TECHOLOGY DIGEST

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"BURN-OFF SIMULATION ANALYSIS OF A RAILROAD ROLLER BEARING,"

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Summary

As part of the Association of American Railroads' (AAR) Bearing Research Program to improve wayside bearing detection technology, a bearing burnoff test was conducted at the AAR's Transportation Technology Center, Pueblo, Colorado. Newly developed data analysis techniques used on this test data showed promise toward providing an early warning of bearing deterioration and/or failure.

The failure was very dramatic, complete with smoke and red hot metal chips spewing from the bearing seals. The bearing reached a temperature of 1500° F on the external cup surface during the failure. Prior to thermal failure, a sudden bearing seizure occurred with the torque reaching 680 lb-ft. Both high-quality audio and video were captured during the test.

During the test, the multiple transducers including a high frequency response microphone, a laser vibrometer, an accelerometer, cone slippage monitors, an infrared camera, torque and speed monitors were employed to collect acoustic, vibration, cone slippage, and temperature data.

Railroad accident statistics in recent years indicate that approximately 500 train accidents in the U.S. occur annually as a result of mechanical and electrical failures. Almost one out of every five of these are the result of axle and journal bearing failures, totaling more than $12.7 millions in damages. Nearly two thirds of these failures are caused from overheated roller bearings.

The bearing research program was initiated to develop effective acoustic processing techniques for use in a new generation of wayside detection systems. Using new signal processing and detection techniques developed by AAR, the characteristic frequencies of a defective bearing under thermal failure were identified.[1] The analysis of the test data leads to several important observations on the characteristic features of acoustic and laser detection techniques for use in a new generation of wayside detection systems.

Suggested Distribution:

- ❑ R&T Dept.
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Association of American Railroads
Research and Test Department

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INTRODUCTION AND CONCLUSIONS

The Association of American Railroads' (AAR) bearing research program was initiated to develop effective acoustic processing techniques for use in a new generation of wayside detection systems. The effort includes verification of the effectiveness of the developed acoustic diagnostics under actual burn-off conditions. The investigation of diagnostic potential also includes a laser vibrometer technique.

Large amounts of acoustic, accelerometer, laser vibrometer, and infrared temperature data were recorded as the bearing operated with the cup temperature approaching 1500°Fahrenheit. Newly developed signal processing and detection schemes were used to identify characteristic bearing defect frequencies.[1] A preliminary analysis provides the following conclusions:

(1) Newly developed signal processing schemes, including envelope detection, 3-dimensional time-frequency analysis, and neural network technology, show promise in a new generation of wayside detectors designed for early failure warning.

(2) The acoustic bearing monitoring technique is an effective method for identifying condemnable defects even when the bearing surface temperature reaches 1500 °F.

(3) Analysis yields a good correlation between acoustic and laser vibrometer data, which indicates that the laser is also a potential technique for bearing defect identification under shop conditions.

(4) Although acoustic and laser vibration detection techniques can be used as diagnostic tools at high temperatures, when temperatures exceed 1000 °F, the overall energy of the vibration signals decreases significantly. The high frequency components of vibration were observed to diminish first as the temperature of the bearing rose.

(5) The heat generated within the defective bearing fluctuated with time. These fluctuations are related to friction coefficient changes and broken components during temperature rise.

(6) As bearing deterioration increases, the dynamic interactions among its components generate strong vibrations. Transient peaks seen at below axle speed could be the result of cone slippage or whirl.

TEST BEARING CONDITION

Exhibit 1(a) shows the inboard test cone assembly and axle conditions before thermal runaway. Except for a machined cut-out in the bearing cage assembly, visual inspections revealed no evidence of internal defects. The photo also shows the axle groove generated by the loose cone on the axle. The photo shown in Exhibit 1(b) was taken after thermal runaway occurred. The broken cage components are clearly revealed. From appearance, the groove depth has not changed significantly from the measurement taken before testing.

RESULTS AND ANALYSIS

Bearing defects usually generate shock pulses in vibration signals. The bearing defect characteristics can be extracted and used for detection since these shock pules repeat at bearing defect frequencies. The envelope detection technique efficiently converts high frequency carrier signals through demodulation into bearing defect frequencies.[1] Exhibit 2(a) shows the acoustic output at 500 °F. After applying envelope detection, the shock pulses are revealed as shown in Exhibit 2(b). The cage defect frequency is clear in the frequency spectrum displayed in Exhibit 2(c).

The laser vibrometer is an instrument that measures the vibration of a test specimen through optical means. The advantage of the laser detection technique is that surface vibrations can be detected remotely. The laser evaluated during this test captured the same defect frequency information as the microphone. This is demonstrated by the high correlation between the acoustic and the laser signals shown in Exhibit 3.

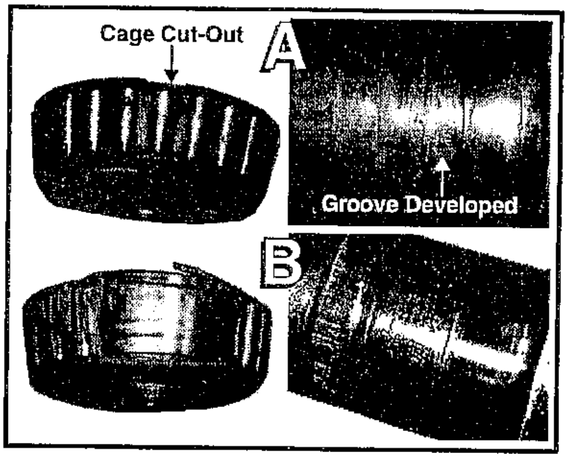

Exhibit 1a&b. Test Inboard Cone Assembly and Axle Conditions

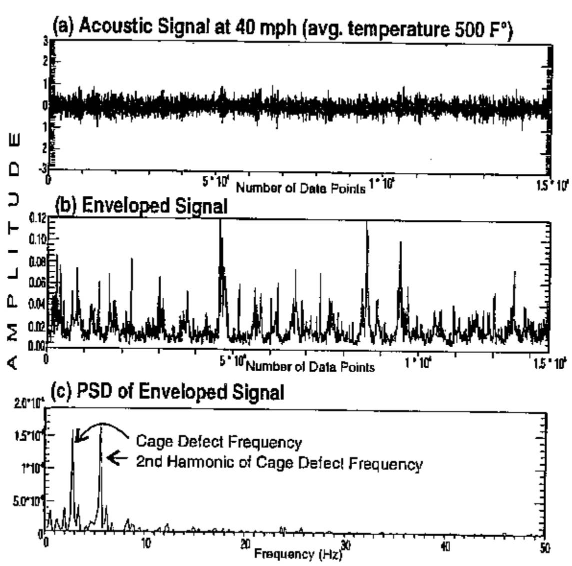

Exhibit 2a,b&c. Test Bearing Acousic Signal and its Frequency Spectrum

As bearing elements deteriorate, the bearing temperature increases rapidly. The highest operating temperatures had a noticeable impact on the effectiveness of the acoustic and laser vibration detectors. Exhibit 4 shows the overall energy level of both acoustic and laser vibrometer signals as the bearing temperature changed during test. As the temperature increased, the highest frequency components in the vibration signal began to diminish. When the temperature rose above 1000°F, the overall energy level dropped significantly.

The change of frequency contents and overall energy level in the signature can be attributed to the changes in thermomechanical properties in the defective bearing. Exhibit 5 shows the temperature-dependent elastic modulus, specific heat and friction coefficient of the cone material.[2] Starting at 1000°F, the specific heat rises rapidly while the elastic modulus trend drops significantly. These properties increase the acoustic and vibration absorbing and damping capacity of the bearing components.

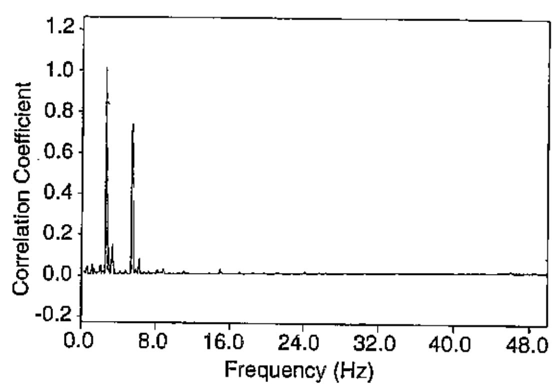

Exhibit 3. Cross-Correlation Between Acoustic and Laser Vibrometer Signal

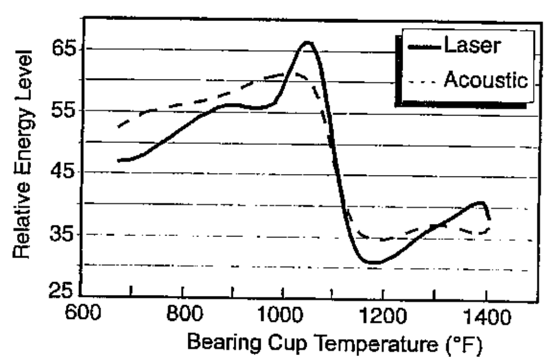

Exhibit 4. Energy Level of Acoustic and Laser Vibometer Signals

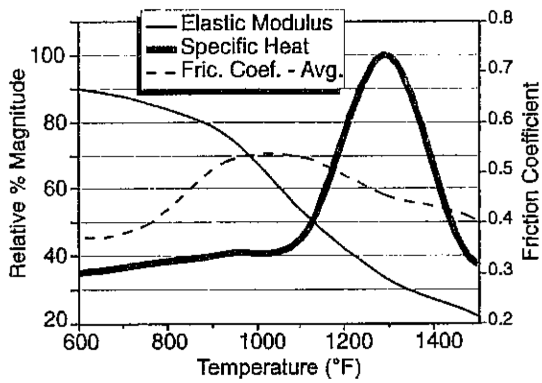

Exhibit 5. Test Bearing Cone Material Properties vs Temperature[2]

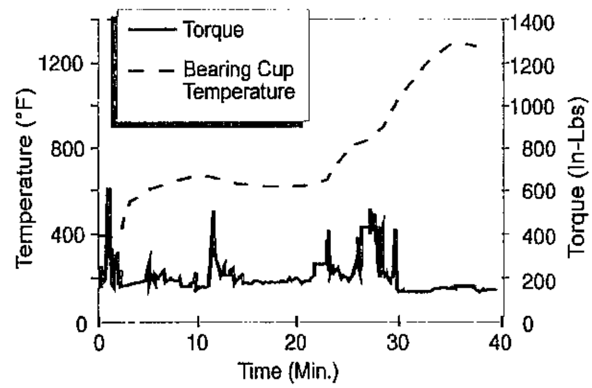

Exhibit 6. Maximum Temperature and Torque Variation during Burnoff Test

Exhibit 6 shows the maximum temperature variation during the course of thermal failure along with the observed torque response. The heat generated depends in part on the fluctuation of friction coefficient with temperature as shown in Exhibit 5. Although the torque is oscillatory, the heat generated by these variations causes the temperature of the bearing to increase steadily. The extremely high temperature permanently damages the internal components.

The distressed conditions just described produce increased dynamic interactions among bearing components and the axle. A strong non-stationary spectral component is shown in Exhibit 7. The cage defect frequency changes with time and is finally locked onto the axle rotation frequency. The transit frequency could indicate the slippage or whirl motion in the components which modulates the defect frequency.

For a non-stationary vibration signature, a conventional FFT analysis cannot be used. Three-dimensional time-frequency analysis is needed to simultaneously represent the bearing response in both the time and frequency domains. The 3-D spectrum can be transformed into defect patterns useful for neural network training processes in bearing defect recognition.

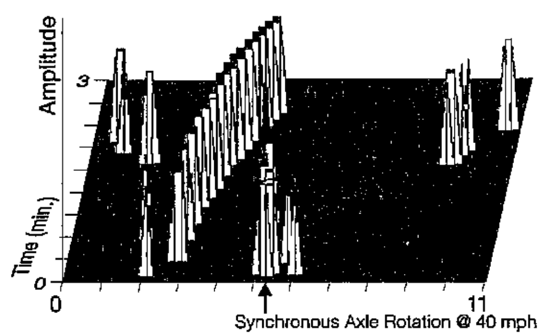

Exhibit 7. Non-Stationary Feature of Acoustic Signal of Test Bearing

References

1. Wang, John M., Gerald Anderson, Richard Smith. "A New Detection Technique to Identify Defective Railroad Bearings," *Technology Digest* 96-004, January 1996, R&T Dept., Association of American Railroads, Transportation Technology Center..
2. Wang, H., T. F. Conry and C. Cusano. "Effects of Cone/Axle Ribbing Due to Roller Bearing Seizure on the Thermomechanical Behavior of a Railroad Axle," Joint ASME/STLE Tribology Conference, 95-TRIB-33.

Contact Gerald Anderson at (719) 584-0550 with questions or comments about this document.

A MORE DETAILED REPORT, WHICH MAY CONTAIN REVISED INFORMATION, WILL BE AVAILABLE AT A LATER DATE THROUGH THE AAR, PUBLICATION ORDER PROCESSING, 50 F STREET NW, 5TH FLOOR, COG, WASHINGTON, D.C. 20001