Precision Train Inspection Methods –
North American Adoption of Global Technology

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ABSTRACT

New technologies enable much higher accuracy and additional inspection modes for rolling stock. The presentation discusses global best practice for bearing, wheel, and brake thermal scanning, as well as the characterization of wheel, truck, and car properties from high rate sampling of rail loads.
INTRODUCTION

The historical response to railway disruptions has been a vehemently reactive one. Railroad C&S managers have a repertoire of career modifying stories about when their systems delayed trains. Disruption due to defects in rolling stock, (or track and signals) causes great consternation, because failures have a randomness and are not directly controllable. Defect reporting systems have no “safe state “ for the manager. They are not expected to miss a defect, and they are not expected to give false alarms.

For a continuous process business like a railroad, we know there are two fronts to fight car defect disruptions. First there is the traditional reactive response, quickly re-planning the routing to mitigate delays when a failure occurs. But the master of Quality management methods W. Edwards Deming taught us that the only way to assure continuous throughput is to take the defects out of a system BEFORE they cause a disruption.

Over the past 15 years interest in preventative approaches with adaptive maintenance has grown. Today the North American railroads are focusing on pro-active maintenance and detection of defects before failure occurs. Recent projects by the industry underway in North America are tracking bearing temperatures between detector sites, looking for trends that flag potentially dangerous wheel bearings long before a critical event occurs. Successful trend analysis of growing defects could allow a planned servicing of the railcar or locomotive without disturbing traffic.

Of course this is not a brand new concept, but what is changing is the technology for instrumentation, including both hardware and software techniques. Higher accuracy and consistency in detection enables recognition of subtle signatures that are forerunners to
many types of growing defects. The technology and methodologies discussed here we believe represent a global best practice for train defect inspection. We will discuss requirements of the railways, how the technologies respond to those requirements, and the ever-growing applications that can be created from analysis of the high-resolution data.

HIGH LEVEL REQUIREMENTS FOR DEFECT DETECTION SYSTEMS

Accuracy, Reliability, Maintainability, False Alarm Rates, and Life-Cycle Cost are all measures we use in the industry to strive for excellence. As we discuss the detector technologies we will show how the system designs challenge the upper limits for some of these measures. In our global benchmarking we have found Hot Bearing Detector systems that require recommended calibration every day, every week, or every month. The design we present here is automatically calibrating, and has a recommended inspection and maintenance cycle of only two times per year.

- HOT BEARING AND HOT WHEEL DETECTION

The FUES II detector is described followed by examples of how it enables special applications. FUES stands for Fahrwerk Überwachung Schwelle, which is German for "Wheel-Set Monitoring Tie". The system was initially developed in Germany for High Speed operations and has now been configured and enhanced to inspect North American rolling stock.
HARDWARE FOR ACCURATE SENSING

One of the challenges to getting accurate and reliable bearing heat signatures is positioning the scanning hardware where it can accurately scan rolling stock attributes and survive the harsh trackside environment. The stationary system is housed in a hollow metal “tie”, suspended by shock damping cables inside another hollow metal tie. This second tie supports normal track structure loading. The scanners use multi-element infrared sensing technology to capture heat from the passing train in 4 scan-lines per scanner assembly. The infrared sensors are composed of Mercury/Cadmium/Tellurium (HgCdTe) elements with 5 elements in an array for each sensor assembly. While 4 elements are used for the scan array, the 5th element does not have external view and is used for auto-calibration. This element views an internal Peltier effect semiconductor cooler maintained precisely at –40 degrees Celsius (+/- 0.1) reference and provides a DC-coupled benchmark for the live heat signatures. This design yields an absolute temperature measurement accuracy of +/- 1.0 degree Celsius.

Each scanner assembly uses zinc-selenid lens, and views the railcar through an external shutter mounted on the instrumented tie, with a front surface mirror in the viewing path. To prevent contamination of the mirror, it has a gold front surface impervious to tarnishing or bonding with other materials. The round mirror spins at 10,000 revolutions per minute to instantaneously fling off any contaminants entering through the shutter.

This view of the calibration element is also by means of a gold front surface mirror so the calibration element emulates the four measuring sensor elements.
Five Element Scanner Assembly with Rotating Gold Mirror, Quartz inner cover and Zinc-Selenid Lens

Positioning of pre-focused sensor assembly and shutter
ELECTRONICS PACKAGING

The instrumentation electronics is contained in a sealed enclosure (Smart Electronics Box- SEB) within the inner steel tie, keeping small-signal cable lengths to a minimum. It contains seven (7) Digital Signal Processors (DSPs), which can support up to four scanners, plugged into the SEB through weather-tight connectors. The SEB contains an Ethernet interface and can connect to a wayside analytical support PC, or directly to a network through fiber optics or conventional cabling.

The result of this hardware configuration is that the system can capture signals from up to 7 scanners with four beams each at data rates per element that yields 120 samples per bearing at a speed of 310 miles per hour. The sampling rate is scales with train velocity, so that regardless of the train speed there are always 120 samples per bearing. Wheel scans capture 240 samples per wheel.

Side view of detector tie showing physical layout and typical scanner assembly positions.
CONNECTIVITY
The system is supported by an industrial PC based workstation connected to the measuring tie by Ethernet. The software in the SEB can be updated remotely through this network connection. In a typical installation the workstation is located wayside for testing purposes and provides the network interface for remote access and reporting.

SYSTEM PERFORMANCE
The result of this design is a system with sufficient sample bandwidth to perform complex analysis to recognize various car components from heat signature, and selectively evaluate or ignore heat signatures as configured in software. The scanner assemblies can be positioned within the tie to view any features under the railcar. The highly repeatable accuracy of +/- 1.0 degrees Celsius allows meaningful site-to-site trending with lower temperature gradients. The high number of samples available for a bearing scan- (4 beams x 120 samples each = 480 samples) enables software filtering solutions to raise performance (Infrared from sun, brakes, and other noise are effectively filtered). FUES Detectors have been installed at 600 sites in Europe, and are capable of keeping the false alarm rate below 1% (this means that for 100 cars inspected after alarms, only 1 does not have a verifiable defect).

Positioning of Scanner assemblies to view Inner Bearing, Outer Bearing, and Wheel Temperatures
Note the close matching of the 4 scan beam temperatures on a normal bearing (Above) versus the uneven distribution when the bearing is heating (Below).
The FUES system installed in High Speed Track

Track Maintenance is facilitated since the tie cribs are unobstructed

Photo of Talgo 350 Temperature reading installed in High-Speed Track in Spain. Elevated temperature of brake caliper is visible to the detector but ignored. E1-E4 in the photo show the scanner element central targets.
APPLICATION 1- Mixed Passenger and Freight Operations – New Jersey Transit

Using these basic building blocks, we have now been able to create new solutions to the challenging inspection requirements of North America. For New Jersey Transit, the challenge was to provide hot bearing and hot wheel detection for inside bearing passenger equipment, wheel temperature scanning, and outside bearings on freight operations. The view of the inside bearings on passenger equipment was extremely limited due brackets obstructing the view.

Angle of scan beams on inner bearing through narrow 1.5” view aperture between traction motor and carrier bracket

By utilizing the coverage of the 4 scan beams in one scanner assemble and dynamically selecting the beam with best coverage based on heat signature, the inner bearing is effectively scanned regardless of variations in truck positioning. Scans of the traction
motor and carrier bracket are excluded based on signature waveforms. Of course traction motor temperatures can also be monitored if desired.

Scan beam coverage of the transit equipment aperture

Clear scan view on two of the 4 sensor elements
APPLICATION 2  Freight Cars And Locomotives

Using the four scan elements with software signature evaluation, effective scanning is performed on AREMA compliant inner bearing races to specified target profile. In addition, more complex locomotive bearings are effectively scanned by the multi-element system, supplementing the on-board locomotive detection devices.
APPLICATION 3 Hot Wheel Scanning (While Braking)
Due to the high number of samples available, Hot Wheel scanning can have the analysis focused on the central plate temperature, rather than just a peak reading. By analysis of the four waveforms available, brake shoes and rim braking temperatures can be ignored and central wheel plate temperatures accurately measured.

Above: This train is not stopped for normal high braking and wheel rim temperatures. However as wheel plate temperature rises alarm will be set regardless of braking.

APPLICATION 4 SLIDING WHEEL DETECTOR
Sliding Wheels can be clearly detected from the unique heat signature and the gradients between scans at different heights on the wheel.
The high level approach used to implement impact and load detection is similar to the principles used for thermal scanning already discussed.

1. Find best fit architecture for railroad requirements
2. Acquire data at high sample rates to prime algorithms
3. Use software techniques to extract meaningful information and ignore noise

The technology described is used in the MATTILD (Main Line and Transit Impact Load Detector) originating from Germany. It was initially developed for protection of concrete ties and high-speed train operations. The system is installed in seven countries including a recent test system in North America on Union Pacific.

HARDWARE FOR DATA ACQUISITION

The sensor assembly is a non-traditional approach for measuring forces in rail. Each sensor assembly consists of a laser diode clamped to the base of the rail aimed at a corresponding receiver similarly mounted a few inches away. The receiver element consists of a charged coupled array device (CCD). As distortion is caused in the rail by loading forces, the laser and receiver are displaced relative to each other, and the beam sweeps across the CCD producing output signal. This gives rise to some fundamental advantages. The first limitation to bandwidth is the physical response of the rail system, so all data that is available at the rail interface can be captured. The discrete step nature of a CCD provides high noise immunity, even with high EMI from locomotives and traction return currents. Since the laser and receiver span a small section of rail rather than a point measurement, the sensor assembly has significant “visibility” to forces outside the span area. It takes very few sensors to sense the entire wheel circumference.

A typical installation for wheel inspection, car overloading and balance uses 6 sensor assemblies per rail for a total of 12 sensor assemblies. No special preparation of the track bed is required unless tariff weighing is desired.
Distortion of the rail displaces the laser beam on the charge-coupled array.

Above-
European Installation with
12 sensors in staggered cribs.

Right-
Close Up Photos
Of Sensor Mounting
A 12 Sensor installation in consecutive cribs as installed in trial site on Union Pacific.

Data measurement rates are 7000 samples / second for each sensor. This yields a sampling resolution for a 36 in. wheel of:

- 0.025 “ (0.64 mm) @ 10 mph
- 0.125" (3.19 mm) @ 50 mph

The inherent discrete step nature of the laser/CCD system provides extremely high signal to noise ratios. This “clean” signal enables analysis of very low level characterizing signatures.

The measurement approach is equally effective in gathering data from both vertical and lateral forces on the rail. The net of both modes is a complete characterization of wheel and truck behavior.
APPLICATIONS OF THE TECHNOLOGY
Using software techniques to examine this data, output reports are generated and compared to alarm limits. The “static” and dynamic components of the loading are separated, and outputs include wheel weights, truck weights, car weights, car imbalance, wheel profile defects and impacts. These are of course expected from any impact detector. The system can identify flat spots down to fractions of an inch, and software transforms the signatures into measurement of length of wheel flat. Having the length information provides a direct comparison for rule based condemnable limits.

The clamp-on sensor installation allows a track location to be fitted with the system in a few hours. In the event of sensor failure, the sensor can be replaced in a few minutes. (If a sensor failures in a multi-sensor installation, the system will continue to function with fewer net data samples.
A single sensor can be installed as a portable or temporary system to capture tonnage on a line or gross overloads on a particular line segment.

This signature shows high frequency noise generated by a traction motor gear defect. The symptom is identifiable before the defect causes a fault and disruption to operations.
The signal in this graph is characteristic of roller bearing defects and appears before temperatures rises to traditional alarm levels. This data can be used alone or combined with trending heat levels to refine the “planned maintenance before failure” decision point. This particular car was observed at a North America test site on Union Pacific.

CONCLUSION

Systems designed for high-speed rail applications provide very high data resolution at freight speeds. The two detection systems discussed in this paper can enhance the capabilities of an inspection checkpoint for both immediate alarms and predictive maintenance. High data accuracy and resolution gives the basis for effective filtering of railcar appliances that normally run at high temperatures (such as brakes) while still measuring bearing and wheel temperatures. Combinations of these systems yield a characterization of the railcar behavior that contains clues for predictive maintenance, even without site to site trending.
RECOGNITION

Thanks to John Vogler, Ben Smith and Robert Milazzo for the opportunity to trial the FUES II System on New Jersey Transit.

Thanks to Bill Gemeiner and Todd Snyder for the opportunity to trial the MATTILD system on the Union Pacific Railroad.
APPENDIX

FÜS II Specifications

Unconfirmed Alarm Rate
Capable of less than 1% false alarms

Defects Detected – Standard Configuration
Hot bearings (inner and outer)
Hot wheels/dragging brakes
Other modes can be specially configured

Scanner
Multi-element HgCdTe infrared detector
4 elements plus self-checking reference element
120 samples per element for each bearing, 240 for each wheel

Detection Temperature
Hot bearing: up to 356°F (180°C)
Hot wheel: up to 1,112°F (600°C)

Calibration & Maintenance
Self-calibration
System notifies user of malfunction
Automatic optical alignment

Installation
Battery: +24VDC for system electronics
AC Power: 100-127 VAC, 50-60 Hz or 220-240, VAC 50-60 Hz for snow/ice heaters
Maximum wiring from measuring tie to wayside house: 328 ft (100 m)
Simple connections

Train Speed
1.86 mph (3 km/h) up to 310 mph (500 km/h)

Operating Temperature
Minimum: -40°F (-40°C)
Maximum: +158°F (+70°C)