TECHNOLOGY DIGEST

Timely Technology Transfer

"A NEW DETECTION TECHNIQUE TO IDENTIFY DEFECTIVE RAILROAD BEARINGS,"

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Summary

New signal processing and detection techniques that may produce a new generation acoustic wayside bearing defect inspection system have been developed recently at Transportation Technology Center (TTC), Pueblo, Colorado.

The ability to detect bearings in early stages of failure, with a high degree of confidence, is AAR's main goal in its bearing research program.

This report briefly demonstrates the effectiveness of the new techniques developed at TTC and used to analyze acoustic data, namely: (1) demodulation envelope detection, (2) three-dimensional time-frequency analysis, and (3) neural network used in bearing defect pattern recognition.

These new signal processing schemes have been applied to analyze the bearing burn off test data collected at TTC's bearing test facility.[1]

Train derailments caused by bearing burnoff failure have remained at a relatively constant rate over the past several years and are a major concern within the industry. For instance, when a bearing fails due to a spun cone defect, the operating temperature can rapidly exceed 2,700 degrees Fahrenheit causing a derailment in minutes.

Solutions to these problems require the identification of a defective bearing in the earliest stages of deterioration, preferably in advance of an overheated condition forcing a train stop. Early detection would provide a railroad with the opportunity to repair or replace the defective bearing.

Suggested Distribution:

- ❑ R&T Dept.
- ❑ Equipment Rolling Stock
- ❑ Equipment Maintenance
- ❑ Operating/Mechanical—Car

Association of American Railroads
Research and Test Department
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INTRODUCTION AND CONCLUSIONS

The rate of derailments due to bearing burn off failure has remained relatively constant over the past several years. Current wayside hot box detectors (HBD's) have played a major role in keeping the number of bearing related accidents at a relatively constant level. While working to prevent derailments, HBD's can be a factor in train delays. This affects the efficiency of railroad operations.

The major focus of the Association of American Railroads' Bearing Research Program is to improve the performance of bearing defect detection systems for early stages of bearing failure detection.

A key step in achieving this objective is to develop improved signal processing techniques. New signal processing schemes have been developed at TTC and are being used to analyze the bearing burn off test data. The results have shown that this new technique is promising for use in new generation wayside bearing defect detectors.

The following conclusions are offered:

(1) Envelope detection indicates a superior ability to identify bearing defect from shock impulse data.

(2) If the energy level of the defects generated by shock impulses vary over time, its frequency contents are best evaluated by a three-dimensional time-frequency spectrum. The three-dimensional spectrum pattern is also very effective in providing training vectors to a neural network.

(3) A properly trained neural network can identify different bearing defect patterns; even signals containing a certain level of noise.

While the newly developed scheme can be used effectively to identify the bearing defect frequencies, further work is needed to develop algorithms for time domain analysis to determine defect severity and to establish standards for assessing condition and lifetime. The AAR, in conjunction with the Federal Railroad Administration, will conduct both laboratory and field tests to establish characteristic patterns for major bearing defect types. Developers of new detector systems will be invited to bring prototype systems to TTC for field trials.

ANALYSIS

__Envelope Detection__. The characteristic frequencies of rolling element defect shock pulses may be extracted efficiently from high frequency carriers. Envelope detection developed by the AAR is an effective method of extracting and demodulating them into bearing defect characteristic frequencies.

Exhibit 1 is the simulated data used to demonstrate how envelope detection works. In Exhibit 1, Window 1 (W1) simulates the amplitude modulated shock impulse signal. Its repetition rate is the objective of detection. To simulate a real environment, the shock impulses are mixed with another signal (W2) and noise data (W3). Window 4 (W4) is the final composite signal. If a power spectral density analysis (PSD) is applied directly to the composite signal, it only shows the frequency contents of the signal, as demonstrated in Exhibit 2. With envelope detection, the extracted signal follows the shock impulse peaks. Its PSD reveals the impulse repetition frequency shown in Exhibits 3 and 4.

Exhibit 5 is the acoustic data from the test bearing with an inboard spun cone defect.The PSD analysis after envelope detection shows the multiple harmonics at running speed, which is a symptom of cone slippage excited by the rolling friction force at the cone-axle interface.

<u>*3-D Time-Frequency Analysis*</u>. Defective bearing acoustic signatures have high frequency components caused by frictional impacts. Shock pulses excited by friction forces occur randomly in time. This makes traditional spectrum analysis methods (FFT or PSD) less effective because non-stationary characteristics are obscured as their frequency content averages to zero. The 3-D vibrational analysis is a useful tool as it represents the signal simultaneously in time and frequency domains. Furthermore, it can generate a sufficient volume of data from short time duration events for pattern recognition by the neural network. Exhibit 6 is the 3-D time-frequency spectrum of the same defective bearing as shown in Exhibit 5.

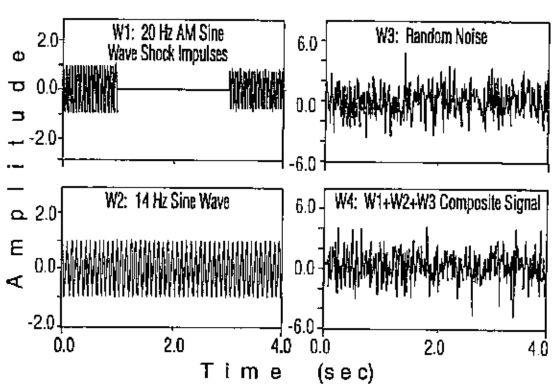

Exhibit 1. Simulated Shock Impulse Signal Buried into Noise

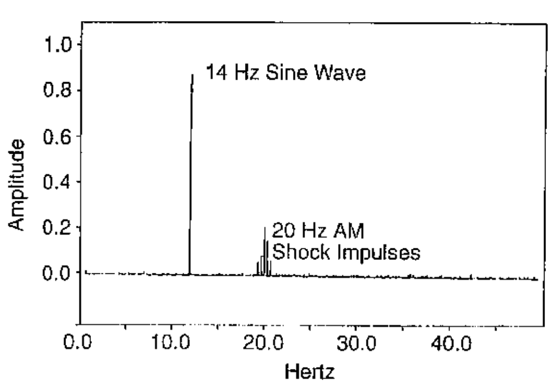

Exhibit 2. Direct PSD of Composite Signal

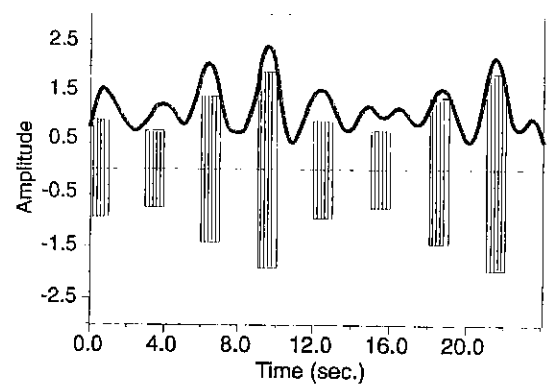

Exhibit 3. Over Plot of Shock Impulse and Enveloped Signal

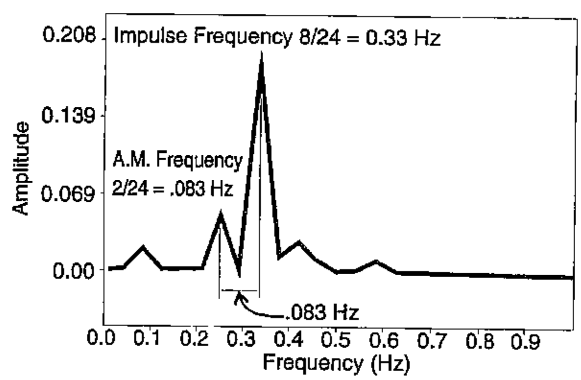

Exhibit 4. PSD of Enveloped Signal

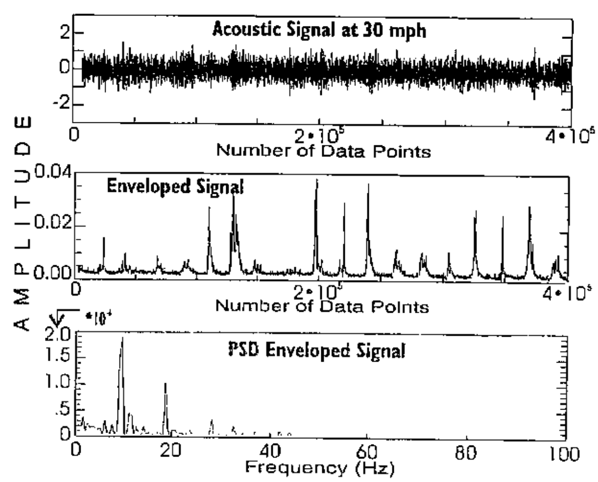

Exhibit 5. Defect Bearing Signal and its PSD at 30 mph

Neural Network. The neural network technology is a computational process which simulates biological brain neurons. Neural networks are particularly applicable to classification and pattern recognition. Exhibit 7 illustrates how this technology can be applied to bearing defect pattern identification.

Frequency domain spectrum from acoustic signals collected by a wayside detector can be fed into a back propagation neural network to train it to learn the bearing defect patterns. The output units represent the bearing defect categories. Later, if an incoming signal matches one of the defect patterns previously trained, the detector will send out a warning signal. In conjunction with other information, such as temperature, the decision to pull the bearing can be made based on preset levels of severity. Exhibit 8 is an example of the neural network performance. The x-axis of Exhibit 8 represents the trained categories. In this case, category A is the acoustic frequency spectrum at 25 mph, B is the frequency spectrum at 30 mph, C is the frequency spectrum at 35 mph, and D is the frequency spectrum at 40 mph.

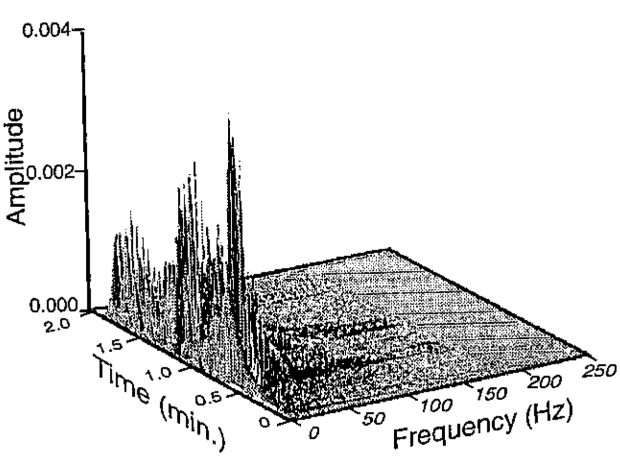

Exhibit 6. 3-D Time Frequency Spectrum of Enveloped Signal

After training the network, another frequency spectrum at 30 mph filtered by a different bandpass filter is presented; the network recognizes it by giving it the highest classification rate as shown in Exhibit 8.

Contact Jim Cline at (719) 584-0679 with questions or comments about this document.

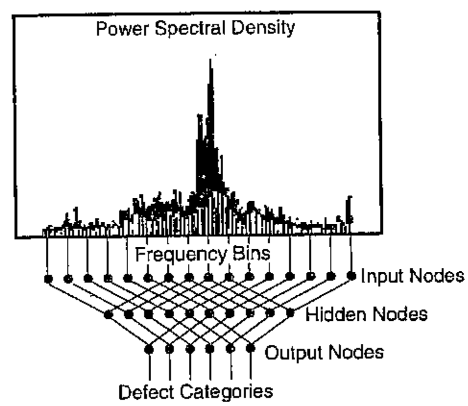

Exhibit 7. Illustration of Neural Network used for Defective Railroad Bearing Detection

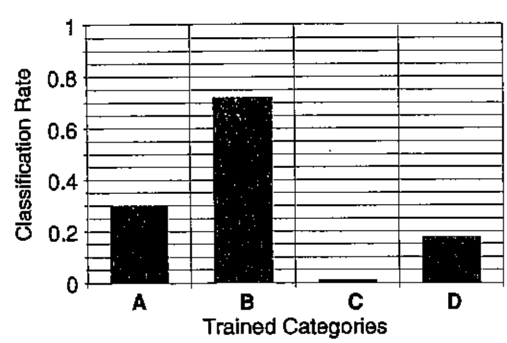

Exhibit 8. Neural Network Prediction of Classification Rate

Reference:

1. Wang, John M. Gerald Anderson, Richard Smith, "Burn Off Simulation Analysis of a Railroad Roller Bearing, " *Technology Digest*, TD96-005, Research and Test Department, Association of American Railroads

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