

Gear Tooth Bending Fatigue Crack Detection by Acoustic Emissions and Tooth Compliance Measurements

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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:

Early detection of cracks in gear teeth subjected to standard bending fatigue tests has long been a difficult prospect. The purpose of this paper is to present the results of gear tooth bending fatigue tests in which the combination of acoustic emissions measurements and tooth compliance measurements are explored as tools for early crack detection. Single tooth bending fatigue tests for several different gear materials were performed on an electrohydraulic fatigue testing machine using a standard SAE fatigue test fixture and gear geometry. Throughout testing, acoustic emissions were monitored using an acoustic emissions transducer affixed to the surface of the gear. Tooth compliance was measured using an accelerometer affixed to the lower platform of the fatigue test fixture. The combination of these two crack detection methods serves to describe such fatigue test characteristics as the probable time of crack initiation, rate of crack propagation, and percent of total fatigue life spent in crack propagation phase. The effects of materials, metallurgical processes such as carburization and shot peening, and the resultant surface finish on the fatigue process as revealed by these crack detection methods are also presented.

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Introduction

Because gear tooth bending fatigue failures tend to be more serious than any other gear failure mode [Alban, 1985], an extensive effort is underway among researchers to develop accurate models for the prediction of gear tooth bending fatigue life as well as to generate experimental data for comparison with such models.

As described by Collins [Collins, 1981], "Fatigue may be characterized as a progressive failure phenomenon that proceeds by the *initiation* and *propagation* of cracks to an unstable size." This implies that fatigue life prediction models must be designed to address both the crack initiation and the crack propagation regimes of the total fatigue process such that

$$N = N_i + N_p$$

where N is the total fatigue life, N_i is the number of cycles to initiation, and N_p is the number of cycles of propagation.

This entire fatigue process, including both the crack initiation and crack propagation phases, can be simulated in the laboratory using an electrohydraulic testing machine fitted with a fixture which allows a cyclic bending load to be applied directly to a single gear tooth. Such testing, known as single tooth bending fatigue testing, allows the exploration of the effects of materials, metallurgical processes, surface finish, geometry, etc. on the fatigue process.

Due to the nature of this type of testing, however, the ability to detect fatigue crack formation during each test can be difficult. Safety concerns prohibit the close-up visual inspection of the tooth fillet during the test. Also, the geometric constraints imposed by the test fixture make conventional crack detection methods difficult to apply during testing. Such

methods include dye penetrant inspection, magnetic particle inspection, eddy current inspection, ultrasonic inspection, and radiography.

Two methods for detecting and monitoring the growth of fatigue cracks, however, have been found to be very compatible with single tooth bending fatigue test conditions: acoustic emissions measurements and tooth compliance measurements. Furthermore, the combination of these two methods applied in parallel during testing has produced reliable characterization of the fatigue process for various gear materials, surface finishes, etc.

The remainder of this paper presents the results of research aimed at exploring the use of these crack detection methods on gears of various materials, surface finishes, and metallurgical processes.

Test Fixture and Gear Geometry

In order to facilitate consistent and reproducible fatigue test results, the Society of Automotive Engineers (SAE) has developed a standard fatigue test fixture, test gear geometry, and testing procedure to be used throughout the gearing industry [Buenneke, et al, 1982]. The standard SAE test gear geometry has 34 teeth, a 20° pressure angle, a diametral pitch of six, and an outer diameter of six inches. A detailed description of this test gear and fixture geometry can be found in the above reference. Throughout this research, the standard SAE geometry and testing procedure were used. Figures 1 and 2 illustrate the test fixture and the test gear geometry.

Gear Materials

Several materials were used for fatigue testing.