US Department
of Transportation

**Federal Railroad
Administration**

Research Results

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Self-Powered Wireless Brake Health Monitor

SUMMARY

The health of the brake system has a dramatic impact on railroad freight car safety and maintenance costs. Scheduled inspections detect many component failures. However, there has been no way to monitor the condition of the brake system in real time. A logical approach is to measure the actual braking force provided by each brake shoe. If the brake force is too low, safety is at risk. If the brake shoe is replaced before the end of its lifetime, maintenance and operating costs are increased.

Under the U.S. Department of Transportation (DOT) Small Business Innovation Research (SBIR) program, Midé Technology Corporation is developing a novel, self-powered, wireless brake health monitoring system. The goal of this system is to improve safety and decrease maintenance costs. In a stand-alone configuration, the device will detect degradation of brake shoe force over time. In a distributed environment, such a system will provide a timely failure warning of individual brake beams to release, therefore reducing costly replacement of skid-flat wheels. Since the maintenance time saved replacing brake shoes could easily be spent in replacing batteries, the system must generate its own power instead. For this reason, Midé developed a piezoelectric energy harvester that utilizes the vibration of the train while moving to generate small amounts of electricity, thus recharging its own batteries.

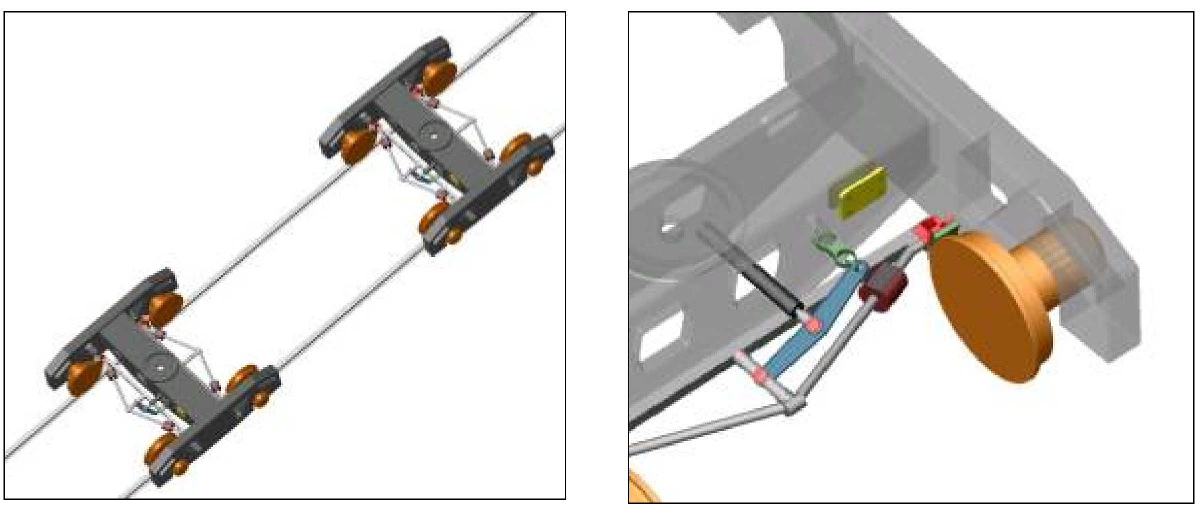

Figure 1: (Left) Two Bolsters outfitted with one measurement node per brake shoe. (Right) Close-up of beam and proposed placement of measurement node, shown as brown cylinder.

BACKGROUND

This project came about as the result of an SBIR solicitation and is funded by the Federal Railroad Administration (FRA) (Contract# DTRT57-06-C-10018). As of the start of the project in 2004, brake-related accidents accounted for 5.5 percent of all accidents, totaling millions of dollars annually[1]. These figures included both mechanical failures and preventable operator errors for the main train brake, as well as hand brakes. With real-time monitoring and operator feedback, many of these faults can be dealt with before they create a problem.

The described system can be used to detect a variety of fault conditions, both mechanical and operator error, on a beam-based brake system including standard pneumatic and electronically controlled pneumatic (ECP) brakes. Midé is working with a railway supply company to develop a commercial brake beam version for the locomotive emergency brake.

OBJECTIVES

The goals of the project include demonstration of the following:

- A reliable energy harvesting system, eliminating the need for consumable batteries;
- A measurement system capable of operating only on harvested power;
- A wireless networking system capable of operating continuously at extremely low power levels;
- A power storage medium suited to harsh environments; and
- Detection of faults resulting from equipment failure and operator error.

METHODS

Operation

Each brake shoe or shoe pair is monitored by one unit attached to the brake beam. Strain gages placed on the brake beam, as close to the brake shoe as practical, provide the force measurement for the system. The high temperature gages are either bonded with ceramic adhesive or flame spray welded onto the surfaces to allow for a rigid, high-temperature connection.

Energy Harvesting and Storage

Piezoelectric materials are crystalline materials that deform in response to applied voltage. Conversely, applying a mechanical deformation to the material produces a usable electric charge. Midé uses this effect in its Volture™ energy scavenger to add self-powering capability to the brake health monitoring system, eliminating consumable batteries. A patented encapsulation method protects the brittle piezo material against humidity, harsh contaminants and breakage due to mechanical shock. Vibrations seen on the railcar during operation often exceed 20g's, with the possibility of much higher occasional spikes.

Figure 2: About the size of a deck of playing cards, the Volture™ energy scavenger captures vibration energy to power embedded sensors.

In order to tune the energy harvester, it was necessary to capture a vibration profile from a real brake beam during operation. With the help of Transportation Technology Center, Inc. (TTCI), an accelerometer package was attached to a car-mounted beam (#24 Conventional) and run during an overnight test. The analysis is shown in Figure 3.

The majority of the vibration was centered on approximately 106Hz, with only a small amount of power present in other bands, and remained consistent throughout variations in locomotive speed and track type. By adjusting the length of the piezo beams and the mass at the tip, the energy harvester design is tuned to this

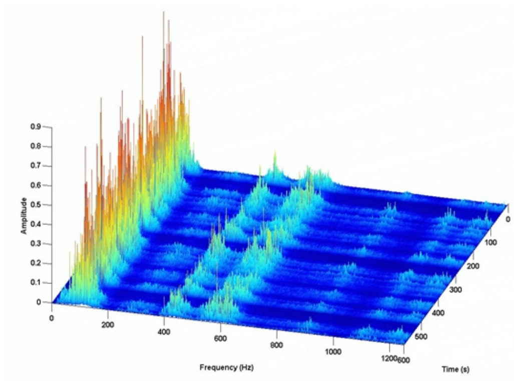

Figure 4: Spectral distribution of a 10-minute sample of beam vibration data.

frequency for maximum power output. Still, the amount of power generated is small (less than the amount needed to power a small MP3 player) and must be used efficiently.

The recorded vibration profile was also used to reproduce the mechanical conditions the harvester would be exposed to on a laboratory shaker for long-term testing. This environment was harsher than anticipated; the design of the energy harvester beams had to be modified several times in order to achieve a system capable of reliably withstanding these conditions over the long term.

Rechargeable batteries used to store the harvested power also had to be qualified for the harsh conditions and temperatures which the measurement devices would be exposed to on the line of road. Samples were obtained and tested in a Thermotron 2800 environmental chamber. The batteries are fully manufacturer-qualified to 140° F and they retain their charge up to 160° F. On the low end, the cells retain functionality down to an incredible -90° F, which is the limit of our environmental chamber. Long-term environmental testing is currently in progress.

Force Measurement

Typically, load cells or strain gauges are measured using a low-noise analog signal chain. Although capable of high-precision measurements, this approach uses a considerable amount of power. The strain measurement approach used in the brake force measurement system uses high-resolution digital timers to measure how quickly a known quantity of electricity flows across each gage. Power is applied across the gage for only a few milliseconds at a time, and the times are measured in picoseconds.

Wireless Transmission

To detect the widest range of potential problems, each measurement device not only measures its own brake, but also listens to measurement data from its nearest neighbors. This allows suspicious discrepancies in measured force between brakes to be detected. Continuous networking between low-power devices has always been a challenge, since the receiver typically must be continually “awake” listening for new data on the air.

Since the amount of harvested power is modest, adding wireless capability required a power-efficient solution. Midé selected the ANT™ RF technology (Dynastream Innovations, Inc.) to maintain persistent wireless connections between sensors at exceptionally low levels of power consumption. This radio technology works by synchronizing a very accurate clock between each transmitting and receiving device; each one wakes up at an agreed time for only a few milliseconds each second to exchange data. This way, each measurement device's CPU and radio transceiver can spend nearly all their time in a low-power sleep mode.

Despite this efficiency, a problem alert from one brake can travel up the train at up to one car length per second, allowing the engineer to be notified of a budding problem within minutes. Additionally, problem reports and historical performance data are stored with each measurement device along with a timestamp, allowing the full history to be downloaded wirelessly on demand. For the hand or parking brake application, the sensor allows end-to-end verification that the required amount of brake force from the actuator end has successfully reached the brake end, reducing the possibility of over- or under-application.

FINDINGS

To date, nearly all of the objectives have been met. Piezo energy harvesting has been validated as a feasible approach in terms of power output and reliability, as well as a fully self-sufficient sensor suite which has been built around it. Naturally, the beam design will have to be fine-tuned for each type of brake beam. That process is quick and straightforward, especially if a live installation is available for measurement.

Thus far, battery performance has proved more than adequate for the application although long-term tests are still ongoing. As with any rechargeable solution, the number of charge/discharge cycles is finite; the battery's capacity is reduced slightly with each cycle. This effect is of limited importance in this application, since the electronics currently draw so little power that each unit will see the equivalent of about one complete charge/discharge cycle per year.

Measurement accuracy targets have been met at very low power consumption levels. The alternate measurement approach delivers excellent efficiency, as well as impressive thermal calibration by measuring each strain gauge element independently, as well as, paired.

At the time of this writing, the mesh networking software that will run on each unit is nearly complete, and development and testing of fault-detection algorithms is currently in progress. Still, the results look promising in the ability to detect faults such as erroneous brake application (pressure loss) while underway, emergency application, and failure to release without advance knowledge of action taken by the engineer.

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REFERENCES

[1] http://safetydata.fra.dot.gov/OfficeofSafety/

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