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Parametric Study of the Failure of Plastic Gears

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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

Researchers at Bradley University have been collaborating with engineers at Winzeler Gear to develop tools for the prediction of plastic gear tooth failure for any given set of operating conditions and to classify failure modes of these gears. The goal of the project is to characterize and predict the failure of plastic gears over a range of given parameters. The experiments to characterize the performance have been conducted on a gear dynamometer. The dynamometer uses two polymer spur gears in mesh; one gear attached to the drive shaft which is driven by a digitally controlled DC motor and the other attached to a parallel driven shaft which is coupled to a digitally controlled hysteresis brake. The dynamometer is equipped with a set of optical encoders which are attached to each of the shafts. Since temperature of the gear is a primary concern, the dynamometer is also equipped with an infrared temperature sensor. The sensor allows for measurement of the tooth flank temperature as it traverses into and out of the mesh zone for either the drive or driven gear. To help control the temperature of the gears, a fan was mounted above the mesh and blows cooling air on the test gears.

A test plan was developed to explore the effect of rotational speed, root stress, and flank temperature on the life of these gears. Instead of using a classical test plan, a Latin Square test design and analysis was used to reduce the number of experiments and the time required. The torque (or root stress) was tested at three levels, the cooling air velocity at three levels, and the rotational speed at four levels. The dependent variable for the experiments was the number of cycles (or rotations) until failure.

Three different gears were used in this test protocol. Each of the gears was injection molded from Delrin 311DP at Winzeler Gear. The three gear geometries were designed to have the same center distance so that the dynamometer did not need to be adjusted during the length of the test. Each of the three gears had a different number of teeth corresponding to a different module. The Latin Square was run on each of the gears and a linearizing and least squares technique was used to fit a power equation to the data. The data showed an average error in the 15–20% range which, according to engineers at DuPont, is similar to the error in their dog bone test specimens.

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Introduction

Over the last seven years, Bradley University has been working with Winzeler Gear Company of Chicago Illinois through a series of graduate and undergraduate research projects. Much of the work has been centered on a parallel-shaft, rotary gear dynamometer. Winzeler Gear manufactures various plastic gears mostly for automotive system uses. Many of these gears are used for window actuators, door locks and HVAC control systems to name a few of the systems. The long-term goal of the projects at Bradley is to characterize and predict the failure of plastic gears over a set of given operating parameter.

The dynamometer

As already noted, most of the testing has been performed on a parallel-shaft rotary gear dynamometer which was designed and assembled through a collaborative effort between Bradley and Winzeler Gear. The dynamometer can be seen in Figure 1. The dynamometer uses two polymer gears in mesh. The gear mesh is shown in Figure 2. The gear on the right is connected to the drive shaft which is driven by a digitally controlled DC motor. The motor controller allows the user to dynamically control the speed of the drive shaft between 0 and 500 RPM. Directional control is also available. The gear on the left is attached to the driven shaft which is coupled to a digitally controlled hysteresis brake. The hysteresis brake has its own controller which is connected to the data acquisition computer. The torque can be digitally varied from 0 to 3.6 Nm. The dynamometer controller also has measured outputs of speed and applied torque. It also has an internal PID control for the applied torque.

The dynamometer is equipped with a set of optical encoders that are attached to each of the shafts. The encoders feature Z referencing and 5000 increments per revolution. With the encoders, the shift in the relative angular position between the gears can be measured to within about 0.1° as the test progresses. This is particularly useful information in the

testing of plastic gears since plastic gears can experience significant deformation during operation and before failure.



Figure 1. Dynamometer



Figure 2. Gear mesh

Heating a plastic gear to a temperature higher than the limits of its normal operating range has a significant effect on the properties of the gears and can lead to a significant reduction in gear life. Since the temperature of the gear is such an important concern, the dynamometer is also equipped with an infrared temperature sensor that measures the surface temperature of the gear flank. This is shown in Figure 3. The sensor is mounted on an orbital track which allows for temperature measurements