TECHNOLOGY DIGEST

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Acoustic Wayside Identification of Roller-Bearing Defects

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Summary

Ongoing tests of acoustic wayside monitoring equipment have yielded technology that may allow the reliable detection of the most difficult-to-detect roller-bearing defects. Since 1995, the Association of American Railroads (AAR) in cooperation with the Federal Railroad Administration has compiled acoustic signatures of various roller-bearing defects from both laboratory and field tests. This data has been distributed to participating universities, national laboratories, and railroad suppliers for the development of new-and-improved techniques for the detection of defective roller bearings.

Transportation Technology Center, Inc., under the AAR's wayside acoustic detector research program, has used this laboratory and wayside test data to design and develop a prototype wayside acoustic defect-detection system. This new detector system has recently been installed on Conrail for a performance evaluation. Improved wayside monitoring systems have been sought for years in an attempt to prevent bearing-related train derailments. Until recently, however, there has been no concerted effort to develop reliable processing techniques to identify the most difficult-to-detect roller-bearing defects.

In its latter stages of operating life, a defective bearing generates excessive amounts of heat as its internal components rapidly degenerate. At this stage, the bearing may be "caught" by a thermal bearing detector, or it may cause a burn-off derailment between detector locations due to the rapidity of the event.[2] Accurate and early bearing-defect detection via acoustic monitoring could prevent some of the annual bearing-related derailments that now occur, and might also provide for preventative maintenance which could prevent or reduce the number of high-cost stoppages on revenue rights of way.

Vibration responses of defective bearings tested in the laboratory were found to be distinct from those obtained from "good" bearings.[1] Typically the spectral content of the vibration signatures obtained from defective bearings show larger amplitudes at the bearing's rolling-element rotational frequencies. In some cases, the spectral content is insufficient to establish the full condition of the internal components of an operating bearing. The laboratory investigations performed in 1995-1996 by the AAR also showed that neural networks could be effectively employed to clearly identify the subtlest operating defects under laboratory conditions.[1,3]

Suggested Distribution:

- ❑ Equipment/Rolling Stock
- ❑ Equipment Maintenance
- ❑ Car Department
- ❑ R&D/Test Department

Work performed by TTCI Transportation Technology Center, Inc.
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INTRODUCTION AND CONCLUSIONS

Although acoustic wayside detectors have been in service for almost a decade, the rudimentary analysis techniques used to date have been insufficient to identify some more-difficult-to-detect defects under revenue-service conditions. Therefore, it has been a major task of the Association of American Railroads (AAR) to study specific bearing-defect types, both in the laboratory and under simulated revenue-service conditions. An extensive laboratory test program, jointly funded by the Federal Railroad Administration (FRA), was undertaken in 1995-96 to classify the acoustic and vibration emissions of various bearing-defect types. The wayside acoustic collection of bearing sounds under full-simulated revenue operation was undertaken in November 1996 at the FRA's Transportation Technology Center (TTC). The following conclusions have been drawn from the wayside data analysis and review:

- The acoustic characteristics of a bearing with internal defects are different from those generated by bearings in "good" condition.[1,3]
- High-frequency diagnostic information from 3 Hz to more than 40,000 Hz is contained in the recorded wayside acoustic data. (AAR-published compact disk.[4])
- Adjacent microphones with the 35-inch spacing pick up approaching (and receding) bearing signals.
- Doppler shifts affect frequency-based analyses.
- Higher train speeds have increased sound output.
- Sound intensity from passing cars is dependent upon load.
- The rotation rate of the wheels (bearings) relates directly to train speed and inversely to the wheel size. This requires the speed of the train and the wheel sizes to be established during each pass.
- Defective bearings exhibit distinctive demodulated spectral frequency peaks that are specific to the bearing's speed, load, and size.[5]
- Loose (or spun) cones slip slowly about their axles. (i.e., ~.5 percent of the running speed).[6,7]

The rate at which FRA-reportable bearing-related derailments occur has remained relatively constant at 50 per year for the past 10 years, in spite of important changes to industrywide bearing-reconditioning standards, and an extensive network of hot-bearing detectors. The detectors have been instrumental in holding the level constant in the face of revenue ton-per-mile traffic increases of 30 percent over the 10-year period. The goal of the AAR bearing-defect detection research program has been to develop techniques for improved wayside defect detection to prevent derailments and costly train stoppages due to real or false detector alarms. A key to the success of the research goal is the early identification of a variety of defects that are known to be culprits in bearing burn-off derailments.

TEST SETUP

Exhibit 1 shows the test train used in the acoustic wayside test program. Two bearing sizes were run in the tests, Class "E" (6"x11") and Class "F" (6.5"x12"). All bearings were subjected to a series of test runs ranging in speed from 25 mph to more than 70 mph. Both empty and fully loaded cars were supported by each test bearing during one or more of the test runs. The temperatures of all defective bearings in the consist were monitored during each test run. Microphone and accelerometer data collection was performed at sample rates sufficient to identify vibration frequencies up to 40 kHz. There were a variety of bearing defects in the test consist. The major test bearing types by class were as follows.

Test-Bearing Description (All Size "E"):

- Remanufactured "good bearing"
- Condemnable multiple connecting cup spalls
- Condemnable multiple connecting cone spalls

Exhibit 1. Test Train Passing Wayside Detectors

- Condemnable water etching
- Small repaired single cup spall — new cones
- Single cone spall — new cup
- Simulated broken roller in outboard cone
- Mystery bearing (blind test sample bearing)

Test bearing description (All Size "F"):

- Remanufactured "good bearing"
- Condemnable single cup spall
- Condemnable multiple connecting cone spalls
- Condemnable water etching
- Condemnable multiple connecting cup spall
- Broken roller
- Mystery bearing (blind test sample bearing)

There were also four bearings with spun-cone defects in the test train. Each of these contained rotation sensors that monitored their relative rotation about the axle. Spun-cone rotation sensors were mounted on both the inboard and outboard raceways, however only the inboard cones were observed to spin during the test program. This was as expected since only the inboard cones were on a grooved portion of the axle. Loose (or spun) cones slip slowly about their axles at approximately one-half of 1 percent of the bearing rotational speed, varying with the depth of the groove. These results are consistent with observations from the simulated burn-off tests, performed in 1995 at TTC.[3]

RESULTS AND ANALYSIS

Acoustic data from a single microphone recording a train pass is displayed in Exhibit 2. The frequency content of the time-based signature ranges from 3 Hz to more than 40 kHz. At the base of the microphone plot is the wheel-pulse detector output showing the location of each of the 32 test wheels (bearings). The test car numbers are noted at the base of the diagram.

Successful analysis involves processing acoustic signatures with an envelope detector. The envelope of the acoustic signal in Exhibit 2 is shown in Exhibit 3. Envelope detection extracts the positive portions of the bearing-component rotational frequencies from the high-carrier frequency vibrations generated by defective bearings. This technique and its diagnostic attributes is discussed in detail in AAR TD 96-004.[5]

An expanded enveloped signature from bearing No. 4 in the train consist is expanded in Exhibit 4.

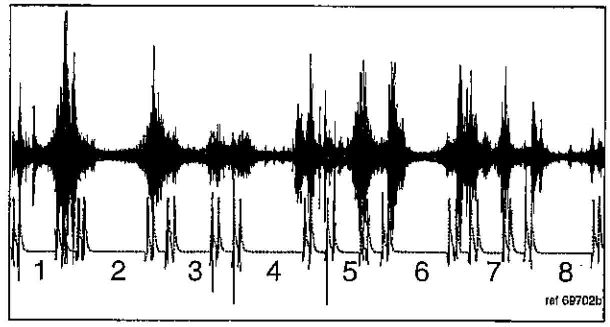

Exhibit 2. Acoustic Microphone Output and Wheel Gate Signatures from Single Train Pass

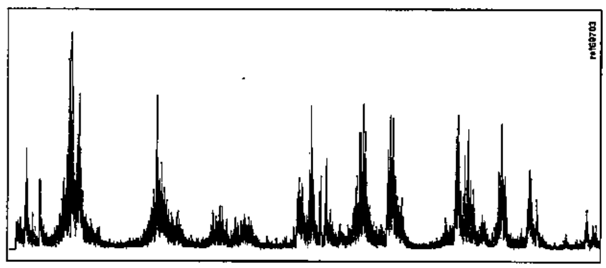

Exhibit 3. Test Run 24AP1N30 Data after Envelope Detection Processing

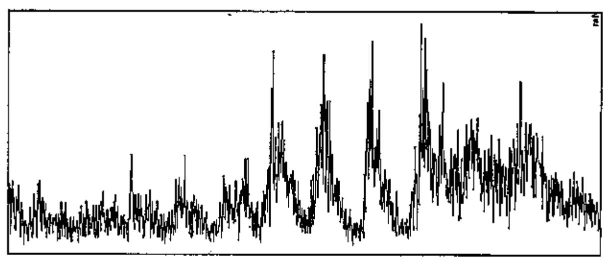

Exhibit 4. Expanded Time Trace of Bearing with Severely Spalled Cup

This exhibit is a spectral plot of the demodulated portion of the cup-spalled bearing on car No. 1 in test run 24AP1N30. Exhibit 5 shows the low frequency spectral peaks contained in the time-based signature displayed previously in Exhibit 4. Two dominant peaks are apparent in the spectrum. The peak at 3.8 Hz corresponds to the base rotational rate (4.6 Hz) of the bearing at 30 mph. The second peak (49 Hz) is directly related to the spalled-cup defect repetition rate at 30 mph.

Exhibit 6 is a greatly expanded time-based view of the acoustic signature from bearing No. 18. This bearing contained a spun-cone defect. On various passes this bearing emitted the very-high-frequency output displayed in the graphic shown. This bearing (and some other spun cones) provided occasional

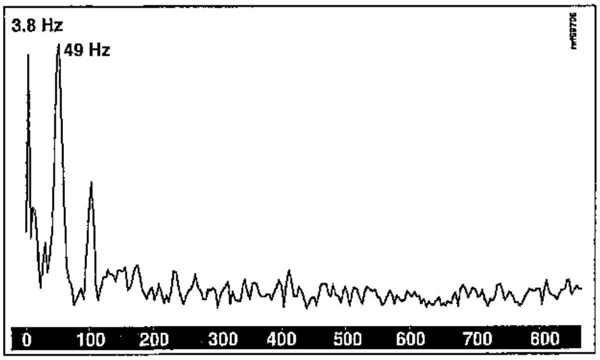

Exhibit 5. Spectrum of Defective Bearing on Axle No. 4 with Severely Spalled Cup

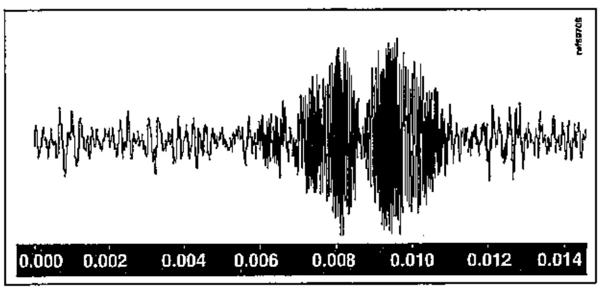

Exhibit 6. Expanded Time Trace of Bearing No. 18

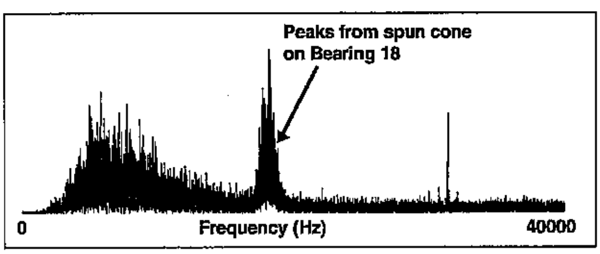

Exhibit 7. Spectrum from a Microphone Array

short acoustic bursts as displayed which were highly pulsed in nature.

Exhibit 7 provides the spectral features of the spun-cone bearing No. 18. The dominant feature of this bearing is its high frequency output. The speed of the bearing was 50 mph at the time the signal was captured. The spectrum clearly shows several peaks. These vibrations were observed in several consecutive wayside microphones indicating the sound propagated a distance greater than the microphone spacing. Adjacent array microphones provided other signals from the same bearing and gave a measure of the Doppler shifts in the approaching and receding signatures.

FUTURE PLANS

To demonstrate the current technology, tests planned in 1998 include a wide range of bearing defects. This will also help answer questions regarding the feasibility of detecting defect severity under service conditions. The additional defective roller bearings will expand the acoustic diagnostic base even further.

REFERENCES

1. Anderson & Bilodeau Laboratory Test Review TD, 1997.
2. Florom, R. L., Hiatt A. R., Bambara J. E., & Smith R. L., "Wayside Acoustic Detection of Railroad Roller Bearing Defects," ASME Paper No. 87-WA/RT-11, December 1987.
3. Wang, J. M., G. B. Anderson, R. L. Smith, "Burn-off Simulation Analysis of a Railroad Roller Bearing," Technology Digest TD 96-005, February 1996, R&T Dept., Association of American Railroads, Transportation Technology Center, Pueblo, Colorado.
4. Smith, R. L., "A Review of the Defective Roller Bearing Vibration CD Data Sets Collected by the Association of American Railroads," Vibration Institute Paper Presented at the Annual Meeting in New Orleans, Louisiana, June 1997.
5. Wang, J. M., Anderson, G. B., Cline, J. E., Smith, R. L., "A New Detection Technique to Identify Defective Railroad Bearings," Technology Digest TD 96-004, February 1996, R&T Dept., Association of American Railroads, Transportation Technology Center, Pueblo, Colorado.
6. Anderson, G. B. and Smith, R. L., "Acoustic Identification of a Spun Cone Roller Bearing," Technology Digest TD 97-028, Association American of Railroads, Transportation Technology Center, Pueblo, Colorado, July 1997.
7. Anderson, G. B. and Smith, R. L., "Acoustic Identification of a Spun Cone Roller Bearing Defect," ASME Paper Presented at the Winter Annual Meeting in Dallas, Texas, November 1997.

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