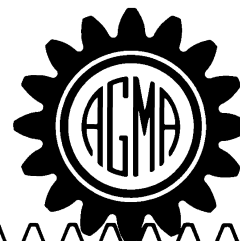


The Effects of Super Finishing on Bending Fatigue

by: G. Blake, Rolls-Royce - Transmissions and Structures

American Gear Manufacturers Association



TECHNICAL PAPER

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Gregory Blake, Rolls-Royce - Transmissions and Structures

[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

Super finishing is a technology that public literature suggests to have potential for increased power density. A study was conducted to characterize this technology's benefit to bending fatigue. Two sample groups were created, one from AMS6265, and the second from AMS6265 with super finishing.

Bending fatigue was characterized using two test methods, Single Tooth Bending Fatigue (STF) and R-R Moore rotating beam. The STF specimen was designed such that the tooth geometry replicated the normal cross section of a Rolls-Royce high power spiral bevel pinion gear. The design then allowed for the special processing of the STF gears to be common to that of the spiral bevel gear.

Two unique heat lots of material were used for each sample population. Each heat lot was processed through manufacturing as a separate machining batch. Thus, a minimum of two carburization and hardening loads, two shot peen batches and two super finishing cycles (if applicable) were processed per sample group.

Sixty-two bending fatigue test points were created. Data analysis of STF and RR Moore test data concluded no statistical difference between the bending fatigue strength of the two populations.

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Introduction

Super finishing is a technology that public literature suggests has potential for increased power density [Ref 1]. A study was designed and conducted to characterize this technology's benefit to bending fatigue. For the study, two sample groups were created: (i) AMS6265 and (ii) AMS6265 with super finish.

Bending fatigue was characterized using two test methods: Single Tooth Bending Fatigue (STF) and RR Moore rotating beam. The STF specimen was designed so the tooth geometry replicated the normal cross section of a Rolls-Royce spiral bevel gear design. The design then allowed for the special processing of the STF gears to be common to those of the Rolls-Royce spiral bevel gear design.

Two unique heat lots of material were used for each sample population. Each heat lot was processed through manufacturing as a separate machining batch. Thus, a minimum of two carburization and hardening loads, two shot peen batches, and two super finishing cycles (if applicable) were processed per sample group.

A detailed metallurgical evaluation of the specimens was performed to characterize the material and compare it to that used in the Rolls-Royce spiral bevel gears.

Data analysis of STF and RR Moore test data concluded no statistical difference between the bending fatigue strength of the two populations.

Nomenclature

Cps	Cycles per second
LCF	Low cycle fatigue, cycles to failure less than or equal to 1e4 cycles
GRI	Gear Research Institute, located within the Applied Research Laboratory at The Pennsylvania State University

HCF	High cycle fatigue, cycles to failure greater than or equal to 1e4 cycles
HL	Raw material heat lot
N	Number of fatigue cycles
Power density	The ratio between transmitted horsepower and power train weight
R	Stress range ratio (full reversing is designated as $R = -1$ and zero to maximum is designated as $R = 0$)
RR Moore	A rotating beam test method that produces a full reversing stress range
SF	Super finishing
S/N	Serial number of specimen within a population
STF	Single tooth bending fatigue in which a special spur gear design is used as a fatigue specimen and a <u>pair</u> of teeth is tested
Super finishing	An isotropic chemical process performed to achieve improved surface finish
T	Bulk temperature of specimen during test °F

Experimental Procedures

This section contains the methods and procedures used to plan, conduct, and verify the fatigue testing. The STF gear design details along with test rig limitations are also discussed in this section.

Number of STF Test Points and Load Levels

The number of test points and load levels were designed around the general relationship between bending stress and life. The general bending stress versus life relationship appears in several literature sources, and a summary is listed as follows (see Refs 2-7):

- Life distribution is logarithmic.
- Scatter is in the life direction between 1e4 and 1e6 cycles.

- Scatter is in the stress direction beyond 1e6 cycles.
- Life increases as stress decreases and life decreases as stress increases.
- The slope of the stress versus life curve changes slope and becomes almost horizontal between 1e6 and 1e7 cycles.
- Infinite life is defined at 1e7 cycles and tests running declared as run outs beyond this point.
- Life cycles greater than 1e4 are considered to be high cycle fatigue (HCF).

Six test points at three load levels in the finite life regime were created to characterize variation in life between 1e4 and 1e6 cycles at each of the given load levels. Fourteen or more test points were created to characterize the variation in stress in the infinite life regime. Fatigue points at each level were created from both heat lots to avoid biasing one load level due to heat lot variation. Four tests were conducted from each individual STF specimen gear. To further avoid bias, all four possible tests from a single gear were not conducted at the same load level. An illustration of the test load levels to characterize the stress versus life relationship is shown in Figure 1.

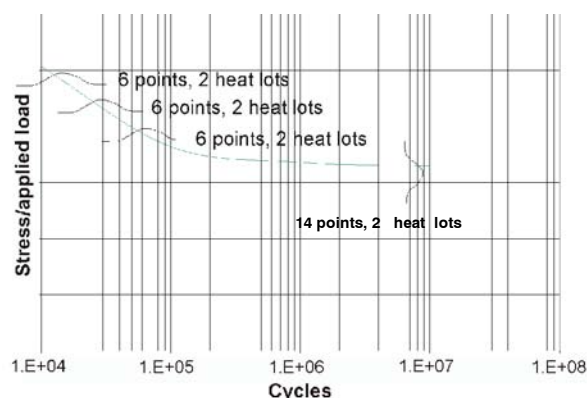


Figure 1. Illustration of test load levels, number of test points, and expected distribution.

Specimen Description and Test Procedure

The delimiting factors, or boundaries, of the bending fatigue project include the material types and surface technologies evaluated. In addition, the basic

testing methods were also delimiting factors. All specific factors are as follows:

- Forged bar stock per AMS6265 specification used for manufacture of specimens
- Common carburize and hardening cycle used for all common specimen designs
- All specimens shot peened per Rolls Royce legacy specifications
- Fatigue test data generated using single tooth bending and rotating beam
- Tests performed at room temperature, approximately 75°F
- Fatigue tests suspended at 1e7 cycles and declared as runouts
- Super finishing process used for specimens as previously developed for the Rolls-Royce spiral bevel gears
- Baseline for surface technology (super finishing) characterized is AMS6265 ground and shot peen
- Full form ground STF specimens, root, root radius, and flanks

The minimum number of STF gears required is equal to the number of fatigue test points required divided by the number of test sections per STF gears, as shown in Table 1. Additional STF gears were necessary for metallurgical evaluation.

Table 1. Required number of STF gears for the project.

Endurance test points to be created	A	14
Test points per load level above endurance	B	6
Number of load levels above endurance	C	3
Total number of tests to be created	$T=A+(B*C)$	32
Tests per gear	D	4
Number of materials (populations) to be tested	E	2
Number of gears for material evaluation per material	F	1
Minimum number of gears required for project	$T*(E/D)+(E*F)$	18

The operating limits of the test rig were considered in the specimen design. The STF gear face width and number of teeth were sized based on the maximum operating limits. Select teeth were reduced in height to allow access for the load and reaction anvils during testing. Each STF specimen gear created a maximum of four test points.

STF Test Setup and Fixture Calibration

The STF testing was conducted at Gear Research Institute located in the Applied Research Laboratory at Penn State University. A test consists of a load being applied on the left side of a gear tooth number 1 while a static anvil reacts the load on the right side of tooth number 4. Thus, two teeth are fatigued during the test, as shown in Figure 2. The desired anvil contact point is in the upper 25% of the active profile.

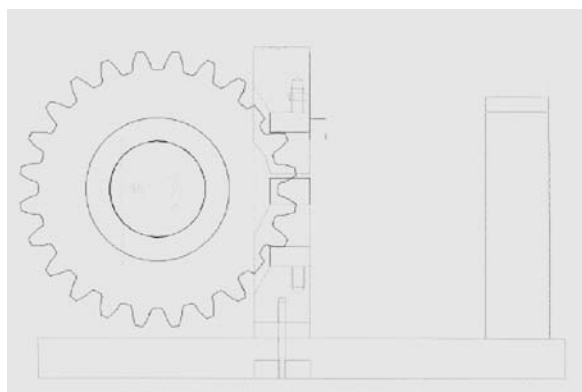


Figure 2. Layout illustration of STF test rig setup.

A rigorous test rig and fixture calibration was performed prior to testing. A gage consisting of 10 individual strain gages was placed at the midface width of one tooth root radius on the loaded side, as shown in Figure 3. The gear was then placed in the fixture with the instrumented tooth oriented up. Strain versus load was recorded for each of the strain gages. The applied load was incremented from zero to a maximum. The process was repeated a minimum of three times to demonstrate repeatability of measured strain. The instrumented tooth was then oriented down and the strain versus load sequence repeated. The reaction anvil of the fixture was then shimmed until the upper readings equaled the lower readings. These values were later used to validate the STF finite element model results not presented in this paper.

The maximum load frequency is a function of the test rig and fixture, and specimen is determined for each setup. A second STF gear was used to determine the frequency for estimating the total testing duration. Figure 4 shows an acceptable load wave form at 20,000 lb and 15 Hz. The actual frequency for each test varied based on the maximum that could be achieved while maintaining a “smooth” load wave form.



Figure 3. Strain gage placement.

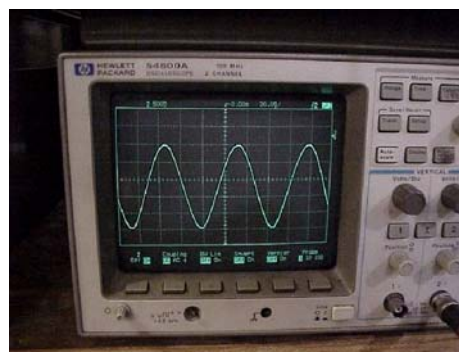


Figure 4. Load cell response at 15 Hz and 20,000 lb.

The temperature of an STF gear was measured using a physical-contact temperature probe. The measurement was made on the end face, near the root radius of the upper fatigued gear tooth. The gear had completed 2.7×10^4 cycles at 20,000 lb load at the time of measurement. The measured STF gear temperature was 74°F.

Manufacturing Processing

The STF and RR Moore specimen manufacturing details are discussed in this section. The STF gears were processed in the same manner that the Rolls-Royce bevel gears were. The RR Moore specimens were also processed in a similar manner as the pro-