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Effects of Gear Surface Parameters on Flank Wear

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[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

Non-uniform gear wear changes gear topology and affects the noise performance of a hypoid gear set. The aggregate results under certain vehicle driving conditions could potentially result in unacceptable vehicle noise performance in a short period of time. This paper presents the effects of gear surface parameters on gear wear and the measurement/testing methods used to quantify the flank wear in laboratory tests. Gear tooth profile, transmission error, gear tooth surface finish determined by cutting, and gear tooth surface finish determined by other processes are the factors considered in this paper. The measurements include transmission error, coordinate measurement machine (CMM), pattern rating, and surface roughness pre and post test. ASTM L-37 based dynamometer test procedure is adopted for the wear study with good correlation to field samples. The laboratory test samples are established based on design of experiment considering the controlled factors. The effects and interaction between controlled factors provided the information for product improvement. The action resulted from this study is anticipated to significantly improve product reliability and customer satisfaction.

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Introduction

Non-uniform gear wear changes gear topology and affects the noise performance of a hypoid gear set. The aggregate results under certain vehicle driving conditions could potentially result in unacceptable vehicle noise performance in a short period of time.

This paper presents the effects of gear surface parameters on gear wear and the measurement/testing methods used to quantify the flank wear in laboratory tests. Gear tooth profile, transmission error, gear tooth surface finish determined by cutting and lapping, and gear tooth surface finish determined by post hard test processes are the factors considered in this paper. The measurements include transmission error, coordinate measurement machine (CMM), pattern rating, and surface roughness pre and post test. ASTM L-37 [1] based dynamometer test procedure is adopted for the wear study with good correlation to field samples. The laboratory test samples are established based on design of experiment (DOE) [2] considering the controlled factors. The effects and interaction between controlled factors provided the information for product improvement. The action resulted from this study is anticipated to significantly improve product reliability and customer satisfaction.

Gear wear can be separated into two different types: one is the uniform wear of tooth surface that doesn't affect the noise performance, and the other is the non-uniform wear of tooth surface that affects the noise performance. The differences are as shown schematically in Figure 1. Curve AA represents the original tooth profile. A uniform wear will remove material from the tooth and create a new profile BB. Due to the non-uniform wear, the actual profile is as shown by curve CC. The discussions in this paper are focused on the non-uniform gear wear.

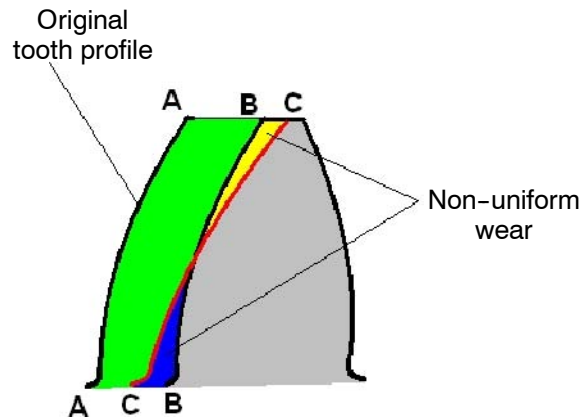


Figure 1. Gear wear

Gear surface parameters

The parameters considered for the DOE include:

- Gear tooth profile
- Gear set TE (transmission error)
- Gear tooth surface finish determined by cutting and lapping
- Gear tooth surface finish determined by processes post hard test

Other factors that have effects on uniform gear wear are identified in the test procedure development stage and excluded from the DOE for reasons explained above.

Measurement methods

Both objective and subjective ratings are used in pre-test and post-test stages for comparison purpose.

- TE measurements (single flank tester): The first order drive side TEs are measured pre-test and post-test. The difference in TE measurements pre and post test (Delta TE) is an important indicator of the uneven wear. This TE measurement process is defined as hard test. It is performed after lapping and prior to final processing.
- CMM measurements: Sum of squared errors compared to a master is a good way of measur-

ing non-uniform gear wear. The sum of squared errors is the sum of the square of error at each grid point.

Sum of squared errors = $\sum_{i,j=1}^N (\text{Deviation at row } i \text{ and column } j)^2$

The uniform gear wear is covered by the tooth thickness change from CMM measurement results. The ratio of the post-test sum of squared

errors versus pre-test number is an indicator of the non-uniform wear based on appropriate resolution of mesh points. Figure 2 shows a typical pinion measured on CMM prior to gear wear test. Figure 3 shows a pinion with less non-uniform gear wear after wear test. Figure 4 shows a pinion tooth surface with more non-uniform wear after wear test.

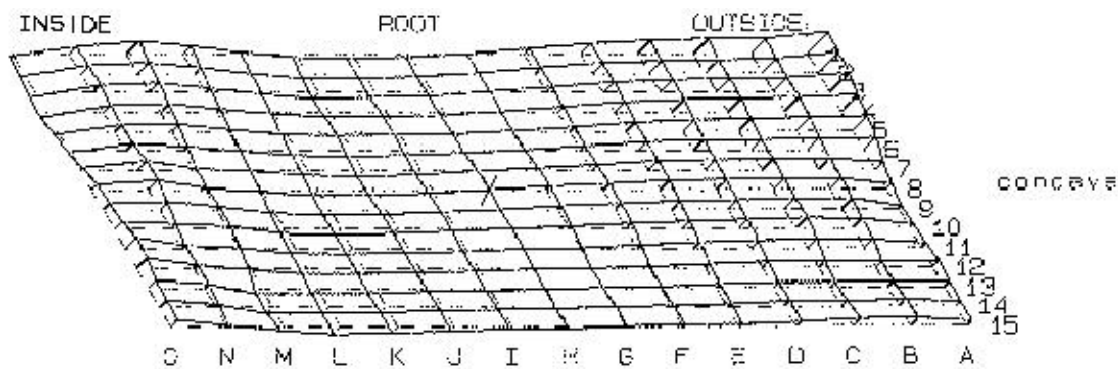


Figure 2. Pre-test pinion CMM results

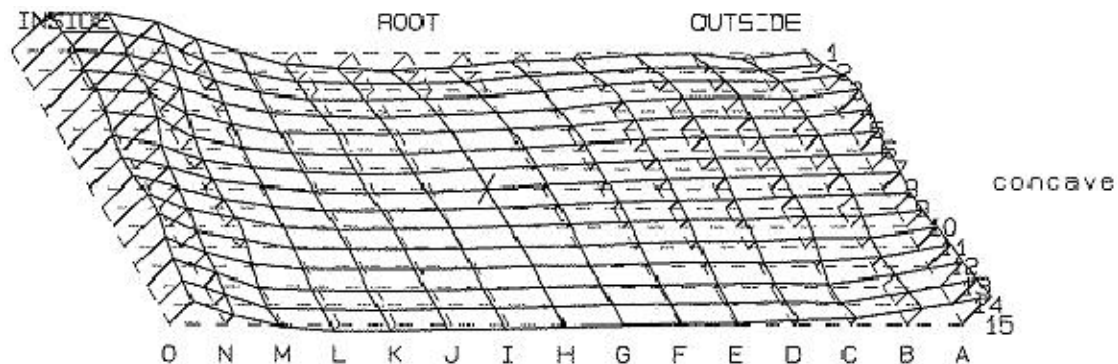


Figure 3. Post-test pinion CMM results with less non-uniform wear

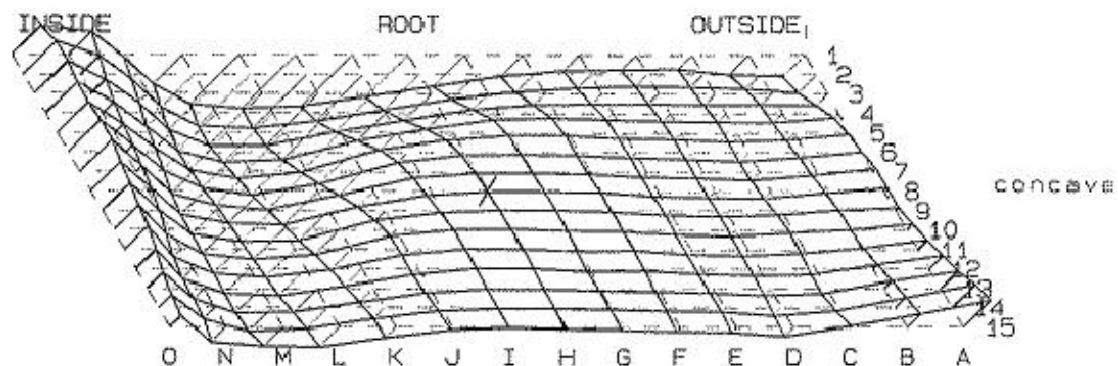


Figure 4. Post-test pinion CMM results with more non-uniform wear

- **Pattern rating:** This is a subjective rating helpful during the development of test procedure. The ratings range from 1 to 10 with 10 as the best pattern and 1 the worst. The patterns of the test gear set are taken and documented before and after test. A qualified gear set representing the development has been used as the semi-masters. Patterns of pinion and gear rolled against semi-masters separately after test are also documented to identify the wear on each part.
- **Surface roughness:** The pre-test and post-test surface finishes are part of the measurements. A typical hypoid gear tooth surface roughness is as shown in figure 5. The three-dimensional surface can be established by scanning an area. The surface roughness numbers used in the

DOE is along the tooth profile direction.

Test method

The developed lab test is based on ASTM L-37 dynamometer testing. Test load and speed were selected on the basis of testing several similar gear sets and observing the induced tooth wear. Care was taken to obtain a set of accelerated test parameters that induce only tooth wear, not any other type of system failure. It is a high load and low speed test intended to duplicate non-uniform gear wear with gear contact pattern in Figure 8. A twenty-four hour test procedure is effective in differentiating non-uniform gear wear of samples with different parameters. The test equipment is shown in Figure 6. A typical pinion after wear test is shown in Figure 7.

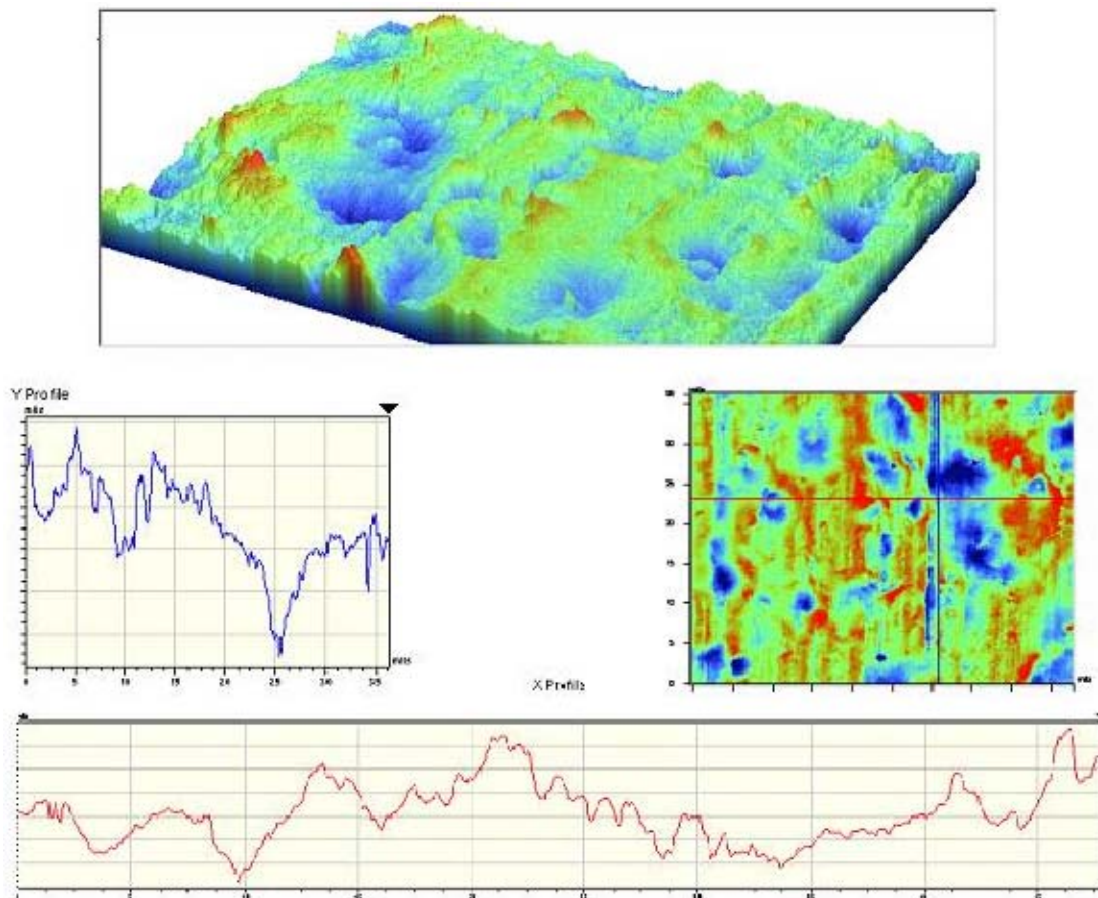


Figure 5. Typical gear tooth surface roughness