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## Review of Rail Neutral Temperature Measurement Technology

by David Read

### Summary

Technology to measure thermal (longitudinal) rail force and neutral temperature in continuous welded rail (CWR) has long been recognized as a critical need by track engineers. The ideal technology would be a nondestructive and continuous measurement of absolute rail force and rail temperature that could be used on all rail types, materials and sections, and track configurations.

Several nondestructive technologies have been proposed over the past 20 years. Most have progressed to the point of laboratory evaluation and, in some cases, field evaluations. While some have given favorable results under laboratory conditions, all technologies that have been subjected to field tests in North America have significant limitations.

Measurement techniques that have been validated include strain gage modules attached to the rail web and measurement of the rail vertical flexural response (rail uplift). The rail uplift technique is based on the principal that the force required to lift the rail beam vertically to a given deflection amplitude is proportional to the longitudinal force.

Both techniques are highly accurate when properly deployed. However, each has significant limitations when compared to the ideal system. For example:

- Strain gage modules are not portable and are location specific.
- Strain gage modules can measure absolute force only after being “zeroed” with the rail in a stress free state. This can be accomplished by installing modules on new rail prior to the rail being installed in track, by cutting the rail, or by using the rail uplift measurement to determine the neutral temperature and normalizing the module output to this value.
- The rail uplift technique is portable but requires a length of rail to be unfastened which adds time to the measurement and creates the hazard of rail buckling if in compression. The technique is also affected by rail curvature which limits its use to straight or very flat curves.

A relatively new portable nondestructive technology based on the relationship between magnetic Barkhausen noise and stress in the rail is being developed in Europe. Initial testing by the European Railway Research Institute indicates that the accuracy of the neutral temperature measurement could be acceptable. However, the accuracy is dependent on calibration for each rail type and manufacturer. Transportation Technology Center, Inc. plans to perform field tests of the technology in 2005.



## INTRODUCTION

The ability to measure longitudinal rail force and rail neutral temperature is a critical track maintenance need that is not adequately met with existing technology. An ideal system would measure absolute thermal force and rail temperature with portable nondestructive technology that is capable of determining rail neutral temperature to within  $\pm 10^\circ$  F and operating continuously from a moving platform or vehicle.

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Both techniques are highly accurate when properly deployed. However, each has significant limitations when compared to the ideal system including:

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- Strain gage modules can measure absolute force only after being “zeroed” with the rail in a stress free state. This can be accomplished by installing modules on new rail prior to the rail being installed in track, by cutting the rail or by using the rail uplift measurement to determine the neutral temperature and normalizing the module output to this value.
- The rail uplift technique is portable but requires a length of rail to be unfastened which adds time to the measurement and creates the hazard of rail buckling if in compression. The unfastening and refastening can also weaken track. The technique is also affected by rail curvature which limits its use to straight or very flat curves.

At least one emerging system in Europe may provide an accurate nondestructive measure of rail force. It is currently deployed as a “stop and measure” technique, and the calibration is highly sensitive to rail manufacturer and type.

## BACKGROUND

Rail neutral temperature ( $T_N$ ) is defined as the rail temperature at which the rail longitudinal (or thermal) force is zero. Temperatures above the  $T_N$  produce compressive forces and those below produce tensile forces. The  $T_N$  is calculated from measured longitudinal force and rail temperature as:

$$T_N = T_M - (P/AE\alpha)$$

Where:

P is the longitudinal force (compressive force is positive)

A is the rail cross sectional area

E is the rail steel modulus of elasticity

$\alpha$  is the coefficient of thermal expansion

$T_M$  is the measured rail temperature

Track is susceptible to buckling under high compressive forces and excessive tension can cause rails and welds to fracture and joints to pull apart. Longitudinal forces are managed by fastening and welding the rail at a  $T_N$  that generates forces considered to be acceptable at temperature extremes.

Any change of the  $T_N$  has a proportional effect on the rail force at a given rail temperature. For example, a  $40^\circ$ F reduction in neutral temperature will increase the maximum compressive force approximately 100,000 pounds for 6-inch base rail sections. Variables affecting the  $T_N$  include:

- Track maintenance activities including broken rail repair, surfacing and alignment.
- Changes in the rail position over time due to rail creep and/or curve movement.
- Changes in track longitudinal stiffness such as turnouts, curves or anchor type.
- Traffic effects such as traction and axle load.

Although research into  $T_N$  behavior is limited, experimental data clearly indicates that  $30^\circ - 50^\circ$  F shifts in neutral temperature are not uncommon. Given the consequences of neutral temperature shift and variability (many buckling derailments can be explained only by significant lowering of the  $T_N$ )<sup>1</sup> the need for measurement technology to monitor and characterize  $T_N$  behavior is necessary for effective management of CWR track. The following is a review of the current technology along with criteria for the ideal measurement system.

## CRITERIA OF THE IDEAL MEASUREMENT TECHNOLOGY

The following are attributes of an ideal  $T_N$  measurement system:

- Nondestructive measurement technology capable of sensing absolute longitudinal rail force without disturbing the rail or fasteners.
- Calculation of the  $T_N$  from measured rail force and temperature.

- The system must be portable and should be able to measure continuously from a moving platform. Revenue service investigations performed by the AAR indicate that the neutral temperature can be highly variable over short lengths of track.<sup>2</sup> Stop-and-measure systems, while clearly of less value than continuously measuring systems, would still be useful if the response time is minimal allowing measurements to be made often enough to adequately map the neutral temperature profile.
- Suitable for use with all types of rail chemistries, sections and worn profiles.
- Not affected by track curvature or configuration.
- Insensitive to rail residual stresses caused by straightening during manufacturing and plastic deformation in service.
- Robust, waterproof, and inherently stable equipment.
- Real time data reduction and exception reporting capability.
- Insensitive to ambient temperature conditions and changes and to temperature gradients in the transverse plane of the rail.
- Longitudinal force resolution of  $\pm 5,000$  lb, temperature resolution of  $\pm 1^\circ$  F, and minimum neutral temperature accuracy of  $\pm 10^\circ$  F.
- *Measurement systems based on strain gages applied to the rail web.* Properly installed, these systems are capable of accurately measuring thermal forces, are not affected by rail type or section, and are insensitive to temperature changes and residual stresses within the desired accuracy range. However, in order to measure an absolute rail force, they must be “zeroed” with the rail in a stress free state. This can be done by installing the measurement module on the rail prior to the rail being installed in track, or, if installed on rail in track, requires the rail to be cut. Another alternative to rail cutting would be to use the VERSE® device to establish the neutral temperature and correlate the data to this value. Strain gage systems (see Figure 2) are location specific and not portable. It is, therefore, difficult to map a neutral temperature profile with sufficient granularity, although location specific sensors do allow accumulation of detailed time histories.
- *Barkhausen magneto-elastic stress measurement developed in Hungary as the Railscan method.* This technology uses the relationship between magnetic Barkhausen noise and stress in the rail to determine thermal force. According to the European Railway Research Institute (ERRI), this relationship requires calibration for each rail material to be measured and the calibration can be affected by residual stresses in the material.<sup>4</sup> The system is mounted to a rail mounted trolley that is pushed by hand and data collected by stopping the trolley and applying the sensor to the rail head fillet. In trials with calibrated UIC 60 and UIC 54 rails, ERRI quotes differences in the neutral temperature obtained by the *Railscan* method with those determined by rail cutting to be on the order of  $\pm 3^\circ$ C ( $\pm 5^\circ$  F). Elektro-Thermit currently represents *Railscan* in North America and has indicated that a system will be available for proof-of-concept testing by TTCI during 2005.
- *Electro-Mechanical Acoustic Transducer (EMAT) systems.* EMAT systems basically correlate time of flight of acoustic waves to material stress. Two systems have been field tested by TTCI in the past 10 years. In both cases the systems performed well in the laboratory but could not correlate adequately with strain gage sensors in the field tests. In the most recent test, the accuracy and repeatability of a mobile EMAT system was highly affected and compromised by residual stresses.<sup>5</sup>
- *Bending wave analysis.* This measurement is being developed by the University of Illinois as an AAR affiliated lab project. A length of unfastened rail is excited laterally within a frequency range and a

## REVIEW OF CURRENT MEASUREMENT TECHNOLOGY

The following are techniques that have histories of application as well as literature that quantifies and documents their capabilities or systems in advanced stages of development:

- *Rail vertical flexural response.* This concept is based on the assumed relationship of longitudinal force to the force necessary to lift a length of rail and was validated in the early 1990's through research sponsored by the FRA and AAR.<sup>3</sup> The concept has since been commercialized as the VERSE® system (Figure 1) and is in general use worldwide. The system is portable and accurately measures absolute rail force of all rail types without cutting the rail or requiring calibration. It is robust and not affected by residual stresses. Limitations of the system include:
  - Need to unfasten the rail over a distance of about 100 feet
  - Inability to be used with the rail in compression
  - Inability to be used on curves sharper than 2.5-degrees
  - Relatively long setup time

bending wave is set up. The speed of the propagating wave is proportional to the longitudinal force. The technique is similar to the vertical uplift measurement in that it requires the rail to be unfastened (although to a much shorter length of about 8 feet) and the two techniques are assumed to be similar in terms of advantages and disadvantages.



Figure 1. VERSE® Rail Uplift Measurement Hardware



Figure 2. The Salient System StressNet™ Module is an Example of a Strain Gage System

## FUTURE WORK

As stated, TTCI anticipates field testing the *RailsScan* device in the summer of 2005. Field tests of the Illinois bending wave system will also be performed when the development has reached the appropriate stage.

TTCI is also planning a “Town Hall Meeting” in conjunction with the annual AAR Research Review to be held in Pueblo, Colorado, in March 2005 to discuss rail force measurement needs and state-of-the art.

## REFERENCES

<sup>1</sup>Kish, A. Presentation AREMA Track Buckling Prevention Seminar 2004, Omaha, NE, July 2004.

<sup>2</sup>Kalay, S., A Hazell and A. Kish. “Rail Longitudinal Force Measurement using Track Loading Vehicle,” *Technology Digest*, TD-92-016, AAR, Transportation Technology Center, Inc., December 1992.

<sup>3</sup>Kish, A., S. Kalay, A. Hazell, J.Schoengart, and G. Samavedam. “Rail Longitudinal Forces Studies Using the Track Loading Vehicle,” American Railway Engineering Association Bulletin 742, Vol. 94, September 1993.

<sup>4</sup>ERRI D 202/RP 9, *Methods for the Non-Destructive Measurement of Forces in CWR Track. Summary*. Utrecht, April 1999.

<sup>5</sup>Tunna, J. and J. LoPresti. “Test of a Scanning-Mode EMAT Longitudinal Rail Stress Measurement System,” final report to the U.S. Federal Railroad Administration, Washington, D.C., January 2003.

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