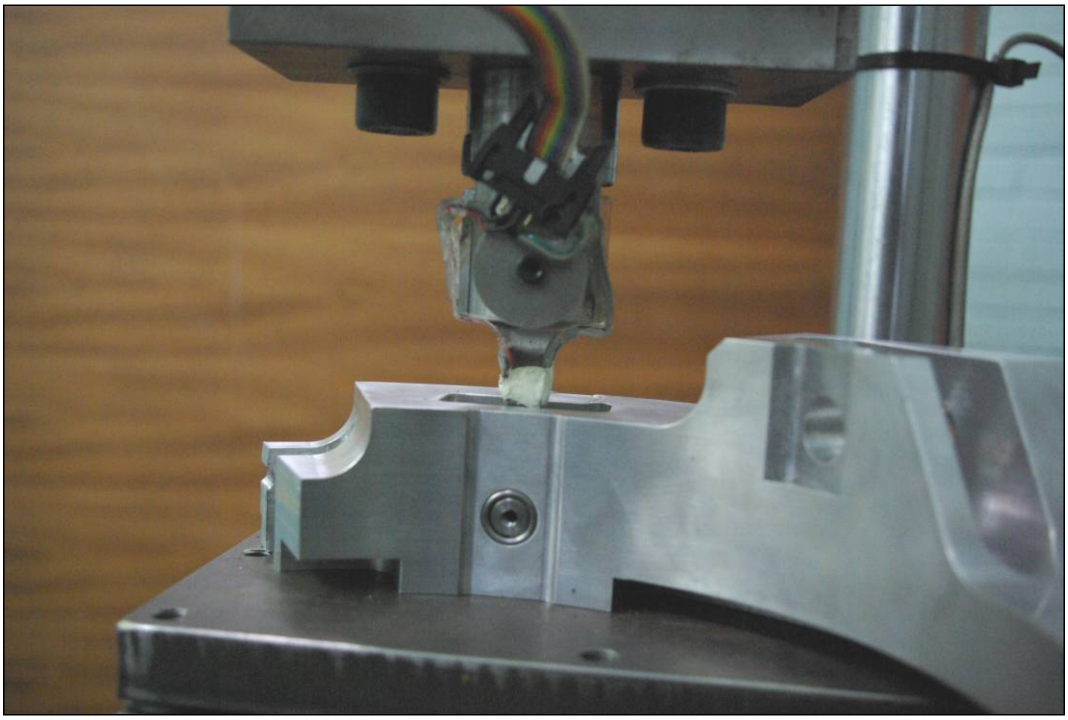

Figure 11 – Fatigue testing of improved flange with original load cell and pin design

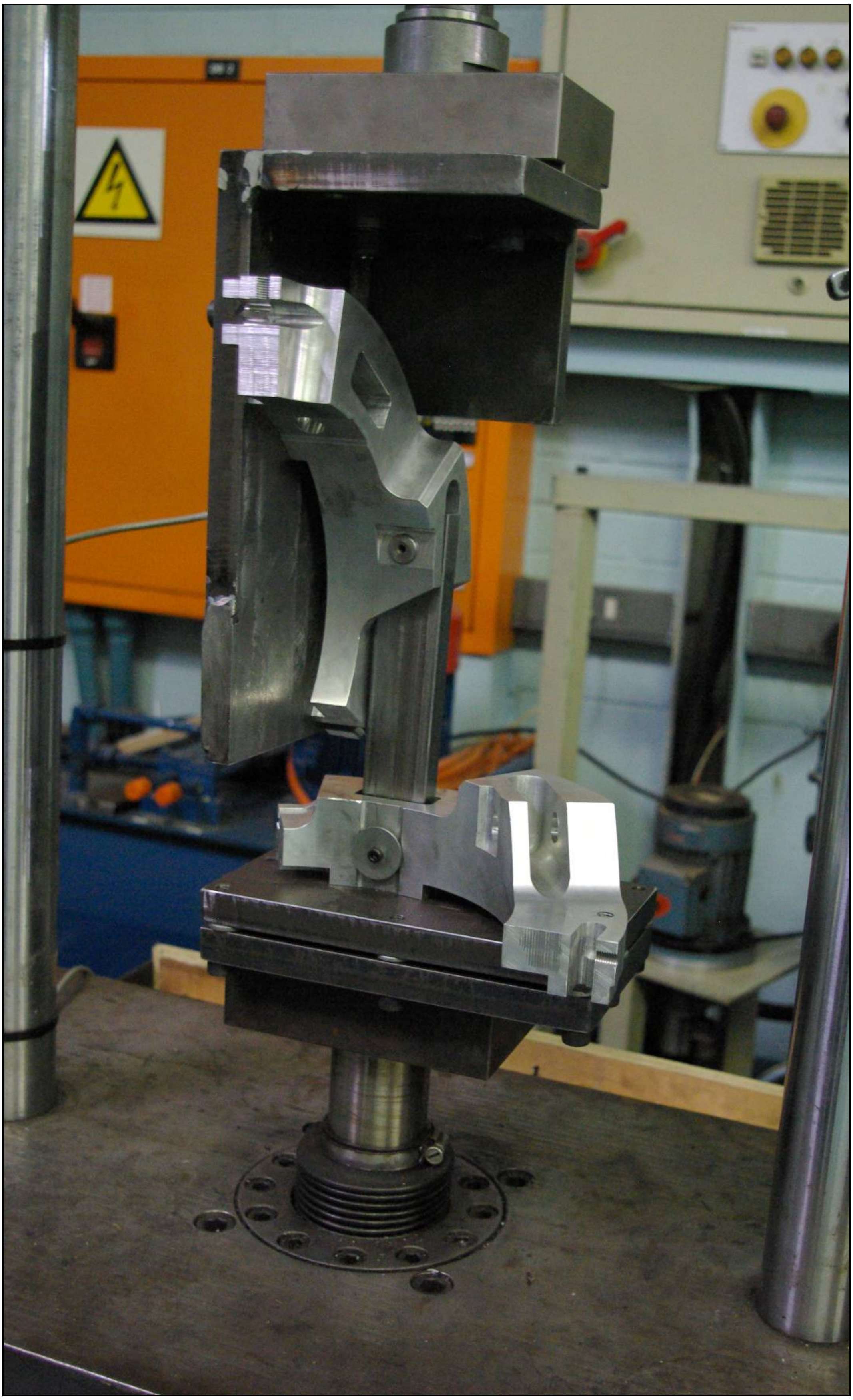

Figure 12 – Fatigue testing

5. Research plans for remainder of the contract period.

5.1. Validate and calibrate the wheel force transducer

A prototype wheel force transducer will be assembled. Individual load cells in the assembly will be calibrated using Schenck Hydropuls test equipment. The wheel rotational angle measurement system will also be calibrated separately. After assembly, the complete wheel force transducer measuring chain will be calibrated against known externally applied loads for all three forces as well as all three moments. The measurements will also be used to validate the mathematical models developed previously.

5.2. Manufacture a set of four wheel force transducers for fitment to a vehicle.

A set of four wheel force transducers will be manufactured, assembled, calibrated and shipped. The telemetry is not included in this study and has to be procured separately. Recommendations in this regard will be made.

A visit to CRELL is planned for 2011 to give feedback on the project progress and to discuss practical details of the project.

6. References

[1] Proposal: Wheel force transducer development, 12 August 2010.

[2] Contract W911NF-10-1-0463, awarded on 16 Sep 2010.

[3] Wheel Force Transducer Research and Development, W911NF-10-1-0463, 1st Interim Report, September 2010 - December 2010, Prof. P.S. Els, University of Pretoria.

[4] Wheel Force Transducer Research and Development, W911NF-10-1-0463, 2nd Interim Report, December 2010 – March 2011, Prof. P.S. Els, University of Pretoria.

[5] NASA Technical Note, NASA TN D-7262, A study of fatigue and fracture in 7075-T6 Aluminium alloy in vacuum and air environments, CM Hudson, October 1973.

[6] Alcoa Alloy 7075 Plate and Sheet, Alcoa document no. SPD-10-037

7. Administrative actions

None

8. Other important information

The project is on schedule and within budget. No other important information needs to be reported on at this stage.