

### FEATURE EXTRACTION FOR ADVANCED BEARING INSPECTION USING NEURAL NETWORKS

by James R. Bilodeau and Gerald Anderson  
TD 97-047

#### Summary

The Association of American Railroads (AAR) is currently developing a shop-based system for identifying bearing defects without disassembling the bearing. This system uses vibration signatures, processed by neural networks, to identify the bearing defects.

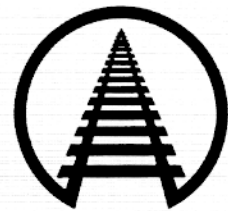
Currently, every bearing that comes into a wheel shop must be dismounted and reconditioned. Even if a wheel set comes in with a wheel tread defect, and less than 1,000 miles in service, the bearings must be reconditioned. The bearing-inspection system discussed in this document will give wheel shops a reliable and quantitative way to evaluate mounted bearings. After evaluation, the bearings may be scrapped, reconditioned, or left on the wheel set depending on its condition. This system may eventually allow railroads to use second-hand bearings in interchange service again.

Using a data base developed under a joint Federal Railroad Administration and AAR program for improved bearing-defect detection, the AAR has developed a methodology to inspect mounted bearings in a wheel shop. A unique signal-processing technique is used to extract features from vibration data taken from bearings that correlate to specific defect types. The defect types include spalling of raceways, roller damage, water etching, and loose cones.

The current system uses neural networks to identify bearing flaws. Prior to neural network processing, features characteristic of the bearing flaws must be extracted from raw accelerometer signals. These signals are obtained from a bearing when it is loaded and rotated on a bearing rotation rig. This procedure was carried out for a relatively small data set as a proof of concept. The proof of concept tests produced successful neural networks and were used to identify optimal bearing loading and rotational rates. The system will be tested on a much larger data set later this year in a railroad wheel shop.

#### Suggested Distribution:

- Equipment/Rolling Stock
- Car Department
- Research and Development
- Computer Operations



Association of American Railroads  
Railway Technology Department

December 1997



## INTRODUCTION AND CONCLUSIONS

According to the most recent statistics, the railroad industry spends approximately \$72 million yearly on bearing reconditioning. Currently, all bearings entering a wheel shop must be removed and reconditioned. In 1994, the AAR began its current Strategic Research Initiative (SRI) on bearing-defect detection, with an objective of developing technology for a new generation of detectors. These detectors should have the ability to reliably detect bearing defects at an earlier stage of failure or bearing degradation. Included in this SRI is a project to develop a bearing-inspection system for use in the wheel shop. If even a small percentage of bearings can be returned to service without removal (i.e. second-hand bearings), then a considerable savings can be achieved. This goal has driven the development of the bearing vibration feature extraction/neural network technology presented here.

Modulation frequencies related to bearing geometry are typically used to study bearing-flaw vibrations. Changes in vibrations between bearing flaws are often very small. Even though neural networks are good at identifying small subtle data variations, cumulative errors and noise from current digital signal-processing techniques often make these small variations unidentifiable.

The goal of this project was to define a set of characteristics or features from the raw accelerometer signals that distinguish a particular bearing defect from good bearings and other defects. Since the computation time necessary to train neural networks increases exponentially with the size of the input data set, the smallest set of features that will still characterize the bearing flaws is desired. A method for feature extraction using carrier frequency analysis was implemented. This process produced a small set of features (<20) that was then used to train several neural net-

works. Although the data set was small, the neural networks produced were able to identify bearing flaws not previously shown to the system. This demonstrated that the system is not simply memorizing the training data.

## BACKGROUND AND PREVIOUS WORK

Vibration signatures are being used to characterize these defects since vibrations are easily and cheaply obtained using standard accelerometers (response < 30 kHz). The following bearing-flaw classes will be studied during this project:

- Cup Spalled
- Cone Spalled
- Damaged Rollers
- Water Etched
- Spun Cone

The data set used for this research comes from a program jointly sponsored by the AAR and the Federal Railroad Administration (FRA). This test consisted of 16 bearings with known defects of the type listed, and two good bearings (no defects). These bearings were mounted on standard Class E and Class F axles. The axles were rotated at various speeds while both light (8,000 pounds) and heavy (Class E 27,000-pound and Class F 33,000-pound) loads were applied to the bearings. The broad range of test conditions was used so the effects of loading, speed, and bearing class could be studied.

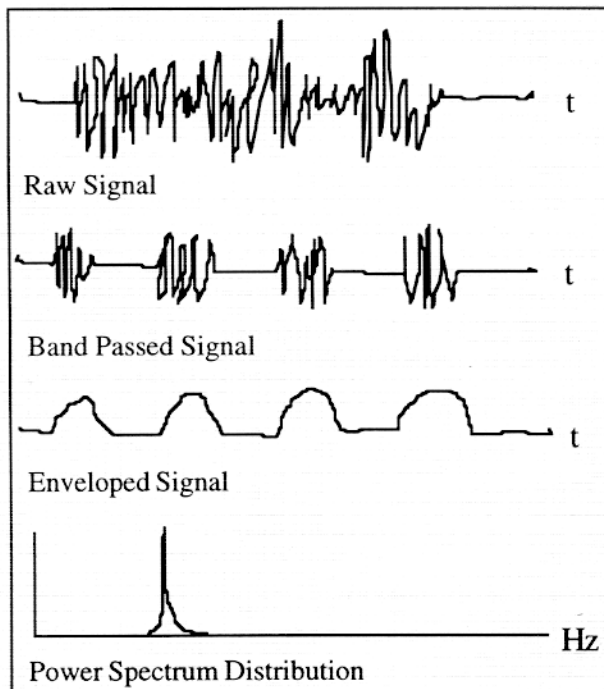
## CARRIER-FREQUENCY ANALYSIS

Bearing defects produce vibrations at intervals or frequencies related to the bearing geometry (i.e. race diameters or number of rollers). These frequencies are called modulation frequencies. The actual frequency of each modulator is called the carrier frequency. An example would be a bell ringing once every second; or the modulation frequency is 1 Hz



and the carrier frequency is the bell's audible frequency (1,000-2,000 Hz). Although modulation frequencies can be calculated directly from bearing geometry, carrier frequencies are much more difficult to determine since they are based on material constants and flaw characteristics. Modulation frequencies are extracted from carrier frequencies using an enveloping technique (See Exhibit 1). Modulation frequencies can then be used to relate bearing vibrations to specific bearing components.

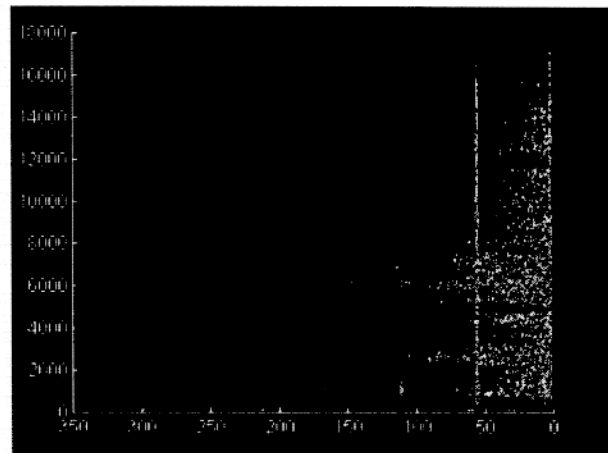
Unfortunately there is no simple way to calculate carrier frequencies for bearing flaws. In order to identify which carrier frequencies are associated with specific flaws, the raw accelerometer signals were put through a series of 300 band-pass filters. These filters ranged from 100 to 30,000 Hz at increments of 100 Hz. Each filtered signal was then enveloped and brought into the frequency domain via a power spectral density algorithm. Contour plots were used to display the



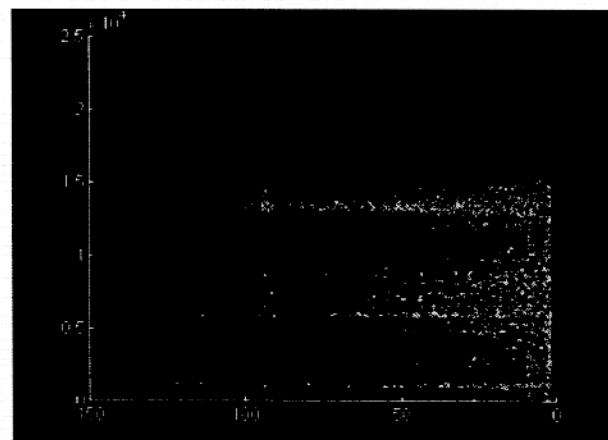
**Exhibit 1. Separating Modulation Frequencies from Carrier Frequencies**

results from this analysis. Exhibits 2 and 3 show contour plots of two different bearing flaws. The horizontal axis represents the frequency spectrum of the modulation frequencies present after enveloping and windowing. The vertical axis represents the filter bands or carrier frequencies.

From these plots, several features or characteristics for the different bearing flaws can be identified. Notice the long vertical bar at roughly 54 Hz in Exhibit 2, this frequency coincides with the outer-race (cup) frequency associated with that particular speed. In the water-etched case (Exhibit 3) vertical bands are not very distinctive but there is more hor-



**Exhibit 2. Carrier/Modulation Frequency Plot for a Cup-Spalled Bearing**



**Exhibit 3. Carrier/Modulation Frequency Plot for a Water-Etched Bearing**



horizontal banding present. These horizontal bands represent carrier frequencies for a water-etched flaw. Both the modulation bands and the carrier-frequency bands provide distinctive features that can be passed to a neural network for analysis.

### BEARING-FLAW FEATURES

The features in the above array convey a large amount of bearing-flaw information. Strong modulation bands are easily identified and are much less sensitive to digital signal-processing noise. The additional information contained in the carrier-frequency bands is useful in identifying carrier-frequency shifts between flaws.

Exhibits 4 through 6 show the feature arrays for several of the bearing flaws studied in the lab tests. Each feature is displayed along the x-axis, the magnitude along the y-axis. The features were extracted for different speeds. The speed is listed along the z-axis in miles per hour (mph). Exhibit 4 graphically depicts data taken from a bearing with cup spalling. Notice the large values for the outer-race feature. Exhibit 5 shows a water-etched bearing. Here there is outer-race, inner-race, and roller activity which is characteristic of a water-etched flaw. Exhibit 6 depicts an unflawed bearing. As would be expected, the feature values are very small indicating that there are no flaws present.

**Note:** Contact James Bilodeau at (719) 584-0687 with questions or comments about this document.

E-mail: james\_bilodeau@aar.com

**Disclaimer:** Preliminary results in this document are disseminated by the AAR for information purposes only and are given to, and are accepted by, the recipient at the recipient's sole risk. The AAR makes no representations or warranties, either express or implied, with respect to this document or its contents. The AAR assumes no liability to anyone for special, collateral, exemplary, indirect, incidental, consequential or any other kind of damage resulting from the use or application of this document or its content. Any attempt to apply the information contained in this document is done at the recipient's own risk.

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

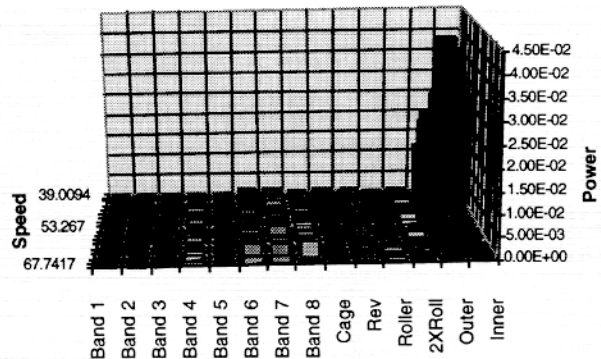


Exhibit 4. Features for a Cup-Spalled Bearing

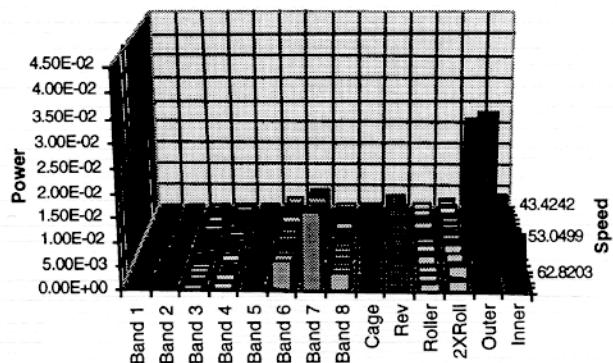


Exhibit 5. Features for a Water-Etched Bearing

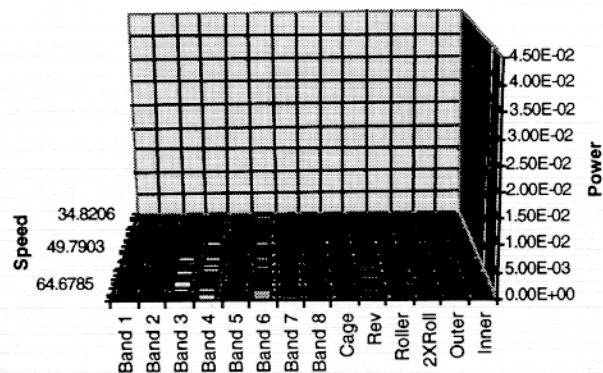


Exhibit 6. Features for a Good Bearing