

An Experimental Methodology to Determine the Low Energy Wear Model

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ABSTRACT

The basis for this paper is associated with off brake disc thickness variation (DTV) generation. This paper focuses on an experimental methodology developed to determine the rotor wear rate given very low pad to rotor contact forces as seen during the off brake condition. The basic elements for the design and development of a semi-automated test system are covered. These elements include: experimental test bench features, test sequence, pre / post test sample preparation / measurements, data acquisition / processing and post test analysis. A brief review of the wear model equation analytical development is also included along with the integration into the Adams Model environment.

INTRODUCTION

Traditionally, low pressure rotor wear tests utilize a 12.7 x 25.4 mm pad sample puck pressed against one side of a rotor face at a specified pressure while the rotor rotates at a specific velocity. This low pressure drag technique is utilized for a specified amount of time. The rotor face is commonly measured using a micrometer or profilometer at various points (typically 3 to 8) equally spaced around the rotor and an average wear number is calculated. Typically, three tests are performed utilizing different pad pressures (0.345, 0.689, and 1.034 bar). These tests result in obtaining three rotor wear values for the three loading conditions that were tested. As an example, the pad may be placed against the inner rotor face at a pad pressure of 0.345 bar while the rotor is rotated at an equivalent speed of 50 mph for 50 hours. The test is then repeated for a 0.689 bar and 1.034 bar loading condition and an average wear result for 0.345, 0.689, and 1.034 bar pad loading condition is calculated. This rotor wear data is then utilized to compare versus a target value or against other friction formulation-rotor interface results.

LOW ENERGY WEAR MODEL METHODOLOGY

To develop a low energy rotor wear model, multiple data parameters are required to build an energy versus wear characteristic curve. To obtain these data points, a fixture was designed and manufactured that allowed 3

pad sample pucks to be tested on each rotor face at one time, in which the sample-to-rotor force could be varied independently. Three tests would be performed, but the tests would be performed at three different rotor velocities. In this way, a total of 9 data points on the inner rotor face and 9 data points on the outer rotor face could be acquired. With the loads varied across each rotor face, an Energy versus Wear equation can now be derived from 18 data points.

TEST STAND FIXTURES

A new test stand had to be devised to allow for constant loading to each individual pad sample puck and allow three pad sample pucks to be used on both rotor faces at one time. Ideally, a new test stand would have been manufactured that could have utilized hydraulic inputs for each pad sample. For cost reasons, a fixture was designed to be compatible with a current Bosch test stand capable of achieving at least a 1000 rpm constant speed. The fixture was designed to be versatile enough to allow for independent loads to be applied to each pad sample puck by installing or removing dead weights. Because the fixture was designed using a bell crank to transfer the load 90° from the vertical to the horizontal, there are some frictional losses that can keep the full dead weight load from being transmitted to the pad sample puck. If there is excessive rotor and/or pad wear, a lever ratio loss or gain can take place during the test. To off-set this loss/gain, thumb screws are installed in the lever to reposition the lever back to the original starting position. Load transducers were installed to record the load throughout the test to ensure that a constant load was achieved. Figure 1 provides a representation of the test fixture.

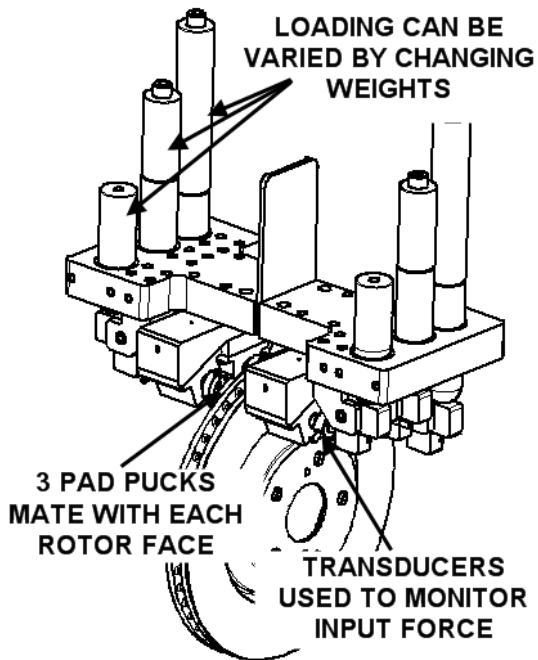


Figure 1: Low Pressure Wear Test Fixture

DATA ACQUISITION

The test stand's data acquisition system was set up to acquire the following parameters

- Load (N) at each sample puck position
- System torque (N-m)
- RPM
- Inner rotor face temperature ($^{\circ}\text{C}$, optional)
- Ambient Temperature

Data is acquired at 100 Hz during the first hour of testing and every hour afterwards for a 10 second interval to insure the loading remains constant over the duration of the test. The rotor temperature typically measured less than 49°C at the highest energy level.

GENERAL PROCEDURE

Friction Material Preparation – Pad samples are acquired and the 12.7 x 25.4 mm samples are cut from the full pads as shown in the below figure. Six pad sample pucks are required for testing, which usually results in multiple full pad assemblies being needed. The sample pucks are also ground to a specified flatness. The sample pucks are then measured for load versus deflection, Rockwell, and E-TEK V21 and V22 measurements.

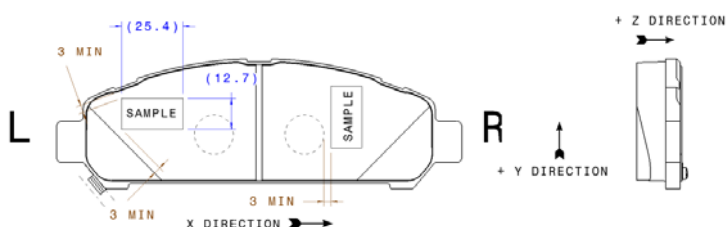


Figure 2: Sample Puck Cut-Out Example

The friction sample pucks are also measured for thickness at three locations from the backing plate to the friction face, which will allow for taper wear and average wear to be evaluated after post test measurements are acquired. Small sample testing requires extra care in specimen preparation, handling, and setup. It is important to understand the condition of the friction material being tested. Different wear amounts may result if the pads are scorched, burnished, or green. A total of 18 sample pucks may be required to perform scorched pad testing.

Rotor Preparation – Three rotors are required to perform the testing. Many rotors typically come with a protective coating for corrosion resistance. The coating must be removed without changing the rotor substrate underneath the coating. This can typically be done using an MEK solution and a shop rag, but some coatings will require other cleaning solutions to be utilized.

After the rotors are cleaned, each rotor is serialized with the test number and rpm test speed of 361, 581, and 726. The rotors are measured for free state LRO and DTV at the center of what will be three wear paths. The rotors are then placed into a holomapper imaging device that maps the rotor position in terms of x, y, and z coordinates. One million data points are mapped out in a 300 x 300 mm area. The sections of the rotor that are not being evaluated are masked off so that only the rotor face data is provided. The holo-mapping process can provide a 2D visual representation of the rotor surface or a 3D rotor face representation as shown in Figure 3.

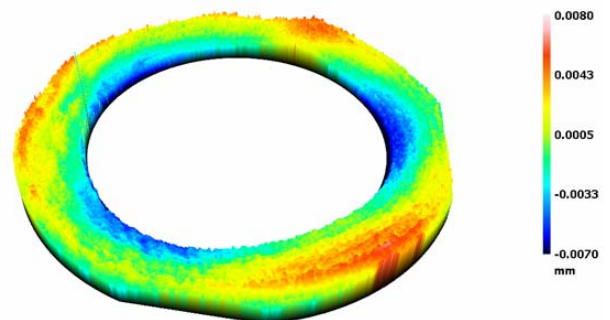


Figure 3: Pre-test Holomapper 3D Image

Test Procedure – Each sample puck is installed into the appropriate position and the sample pucks are pressed against the rotor at each sample puck's respective load for 67 hours at a velocity of 361 rpm's. The load applied to each sample puck is monitored and recorded during the 67 hours of testing. Each loading condition creates three independent wear paths on the inner and outer rotor face. As an example, the inner rotor face is shown in Figure 4.



Figure 4: Post-test Inner Rotor Face Example

Post Test Measurements – After the 67 hours are completed, the sample pucks are measured at the same three places as the pre test measurements for thickness. The sample pucks are reground flat and the test is repeated at 581 rpm's using a new rotor. The test is repeated a third time at 726 rpm's using a new rotor and reusing the sample pucks from the 581 rpm test after the pucks have been ground flat.

The rotors are again measured for the free state LRO and DTV along with the holo-mapper imager. The post test holo-mapper imager typically yields a 3D image as shown below where any rotor wear in the sample pucks path can be visualized. In Figure 5, the depth of the inner path can be seen to vary around the face of the rotor.

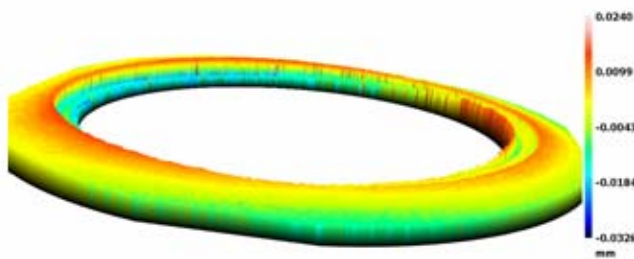


Figure 5: Example of Post-test 3D Holo-mapper Wear

DATA ANALYSIS PROCESS

Data analysis is performed using Matlab® and Microsoft Excel.

Rotor Wear – Rotor wear is calculated by taking the pre test holomapper measurement and subtracting the post test holomapper measurement. In order to acquire accurate wear measurements, the x and y coordinates must line up between the pre and post test measurements. The z coordinate must also match up for any non worn position on the rotor. There are always two diametrical non worn areas on the rotor surfaces. One is between the lower and middle wear paths and

one is between the middle and high wear path. These non worn paths are dictated by the fixture geometry. When these non worn path z values are the same between the pre and post test measurements, along with the x and y coordinates, then subtracting the post test measurement from the pre test measurement yields the wear value associated with each x, y, and z value in the wear path.

The holomap dataset is converted from the native holomapper format to an x, y, and z text format. The pre and post test inner and outer rotor faces are imported into a Matlab program which aligns the x, y, and z coordinates for the non worn areas. This process confirms the special orientation of the rotor. The Matlab program then calculates the average wear in one degree increments around the rotor face in each of the three wear paths on both rotor faces. This yields 360 data points for each of the 6 wear positions, in which the 0° position is aligned with the rotor date code position. This methodology allows the user to see the rotor wear signature around the rotor face. In Figure 6, the wear variation around the rotor face can be seen by plotting the average wear for each sample puck by degree. For this reason, acquiring only a few data points around the rotor face will result in an incomplete wear signature. As an example, if only 3 wear measurements were made starting at the 0° position, then the 120° and 240° position, the average wear would be 0.014 mm for the outer low sample puck position (OL Wear) shown in Figure 6. If the first measurement were made at the 80° position followed by the 200° and 320° position, the average wear would be 0.018 mm, 4 microns or 29% greater.

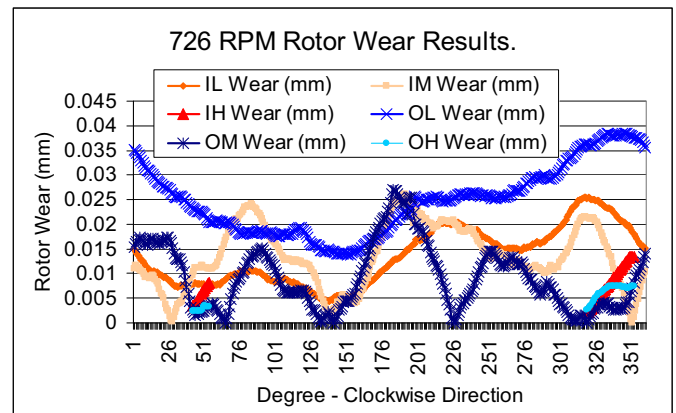


Figure 6: 360° Circumferential Signature Rotor Wear

Rotor LRO is measured for each wear path. Rockwell hardness is measured on a non worn path at 12 positions around the rotor face. These results are laid over the top of the wear results to see how the hardness and LRO line up with the rotor wear as shown in Figure 7.