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AN EXPERIMENTAL INVESTIGATION OF GEAR PITTING SURFACE FATIGUE FAILURE

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Abstract

Pitting is a surface fatigue failure of the gear tooth. It occurs due to repeated loading of tooth surface and the contact stress exceeding the surface fatigue strength of the material. Material in the fatigue region gets removed and a pit is formed. The pit itself will cause stress concentration and soon the pitting spreads to adjacent region till the whole surface is covered. Subsequently, higher impact load resulting from pitting may cause fracture of already weakened tooth. However, the failure process takes place over millions of cycles of running. There are two types of pitting, initial and progressive. Initial pitting occurs during running-in period wherein oversized peaks on the surface get dislodged and small pits of 25 to 50 μm deep are formed just below pitch line region. Later on,the load gets distributed over a larger surface area and the stress comes down which may stop the progress of pitting. Experimental contact fatigue tests utilizing spur gears were performed using FZG gear test machine.

Index terms - Pitting, Surface fatigue failure , FZG gear test machine, Initial pitting ,Progressive pitting

I. INTRODUCTION

Pitting is a form of surface fatigue which may occur soon after operation begins and may be of three types: 1 - initial (corrective) 2 - destructive 3 - normal initial pitting is caused by local areas of high stress due to uneven surfaces on the gear tooth. This type pitting can develop within a relatively short time, reach a maximum and with continued service polish to a lesser severity. Initial pitting usually occurs in a narrow band at the pitch line or just slightly below the pitch line. It is most prominent with through-hardened gears and is sometimes seen with surface-hardened gears. The Classical pit appears as an arrowhead pointing in the direction of on coming contact. Starting at the surface of the tip of the arrowhead, the fracture proceeded inward at a shallow angle to the surface. Simultaneously, the crack broadened forming the arrowhead. The back side of the pit has a steep side. Although there were several large pits on the tooth surface, this pitting was

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corrective since it progressed no further with continued operation. For most through-hardened industrial type gears, initial pitting is considered normal and no remedial action is required. Where necessary, initial pitting can be reduced by special tooth finishing means and sometime by a careful break-in at reduced loads and speeds. In some special critical applications, teeth are copper or silver plated to prevent or reduce initial pitting.

II. BACKGROUND INFORMATION

EXPERIMENT TEST SET-UP

Experimental contact fatigue tests utilizing spur gears were performed using three similar FZG gear test machines. These FZG machines create a four-square power circulation loop, within which specified test torque loads are applied. A schematic of the FZG machines used for testing is shown in Figure 1 The FZG machines have two gearboxes each. The reaction gearbox on the motor side includes a reaction gear pair which has a greater face and hence very low contact stresses and greater life expectancy than the test gears. The reaction gearbox used a more viscous gear lubricant to offer greater wear protection to the reaction gears. The test gear pair is installed in the test gearbox farthest from the motor. This allows greater accessibility to the test gears for easier visual and measured inspections.

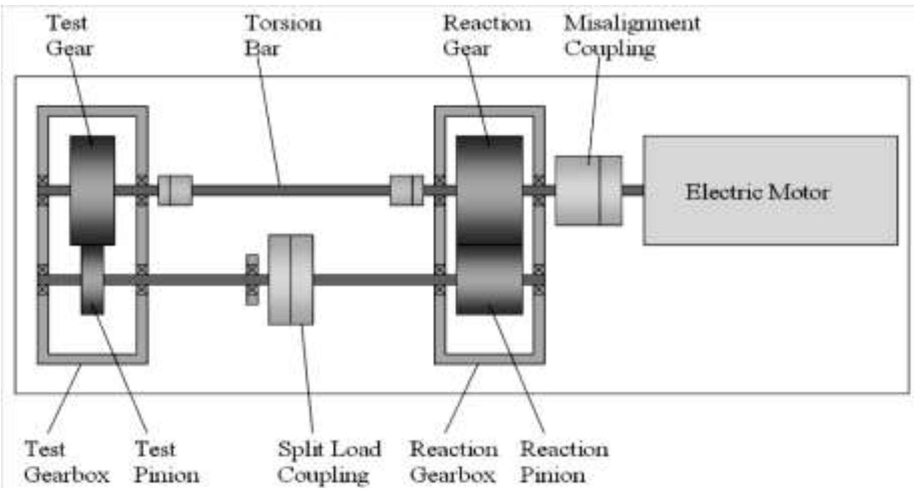

Figure 1: A detailed FZG schematic from Bluestein.

Initial tests performed by a sponsor used Dexron III automatic transmission fluid as the lubricant. Another variation, Dexron VI, was used in pitting tests performed by Bluestein . Dexron VI was also used for all testing performed for this thesis study. Although there were concerns for potential disparities in the results from the use of these two lubricants, these differences were found to be insignificant when fatigue data for these two lubricant variants were compared. For this reason, the test data sets for each lubricant have been combined into one data set.After the spur gear pairs were installed within the FZG machines, the lubricant reservoir was filled with Dexron VI until the spur gears were halfway immersed within the fluid. Fresh lubricant was used at the start of each test, and the same fluid was used throughout the test until the test was completed. During the progression of a test, any metallic debris that might be produced due to wear or small pits on the pinion surface were separated from the oil bath through a magnet placed at the bottom of the gearbox.

III .TEST PROCEDURES

Before the start of each fatigue test, pinions and gears were thoroughly cleaned with isopropyl alcohol and then put on a Taylor-Hobson Form Talysurf-120 surface profiler to measure their surface roughnesses in the direction of sliding (profile direction). These measured roughness profiles were quantified by using *Ra* (centerline average roughness) and *Rq* (root-mean-square roughness) values as the roughness parameters. Pinions and gears that exhibited any unusual surface roughnesses, such as those having higher *Ra* and *Rq* values than the typical values associated with the finishing process, were discarded. In addition, a Gleason M&M 255 gear coordinate measurement machine (CMM) was used to measure four different teeth on each pinion and gear. Three involute and three lead profile traces were obtained on each tooth surface. Similar to the procedure for surface roughness measurements, any pinion and gear that exhibited excessive deviations from the intended leads and involute profiles, were not used for testing. Lastly, an optical microscope with a 1/2X objective lens and 5X magnification was utilized for inspecting and taking digital pictures of the pinion tooth surfaces before testing. Once the pinions and gears were measured, a fatigue test was initiated with a 120 minute run-in test period at a low pinion torque level of 143 Nm and speed of 1440 rpm. After this run-in period, the pinion and gear were wiped clean and visually inspected for any abnormalities. Following visual inspection, a fatigue test was started under the decided upon torque value. The FZG machines were run at a constant gear speed of 1440 rpm ± 5 rpm, and the temperature of the Dexron VI was kept at 90^{o}C ± 3^{o}C throughout both the run-in period and the remainder of each test. During testing, the pinion and gear specimens were inspected every 10% of their predicted life with each inspection alternating between visual inspections and those involving physical inspections. During visual inspections, the lubricant was drained from the test gear box, and the test gear box lid and front cover were then removed. Both the pinions and gears were wiped with a clean rag and visual changes to the pinion and gear tooth surfaces were noted. If any fatigue pits or crack initiations were observed during a visual inspection, a physical inspection was obtained before any additional testing cycles were performed. If none of the failure criteria was met, additional testing resumed. Physical inspections of test specimens involved removing the pinion and gear from the FZG machine and thoroughly cleaning the pinion and gear surfaces with isopropyl alcohol. Upon cleaning the specimens, measurements were obtained from both the Talysurf roughness machine and the gear CMM. An optical microscope was also utilized to obtain digital pictures of the pinion tooth surfaces. All measurements obtained with the Talysurf and the Gleason M&M were always made on the same gear teeth as those measured during the initial measurements. If fatigue pitting prevented an accurate surface roughness from being obtained, the nearest tooth surface without any signs of pitting was utilized for the interim roughness measurement.

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IV. MAIN RESULT IV .TEST SPECIMENS

The spur gear specimens utilized for experimental testing in this work had identical gear geometries to those utilized by the sponsor during the phase-one study and those tested in the study by Bluestein . Design parameters of the test gear pair is shown in Table 1. All tested gear specimens were heat treated to a surface hardness value of 60 HRC with a case depth of approximately 1.3 mm. The test gears were made of AISI 8620 and AISI 4620M steel alloys. Differences in elemental composition of the AISI 8620 and AISI 4620M alloys are shown in Table 2. In order to determine the significance of various surface treatments on gear pitting fatigue life, several types of treatments were used for the AISI 8620 gears. In addition to studying contact fatigue dependence on surface treatments, ground gears manufactured from AISI 4620M steel were also tested in order to investigate impact of changing the material type.

Table 1: Basic design parameters of the spur gear pair.

Parameter	Pinion	Gear
Module (mm)	4.23	
Center Distance (mm)	91.50	
Number of Teeth	17	26
Pressure Angle (deg)	22.5	
Face Width (mm)	14.00	20.29
Pitch Diameter (mm)	71.97	110.07
Base Diameter (mm)	66.49	101.69
Outside Diameter (mm)	80.02	117.11
Root Diameter (mm)	62.87	99.95
Start of Active Profile (mm)	67.92	105.33
Circular Tooth Thickness (mm)	7.81	5.65

Table 2: Elemental Composition by Weight % of Test Specimens

Element	AISI 8620	AISI 4620M
Cr	0.4-0.6	0.2 Max
Ni	0.4-0.7	1.65-2.00
Si	0.15-0.35	0.15-0.35
P	0.035 Max	0.025 Max
Mn	0.7-0.9	0.45-0.65
Cu	0.1	0.35 Max
Mo	0.15-0.25	0.5-0.7
S	0.04 Max	0.025 Max
C	0.18-0.23	0.17-0.22

Hobbed and Shaved (HS) – These AISI 8620 gears were hobbed and shaved before heat treatment. Irregularities in the involute and lead profiles from the shaving process and the heat treatment process can occur on the tooth surfaces. For this reason, all specimens were physically measured before all testing. It is considered that for the surface Treatment HS ,the average initial Roughness

– R_a as 0.35 µm. The test load levels and their related normalized torques and contact stresses are shown in the Table 3.

Table 3: Test Load Levels and their related normalized torques and contact stresses.

Load Level	Normalized Torque	Normalized Pitch Line Contact Stress	Normalized Maximum Contact Stress
L1	3.81	1.55	1.62
L2	3.27	1.46	1.53
L3	2.67	1.35	1.42
L6	1.94	1.20	1.26
L4	1.73	1.16	1.22
L5	1.20	1.03	1.09

V. RESULTS

GEAR PITTING TEST RESULTS

In previous testing preformed by Bluestein , the majority of experimental tests were performed at higher torque values. These high torque values produced a large number of successful experiments in a relatively short period. In order to obtain confidence data for lower torques and contact stresses, the majority of testing included in this work involved lower loads. All tests performed in this work had procedures and failure criteria that were consistent with the original study. For the tests using Hobbed and Shaved (HS) gears, there were a total of 50 successful tests (46 pit failures and 4 suspended tests). Of these successful tests, 8 tests (5 pit failures and 3 suspended tests) resulted from this work. One suspended test occurred at load L6, and the rest of the tests occurred at load L4. Stress-life (S-N) charts for both normalized pinion torque and normalized contact stress of the HS tests are shown in Figure 1.The large number of successful tests at load L4 allowed the confidence intervals to be calculated and plotted on the S-N curves along with the test data points as shown in Figure 2. As mentioned previously, tests that were suspended without failure were included when calculating the confidence intervals. The inclusion of suspended tests within the confidence data was done .

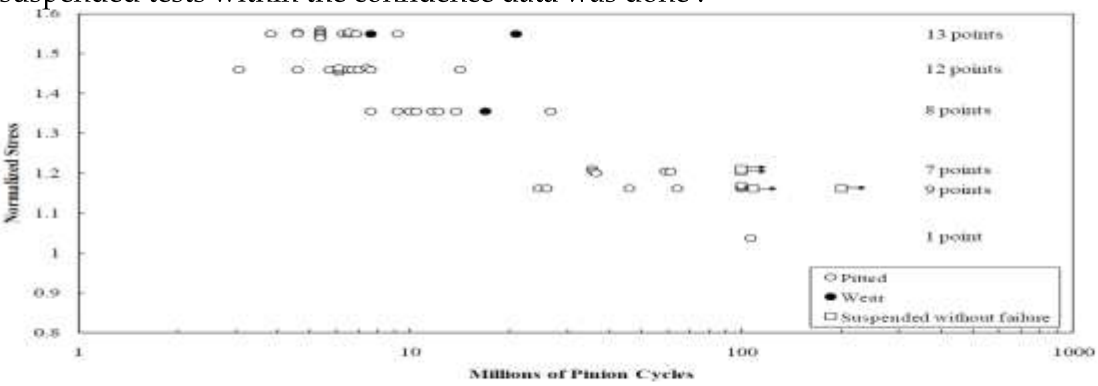

Figure 2: Normalized pinion pitch line stress versus pinion cycles for HS gears.

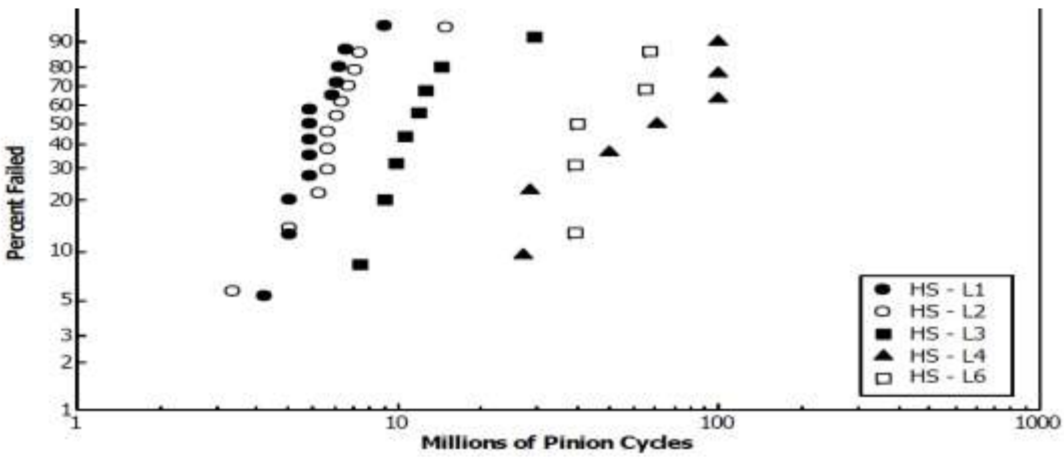

Figure 3: Weibull distributions of HS pitted tests at different load levels.

Although the number of cycles for the pitted specimens does not exceed 60 million pinion cycles, the 90% Confidence Interval occurs at approximately 70 million cycles. This result occurs from the inclusion of the two tests suspended at 100 million cycles with no pits. Weibull distributions were calculated for each of the load levels of the HS tests. Unlike the confidence intervals mentioned above, these Weibull distributions did not include suspended tests and, therefore, have less data points. Although the roughness values for the HS and ground specimens were very similar to each other, it was also worthwhile to make a comparison of Rq roughness values between the specimens. Higher values in these *Rq* values would suggest a greater variation in asperity contact magnitudes along the tooth surface and may influence the contact fatigue life of each specimen. For the HS gears the average Surface Roughness (*Rq)* value was 0.5001µm .

VI. CONCLUSION

Based on the tests results presented in the previous section, the following conclusions can be listed in regards to the effects of surface treatments and material variations on fatigue pitting of gears . At lower load levels, the expected fatigue life for HS gears significantly longer than other type of gears. However, the difference in measured fatigue life was not as great at higher contact stress conditions. Additional testing at different load levels and an increased number of data points at previously tested load levels are needed to confirm this suggestion.

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