BGA PROJECT 11

Materials for Enhanced Gear Bending Fatigue Performance

DRAFT PROPOSAL

(Version 6, September 2010)

INTRODUCTION

This proposal has been updated following the meeting held on 24th August 2010 and outlines the topics discussed for investigation as a continuation of the work carried out in BGA Project 5 Phase 2 Parts B and C. Whilst these projects were previously run as separate programmes of work (Project 5 Phase 2 Part B as a BGA consortium project and Project 5 Phase 2 Part C as a stand-alone consortium project), it is has been decided to move forward as a single, combined follow-on study.

The work proposed here aims to explore in more detail gear material developments that result in improved load carrying capacity and reliability whilst taking into consideration aspects of performance/cost benefits. The work proposed concentrates on evaluating gear tooth bending fatigue strength using single tooth pulsator testing as has been used in previous phases of the project. The variables to be investigated include the base steel type, heat treatment method and post heat treatment processing.

Specific topics included for investigation are:-

1) The benefits to be expected from vacuum carburising when using appropriate steel selection.
2) The effect of increasing the core strength of a nitriding steel or the assessment of another nitriding steel with the potential to improve overload capacity and/or reduce cost relative to the grades currently used in industrial applications.
3) Assessment of re-heat hardened AISI 9310 VAR and LESCO 53 VIM VAR for comparison with the direct hardened data generated in Project 5 Phase 2 Part C.
4) Assessment of re-heat hardened air melt grades of AISI9310 and 18CrNiMo7 for comparison with the direct hardened data generated in Project 5 Phase 2 Part C.

5) Methods to prevent end chamfer related failures on gas carburised and root ground gears linked to initiation from remaining intergranular oxidation.
6) Evaluation of newly developed shot peening techniques for increasing the fatigue strength of carburised gears.

In addition to the work outlined above, in-situ Barkhausen Noise measurements will also be carried out using equipment provided by Stresstech. The aim of the analysis is to identify any changes in the Barkhausen Noise signal that occur during cyclic loading and the early stages of fatigue crack initiation.

1. WORK PACKAGE 1: VACUUM CARBURISED STEEL

1.1. SCOPE OF WORK

This work package will investigate the bending fatigue strength of vacuum carburised gears manufactured using a grade of steel selected by CES. For the results to be comparable with those generated previously, it is proposed that the test gears will be manufactured to the same geometrical specification as the vacuum carburised 16MnCr5 gears tested in BGA Project 5 Phase 2 Part B. The proposed test matrix for Work Package 1 is shown in Table 1.

Table 1: Proposed bending fatigue test matrix for Work Package 1.

Material	Heat treatment	Root condition	Number of gears
TBC	Vacuum carburised	Hobbed	6

It is noted that data for Ovatec™ 277L steel in the vacuum carburised condition will be provided by the BGA as in-kind support for the project. This supplementary data was generated during the X-GEAR project to give an S-N curve based on 20 staircase tests and 6 finite life tests.

1.2. COSTS

It is assumed that the material and heat treatment will be provided FOC by CES and Wallwork Heat Treatment Ltd respectively.

- Manufacture 6 pulsator test gears
- Metallurgical characterisation:
    - Micro-hardness profile and microstructural analysis
    - Retained austenite measurements (3 data points)
- Residual stress measurements (8 data points)
- Metrology checks and root scans
- Pulsator testing:

- Fixture setup and calibration
- Staircase tests (≥40 data points)
- Finite life tests (≥12 data points)

- Analysis and reporting:
  - Staircase analysis
  - Metrology interpretation and stress analysis
  - Uncertainty evaluation
  - SEM analysis of fracture surfaces

2. WORK PACKAGE 2: NITRIDED STEELS

2.1. SCOPE OF WORK

This work package will focus on the investigation of <u>one</u> of the following:-

- The effect of core hardness on the bending fatigue strength of gas nitrided gears manufactured using En40B steel.
- The performance of a different grade of nitriding steel with the potential to improve overload capacity and/or reduce cost relative to the gas nitrided En40B gears tested in Project 5 Phase 2 Part B.

For the data to be comparable with that generated previously, it is proposed that the test gears will be manufactured to the same geometrical specification as the gas nitrided En40B gears tested in BGA Project 5 Phase 2 Part B. The proposed test matrix for Work Package 2 is shown in Table 3.

Table 2: Proposed bending fatigue test matrix for Work Package 2 (either A or B will be tested, <u>not</u> both).

Material	Heat treatment	Root condition	Number of gears
A) En40B	Gas nitrided (core hardness TBC)	Hobbed	6
B) TBC	Gas nitrided	Hobbed	6

2.2. COSTS

It is assumed that the material and heat treatment will be provided FOC by CES and Wallwork Heat Treatment Ltd/Allen Gears respectively.

- Manufacture 6 pulsator test gears
- Metallurgical characterisation:
  - Micro-hardness profile and microstructural analysis
  - Residual stress measurements (10 data points per condition)

- Metrology checks and root scans
- Pulsator testing:
    - Fixture setup and calibration
    - Staircase tests (≥40 data points)
    - Finite life tests (≥12 data points)
- Analysis and reporting:
    - Staircase analysis
    - Metrology interpretation and stress analysis
    - Uncertainty evaluation
    - SEM analysis of fracture surfaces

3. WORK PACKAGE 3: RE-HEAT HARDENED AISI 9310 VAR AND LESCO 53 VIM VAR

3.1. SCOPE OF WORK

This work package will investigate the bending fatigue strength of re-heat hardened, gas carburised gears manufactured from both AISI 9310 VAR and LESCO 53 VIM VAR steel to generate comparison data with previously tested gears in the direct hardened condition. The gears will be manufactured to the same geometrical specification as the carburised gears tested in Project 5 Phase 2 Part C and the proposed test matrix is shown in Table 4.

Table 3: Proposed bending fatigue test matrix for Work Package 3.

Material	Heat treatment	Root condition	Number of gears
AISI9310 VAR	R-H harden	Ground	6
LESCO 53 VIM VAR	R-H Harden	Ground	6

3.2. COSTS

It is assumed that the material and heat treatment will be provided FOC by CES/Timken and Wallwork Heat Treatment Ltd respectively.

- Manufacture 12 root ground pulsator test gears
- Metallurgical characterisation:
    - Micro-hardness profile and microstructural analysis
    - Retained austenite measurements (3 data points per condition)
    - Residual stress measurements (8 data points per condition)
- Metrology checks and root scans
- Pulsator testing:
    - Fixture setup and calibration
    - Staircase tests (≥40 data points per condition)

- Finite life tests (≥12 data points per condition)

- Analysis and reporting:
  - Staircase analysis
  - Metrology interpretation and stress analysis
  - Uncertainty evaluation
  - SEM analysis of fracture surfaces

4. WORK PACKAGE 4: RE-HEAT HARDENED AIR MELT AISI 9310 AND 18CrNiMo7

4.1. SCOPE OF WORK

This work package will investigate the bending fatigue strength of re-heat hardened, gas carburised gears manufactured from Air Melt grades of AISI 9310 and 18CrNiMo7 steels to generate comparison data with previously tested gears in the direct hardened condition. The test gears will be manufactured to the same geometrical specification as the carburised gears tested in Project 5 Phase 2 Part C and the proposed test matrix is shown in Table 5.

Table 4: Proposed bending fatigue test matrix for Work Package 4.

Material	Heat treatment	Root condition	Number of gears
AISI9310	R-H harden	Ground	6
18CrNiMo7	R-H Harden	Ground	6

4.2. COSTS

It is assumed that the material and heat treatment will be provided FOC by CES/Timken and Wallwork Heat Treatment Ltd respectively.

- Manufacture 12 root ground pulsator test gears
- Metallurgical characterisation:
  - Micro-hardness profile and microstructural analysis
  - Retained austenite measurements (3 data points per condition)
  - Residual stress measurements (8 data points per condition)
- Metrology checks and root scans
- Pulsator testing:
  - Fixture setup and calibration
  - Staircase tests (≥40 data points per condition)
  - Finite life tests (≥12 data points per condition)
- Analysis and reporting:
  - Staircase analysis
  - Metrology interpretation and stress analysis
  - Uncertainty evaluation

- SEM analysis of fracture surfaces

5. WORK PACKAGE 5: PREVENTION OF CHAMFER FAILURES INITIATED FROM IGO PRODUCED DURING GAS CARBURISING

5.1. SCOPE OF WORK

This work package will investigate the bending fatigue strength of root ground gears treated to remove the detrimental effect of remnant IGO in end chamfers, as was identified in Project 5 Phase 2 Part C. For comparison with Phase 2 data, it is suggested that direct hardened, gas carburised gears manufactured from 18CrNiMo7 steel should be used, but depending on the final programme, this may change (e.g. to be a re-heat hardened version from WP 5). It is proposed that 2 methods are investigated as possibilities to influence the detrimental chamfer effect; a) mechanical removal prior to root grinding, b) shot peening prior to root grinding. The test gears will be manufactured to the same geometrical specification as the carburised gears tested in Project 5 Phase 2 Part C. The proposed test matrix is shown in Table 6.

Table 5: Proposed bending fatigue test matrix for Work Package 5.

Material	Chamfer treatment	Root condition	Number of gears
18CrNiMo7	Mechanical removal	Ground	6
18CrNiMo7	Shot peen	Ground	6

5.2. COSTS

It is assumed that the material and heat treatment will be provided FOC by CES and Wallwork Heat Treatment Ltd respectively. It is also assumed that MIC will provide shot peening FOC.

- Manufacture 12 root ground pulsator test gears
- Metallurgical characterisation:
  - Micro-hardness profile and microstructural analysis
  - Retained austenite measurements (3 data points per condition)
  - Residual stress measurements (8 data points per condition)
- Metrology checks and root scans
- Pulsator testing:
  - Fixture setup and calibration
  - Staircase tests (≥40 data points per condition)
  - Finite life tests (≥12 data points per condition)
- Analysis and reporting:
  - Staircase analysis

- Metrology interpretation and stress analysis
- Uncertainty evaluation
- SEM analysis of fracture surfaces

6. WORK PACKAGE 6: EVALUATION OF ADVANCED SHOT PEENING METHODS

6.1. SCOPE OF WORK

Metal Improvement Company has recently developed a new method of shot peening with ceramic media that has been found to give a significant improvement in the developed level and depth of compressive residual stress. This work package will evaluate the bending fatigue performance of carburised gears that have been shot peened using these advanced methods.

The proposed test matrix is shown in Table 7 and this assumes that the base level, unpeened, reference data will be sourced from another Work Package or Project 5 Phase 2 Part C.

Table 6: Proposed bending fatigue test matrix for Work Package 6.

Material	Heat treatment	Root condition	Number of gears
TBC	Carburised	Ceramic Media Advanced Duplex	6

6.2. COSTS

It is assumed that the material, heat treatment and shot peening will be provided FOC by CES, Wallwork Heat Treatment Ltd and Metal Improvement Company respectively.

- Manufacture 6 root ground pulsator test gears
- Metallurgical characterisation:
  - Micro-hardness profile and microstructural analysis
  - Retained austenite measurements (3 data points per condition)
  - Residual stress measurements (8 data points per condition)
- Metrology checks and root scans
- Pulsator testing:
  - Fixture setup and calibration
  - Staircase tests (≥40 data points per condition)
  - Finite life tests (≥12 data points per condition)
- Analysis and reporting:
  - Staircase analysis
  - Metrology interpretation and stress analysis

- Uncertainty evaluation
- SEM analysis of fracture surfaces

8. TOTAL PROJECT COST

8.1. RESEARCH PROGRAMME

• Work Package 1	£ 12,584
• Work Package 2	£ 13,364
• Work Package 3	£ 24,624
• Work Package 4 (50% funded by MoD(N) MPS211)	£ 12,312
• Work Package 5 (100% funded by MoD(N) MPS211)	
• Work Package 6 (100% funded by MoD(N) MPS211)	
• Preparation for and attendance at meetings	£ 9,000*
• Preparation of final report and presentation	£ 6,800
RESEARCH SUB-TOTAL (DU)	**£ 78,684**

* Estimate of cost based upon 9 meetings over the duration of the project. This cost will be reduced if the meetings are held at DU and/or combined with other meetings.

8.2. PROJECT ADMINISTRATION

• Administrative costs (Cristech and MTM Precision)	£ 12,000
• Financial/contract administration (BGA)	£ 2,500
ADMINISTRATION SUB-TOTAL	**£ 14,500**
TOTAL PROJECT COST	**£ 93,184**

Based upon a suggested project partner fee of £5000 per annum, for a 3 year period, the above project therefore requires a consortium of at least 6 partners to proceed.

9. TIMESCALES

It is proposed that this project runs over a 3 year period. DU can start work on gear manufacture as soon as steel is made available. The work will be directed by the Project Co-ordinator in conjunction with the project consortium who, by a majority vote, may decide to alter the direction of the research as the project progresses and results become available.

The initial milestones are outlined below with priority given to the Work Packages for which materials have been selected:

- End of Project Year 1: complete Work Packages 3 and 4
- End of Project Year 2: complete Work Packages 5 and 6
- End of Project Year 3: complete Work Packages 1 and 2