

ONBOARD REAL-TIME RAILROAD BEARING-DEFECT DETECTION AND MONITORING

by Bill Sneed and Richard Smith

Summary

A study of freight-car roller bearing vibration dynamics by Transportation Technology Center, Inc., has provided the railway industry with valuable data for the future development of reliable onboard failure prevention and condition-based maintenance systems. Real-time identification of bearing defects or defect growth would enhance bearing reliability by providing the train's engineer an advance notification of the need for bearing maintenance and advanced warning of a critical defect that could affect train-handling safety. It is expected that an onboard detection system would be integrated into intra-train communication networks (i.e. ECP brake systems). Feasibility testing has shown that the identification of "good" and defective bearings is possible, including the critical loose or spun-cone defect. Testing also showed that the sensor environment is harsh and sensor capability would be demanding.

A major goal of this research is to determine the feasibility of identifying bearing defects on a moving freight car by analysis of vibrations at or near the wheel bearing. Ultimately, such a detection system would provide early detection of internal bearing defects to provide for condition-based maintenance, as well as failure prevention. Wayside detectors can achieve many of these goals, with the advent of advanced technology as in the improved acoustic wayside bearing-defect detector. However, onboard sensing offers several advantages over wayside detectors, including:

- Continuous rather than intermittent monitoring
- Evaluation of defect-related signatures over longer time periods
- Evaluation of structure-born sources of data
- Immediate notification of a component crisis situation
- Accumulation of several minor transient data spikes for an eventual warning notification

Onboard detection devices or sensors must be designed to provide continuous operation in the high-vibration, high-impact environment commonly found in the railway industry. Since each railcar (or even bearing) would require its own sensor, any developed sensor will have to be inexpensive to implement, require little or no maintenance for long-term operation, and be highly reliable. The smart sensor concept, incorporating sensing element, data processing, and communications in a single chip, is a likely candidate to fit these requirements. This technology shows the promise of improving railroad-customer service while potentially reducing derailments, train delays, and unscheduled equipment maintenance.

Suggested Distribution:

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



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INTRODUCTION AND CONCLUSIONS

A study of thermal and vibrational signals obtained from defective bearings may help railroads develop reliable onboard failure-prevention systems. These real-time signals would give train engineers earlier warning in the event of bearing failure, and may help prevent derailments. This two-year study includes recent findings by Transportation Technology Center, Inc., in addition to data from tests ongoing since 1996.¹

This review compares thermal and vibrational data from bearings with no internal defects to those with spun cones, broken rollers, and water-etched surfaces. Of all bearing-defect types, one of the most challenging to detect is the "spun-cone" bearing — a bearing with a loose inner raceway. Normal roller bearings have "press fit" inner raceways which keep them from rotating or sliding about the axle. The spun-cone bearing has lost its tight "press" and can slowly spin about the axis. This bearing defect is a likely candidate for many of today's confirmed hot-bearing setouts.²

Examination of the available data provides the following conclusions:

- "Like-new" or reconditioned bearings have low-amplitude vibration characteristics that are distinct and clearly different from all the defective bearings tested.
- Bearings with spun-cone defects have identifiable vibration characteristics that are distinct from the other bearings reviewed, regardless of whether they contained defects. Bearings with spun-cone defects:
 - Produce higher vibration levels in the low-frequency ranges (<200 Hz) than all the other bearings reviewed.
 - Contain enveloped signature spectral peaks at less than one-half the running speed of the bearing. These low-frequency peaks appear at frequencies that are proportional to, but well below, the running speed of the bearing.
 - Exhibit raw-signal spectral side-band peaks on either side of the running-speed frequency of the bearing.

- Spectra derived from demodulated envelope-processed signatures provide distinct peaks that are typically lower in frequency and independent of the contents of the raw-signature spectra.
- Bearing vibration spectral amplitudes tended to be proportional to the running speed of the bearing.
- Loaded and unloaded cars generated distinctly different vibration output levels in the bearings tested.
- Peaks generated in the test bearing containing the broken roller appeared to be directly related to the monitored temperatures during testing, whereas the other bearing-defect types did not yield such a dependence.
- Auto-correlation processing of time-based data collected from accelerometers mounted near bearings containing internal condemnable defects enhances the defect signature and provides greater discrimination capability.

TEST DESCRIPTION

The test trains included a variety of equipment and configurations. Two bearing sizes, Class "E" (6"x11") and Class "F" (6.5"x12") were deployed in the test cars. The train consists included both empty and loaded cars. Empty cars had approximately 8,000 pounds per bearing of applied load; loaded cars supported 27,000 to 33,000 pounds per bearing. The test train was operated at speeds ranging from 25 to 70 mph.

All bearing vibration data was processed using a technique referred to as envelope detection.¹ Envelope detection extracts rotational information from the low-frequency bearing elements from the higher-frequency "carrier" vibrations generated by any defective components within test bearings. Envelope processing has a distinct capability of revealing the presence of very small modulating signals, even when large amounts of noise are present. Envelope processing is an effective diagnostic tool for evaluating bearings.

RESULTS AND ANALYSIS

Exhibits 1 and 2 consist of eight seconds of vibration data collected from sensors mounted on adapters located directly over four test bearings.

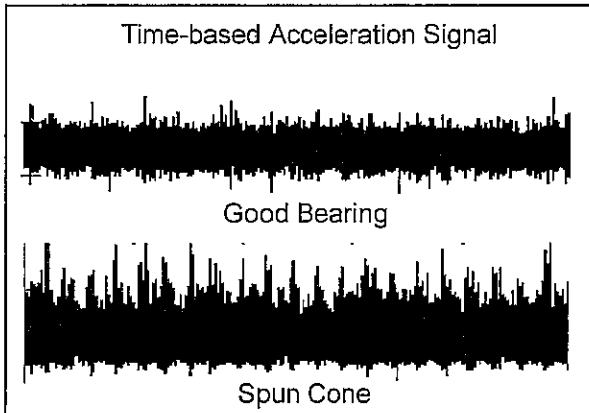


Exhibit 1. Vibrations from Bearing-Mounted Accelerometers

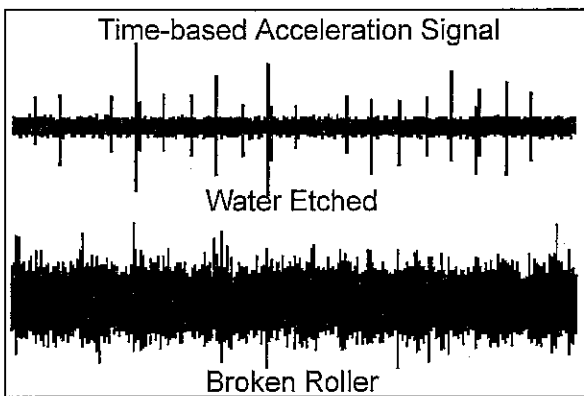


Exhibit 2. Vibrations from Bearing-Mounted Accelerometers

The defective spun-cone signature in the lower half of Exhibit 1 has a distinct modulated character that is not present in the vibration signature of the upper "good" bearing trace. Exhibit 2 shows vibration signatures from two other defects.

Field testing involved 49 train runs past the wayside monitoring station. Four of the test bearings contained spun-cone defects. Exhibit 3 is a comparison of the average spectra obtained after enveloping from the "good" reference bearing and those containing the spun cones for test runs 27 through 49. The trend is obvious: Bearings with spun-cone defects vibrate at higher levels than good bearings over the frequency range from 0-187 Hz. Data from the two bearings suggests that there is a full decade (10:1) separation between their vibration levels.

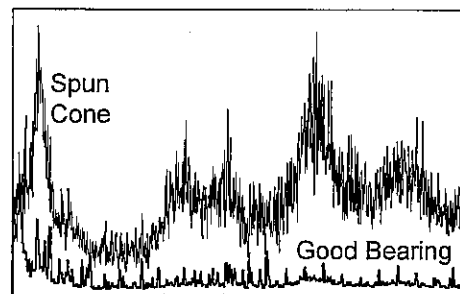
The test train ran at speeds from 25 to more than 70 mph during the investigation. An increas-

ing trend of vibration with speed was observed for the three bearing-defect types reviewed on board: spun cones, damaged roller, and water etched.

The various tests also demonstrated a range of operating temperatures for bearings. In most cases each test run lasted from 10 minutes to more than an hour as the train circled the 13-mile test track. On some mornings the starting ambient temperature was as low as 20 degrees F and on other days it was as high as 50 degrees F.

In all cases, the thermocouples used in recording bearing temperature were attached directly to the outer casing of test bearings. The trend of temperature with increased running speed was positive. As expected, higher train speeds provided hotter outer-race operating temperatures. A rise in temperature trend for all operating speeds and tests was reviewed and it suggests that the bearing outer race goes up approximately 1.5 degrees F for every increase of 1 mile per hour in running speed. The various runs, car loads, bearing sizes, and variety of bearing defects provided some scatter in the data. The average trend, however, indicated that a 1.5-degree F rise per 1 mph is a good rule of thumb for operational temperature rise.

One advantage of onboard data collection is that long data samples are available for processing. Long periods of observation allow analyses that cannot be exercised with wayside data-collection systems which are usually limited by time. "Auto-correlation" is an example of such a process and its diagnostic advantage is portrayed in Exhibit 4.



Frequency (0- 187 Hz)

Exhibit 3. Comparison of Spun-Cone and Good-Bearing Spectra

The upper trace of Exhibit 4 is a spectra from an onboard accelerometer mounted on one test car. The sensor was placed near a bearing that contained a condemnable defect. The accelerometer should have sensed the periodic vibrations that this bearing generated. Although the spectra has several large peaks, none are actually observable at the defect frequency this defect is producing. In this case, the background vibrations from the car body and other equipment mask the expected defect peaks. From this spectrum alone, it is not obvious that a defective bearing is anywhere near the sensor that collected this vibration information.

The center spectrum reveals the enhancement attained after the time-based data has been filtered and envelope detected. The signal has also been increased in amplitude at this stage for visual comparison. Clearly the peaks generated by the bearing defect at the expected frequencies are visible at this stage. A "warning" based on the presence of significant peaks could be generated from this display.

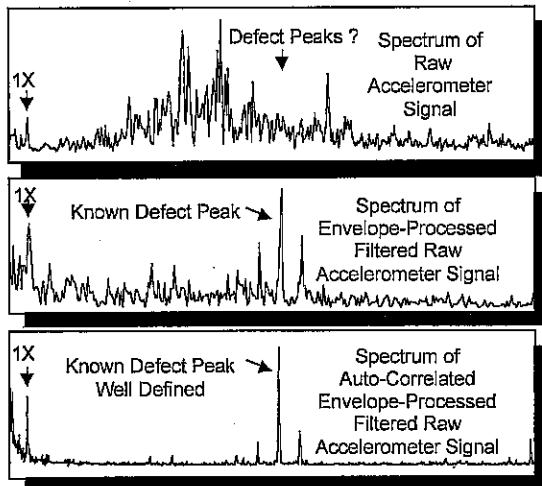


Exhibit 4. Auto-Correlation of Long Onboard Data Samples

The data also provides for the possibility of using the "auto-correlation" technique to enhance the truly periodic information available. This process suppresses the random nature of the vibrations at the same time. The bottom trace of Exhibit 4 shows the enhancement provided by adding auto-correlation.

FUTURE WORK

As a follow-up to this preliminary onboard testing and analysis, TTCI is investigating methodology for developing a smart sensor application for bearing detection. A relatively new time-based analytical technique involving pattern recognition is being explored for this application. This new technique has evolved from speech-recognition studies, and shows the possibility of performing the necessary data processing on a single computer chip at low cost and low power.

REFERENCES

1. Smith, R. L., "A Review of Selected On-Board Test Train Bearings — Accelerometer Vibration Diagnostic Analyses of Reconditioned, Broken Roller, Water Etched, and Spun Cone Bearings," NSEW Report to AAR, April 31, 1997.
2. Anderson, G.B and Smith, R.L., "Acoustic Identification of a Spun Cone Roller Bearing," Technology Digest TD 97-028, AAR/TTC, Pueblo, CO., July 1997.
3. Wang, J. M., Anderson, G. B., Smith, R. L., "A New Detection Technique to Identify Defective Railroad Bearings," Technology Digest TD 96-004, February 1996, R&T Dept., AAR/TTC.

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