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Evaluation of the MAPS-SFT Rail Neutral Temperature Measurement Technique

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Summary

Tests performed by Transportation Technology Center, Inc. (TTCI) confirmed that the MAPS-SFT (stress free temperature) rail neutral temperature (RNT) measurement technique was capable of measuring RNT with acceptable accuracy when used on rail types having well defined residual stress conditions.

MAPS-SFT is a nondestructive and portable rail stress measurement technique developed by MAPS Technology Ltd of the United Kingdom. MAPS-SFT exploits the relationship between stress and the magnetic properties of ferromagnetic materials. The magnetic properties are sensitive to the rail's total stress condition that includes residual stresses from manufacturing and thermal stresses from restrained thermal expansion. Calibration of the residual component for different rail types is necessary to resolve the thermal stress required to determine RNT.

Field and laboratory tests were performed comparing MAPS-SFT RNT values to those calculated from rail mounted strain gages. The results showed the difference between MAPS-SFT, and the strain gage/free rail RNT values did not exceed 8°F. TTCI has established $\pm 10^\circ\text{F}$ or less as an acceptable correlation requirement for RNT measurement technology when compared to strain gage or free rail RNT values.

Testing was limited to 141/136RE section, head-hardened rails manufactured by Rocky Mountain Steel Mills, and the matrix included:

- Unrestrained rails with and without temperature change
- Rail with compressive stress applied using a rail tensor
- Field tests on the High Tonnage Loop on tangent and spiral track and a 5-degree curve at the Facility for Accelerated Service Testing

Residual stress calibration lines were developed by MAPS Technology™ for a number of North American rail types by measuring the longitudinal and vertical residual stresses present in unstressed (zero thermal force) service worn rails under fairly constant temperature conditions. The curves were incorporated into the measurement software as a baseline from which the thermal stress and RNT were computed.

Evaluation of MAPS-SFT technique was undertaken by TTCI as part of the Association of American Railroads' Longitudinal Rail Stress Management Strategic Research Initiative.



INTRODUCTION

Track engineers have long recognized the need for technology capable of measuring RNT easily and nondestructively. Thermal stresses develop in rail that is restrained from thermal expansion and the RNT is the rail temperature at which the thermal stress is zero. The RNT is an important track performance and safety parameter as it governs the magnitude of tensile and compressive rail forces during periods of temperature extremes. Despite its perceived importance, however, the RNT throughout the North American rail system is essentially unknown due to the limitations of existing measurement systems.

TTCI has established the evaluation and development of emerging RNT measurement technologies as a core objective of the Longitudinal Rail Stress Management Strategic Research Initiative. The MAPS-SFT technique is the most recent method to be evaluated by TTCI and is the subject of this *Technology Digest*.

MAPS Stress Free Temperature Approach

MAPS Technology™ is based on the relationship known to exist between the magnetic properties of ferromagnetic materials, such as rail steel, and stress. A probe applies a magnetic field to the surface of the component being measured, and readings are taken at various angles of probe rotation to determine the axes of stress. The measurement software computes the stress levels at the measurement points and delivers a biaxial stress distribution.¹ MAPS Technology™ has been applied to a number of condition monitoring functions including determination of rail stress and RNT where it is packaged as MAPS-SFT.

System Hardware and Measurement Process

The MAPS-SFT system is highly portable, nondestructive, and can be installed or removed from the rail in less than 30 seconds. System hardware includes two head units that attach to the gage and field side of the rail web in the crib between ties and are connected with cables to a base unit that controls the system (Figure 1).

The head units clamp to the rail with magnets and each unit contains a rotating magnetic probe and rail temperature sensor. Positioning feet on the head units allow the magnetic probes to be located at the rail neutral axis. The head units can be used on 132, 133, 136, or 141RE rail sections by changing the positioning feet.

The base unit powers the system with two lithium-ion batteries, controls the magnetic scanning operation of the head units, collects and analyzes the magnetic data, and produces the final RNT result. The head unit contains a touch screen operator interface that directs the operator through the measurement process.

The measurement process currently requires collection of at least eight data points, or scans, and a scan currently takes about 4 minutes to complete once the head units are on the rail. (MAPS Technology Ltd is working to reduce the scan time from 4 to 2 minutes). The measurement software calculates a provisional RNT from each scan, and the software performs a statistical analysis of the dataset following each scan. The base unit outputs a final RNT when the dataset variance is less than a specified value. The measurement software will ask for additional scans beyond the initial eight until the variance requirement has been met. The measurement procedure recommends not measuring the same crib more than twice to avoid the possible effects of an anomalous data point.

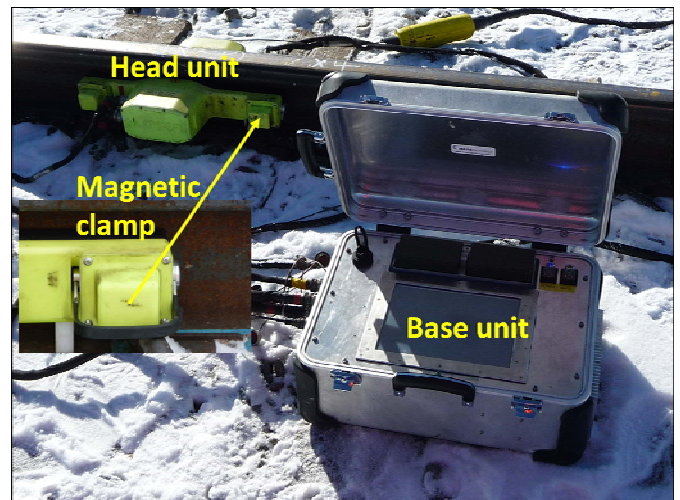


Figure 1. MAPS-SFT System Hardware

Determination of Rail Thermal Stress

The MAPS technique measures the total component stress, which includes the applied stress plus any residual stresses. Because computation of the RNT requires measurement of only the applied thermal stress and rail temperature, it is necessary for MAPS-SFT to determine the residual component and remove it from the total measured stress.

Residual stresses in the rail web are induced primarily by the rail straightening, rail cooling, and head-hardening processes that take place during manufacturing. MAPS Technology Ltd has determined that a linear relationship exists between the vertical and longitudinal residual web stresses for rails of similar grade and manufacturer.² The vertical/longitudinal residual stress relationship is established by measuring a number of unrestrained rails that have no thermal stress. Having defined the slope of the residuals stress curve, the thermal stress component is determined as Figure 2 shows.

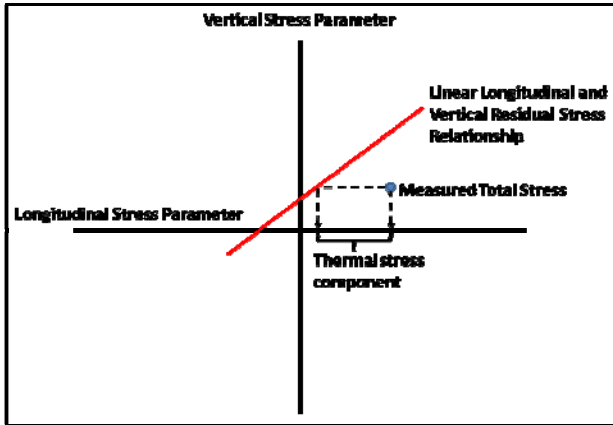


Figure 2. MAPS-SFT Determination of Thermal Stress

RESIDUAL STRESS CALIBRATION

The longitudinal and vertical stress relationship was measured on the rails listed in Table 1. All rails were service worn, 20 to 40 feet in length, unrestrained longitudinally, located in a building with minimal temperature change and were considered to be in a zero thermal stress state during the residual stress measurement process.

A statistical relationship line (residual stress calibration line) was fitted to the measured vertical/longitudinal stress data points as shown in Figure 3 for the various rail types. The calibration lines were then incorporated into the measurement software and testing was initiated to confirm the MAPS-SFT RNT output.

Table 1. Summary of Residual Stress Calibration Rails

| Manufacturer | Section | Grade | Total |
|--------------|---------|------------|-------|
| RMSM | 133RE | Std Carbon | 2 |
| RMSM | 136RE | Std Carbon | 16 |
| RMSM | 136RE | HH | 19 |
| RMSM | 141RE | HH | 6 |
| NKK | 133RE | HH | 11 |
| NKK | 136RE | HH | 15 |
| Mittal | 132RE | Std carbon | 4 |
| Mittal | 136RE | HH | 5 |
| Mittal | 141RE | HH | 2 |
| DO | 136RE | HH | 3 |

RMSM=Evraz Rocky Mountain Steel Mills, DO=voest alpine

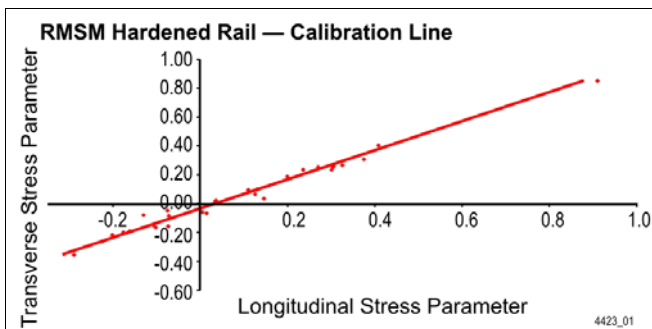


Figure 3. Example of Residual Stress Calibration Line for RMSM Head-Hardened Rail

RAIL NEUTRAL TEMPERATURE TEST RESULTS

The following tests were performed at the Facility for Accelerated Service Testing (FAST), High Tonnage Loop (HTL), Pueblo, Colo., on RMSM head-hardened rail comparing MAPS-SFT values to those calculated from rail mounted strain gages or to the ambient temperature of rail that was longitudinally unrestrained:

- Rails 20 to 40 feet in length, setting on blocks, unrestrained longitudinally and located inside and outside of a laboratory where the RNT was equal to the ambient rail temperature (results are listed in Table 2).
- An unrestrained rail with compressive forces applied by a rail tensor and the MAPS-SFT output compared to the RNT calculated from strain gages.
- Field tests on the HTL where the MAPS-SFT output was compared to the RNT from strain gages.

Table 2. Longitudinally Unrestrained Rail Test Results

| Rail Type | MAPS RNT | Ambient Rail Temperature |
|---------------|----------|--------------------------|
| RMSM 136RE HH | 58 | 55 |
| RMSM 141RE HH | 51 | 55 |
| RMSM 136RE HH | 40 | 43 |
| RMSM 136RE HH | 47 | 56 |
| RMSM 136RE HH | 55 | 50 |
| RMSM 136RE HH | 24 | 24 |

Rail Tensor and Field Tests

Rail tensor testing was performed on a rail located inside a laboratory where the rail temperature was constant. A compressive force of about 80,000 pounds was applied in two steps and the equivalent RNT calculated by MAPS-SFT and strain gages at each increment of load. Figure 4 shows the results of the test where the MAPS-SFT and strain gage RNT values are plotted as functions of the applied force.

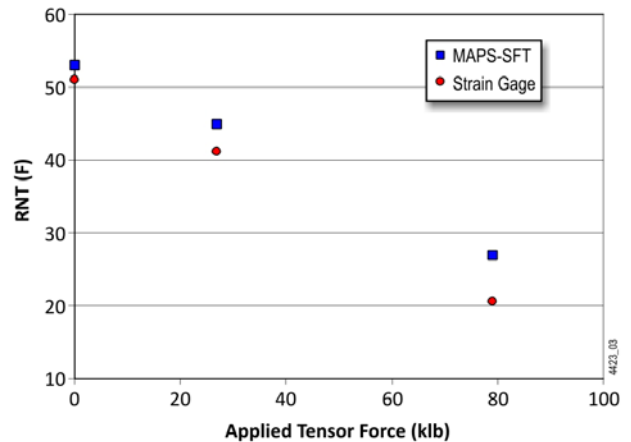


Figure 4. Compressive Force Rail Tensor Test Results 136RE RMSM HH Rail

Nine field tests were performed at four locations on the HTL comparing MAPS-SFT to nearby strain gage sensors. The locations included tangent, spiral, and 5-degree curve alignment. The rail was RMSM head-hardened and either 136RE or 141RE sections. The average difference between the two measurements was 4°F and the maximum difference was 8°F. Table 3 lists a summary of the test results.

Table 3. Summary of HTL Field Test RNT Values

| Location Description | Average Rail Temp | MAPS-SFT RNT | Strain Gage RNT |
|---|-------------------|--------------|-----------------|
| Tangent, 141RE HH rail, wood ties, track spikes every other tie anchored (EOTA) | 40 | 65 | 73 |
| Tangent, 141RE HH rail, wood ties, EOTA | 46 | 93 | 85 |
| Spiral , 141RE HH rail, wood ties, EOTA | 67 | 96 | 93 |
| Spiral , 141RE HH rail, wood ties, EOTA | 68 | 90 | 93 |
| 5-deg curve, 141RE HH rail, concrete ties | 28 | 75 | 76 |
| 5-deg curve, 141RE HH rail, concrete ties | 30 | 72 | 76 |
| 5-deg curve, 136RE HH rail, concrete ties | 19 | 48 | 52 |
| Tangent, 141RE HH rail, wood ties, EOTA | 37 | 70 | 68 |
| Tangent, 141RE HH rail, wood ties, EOTA | 63 | 95 | 88 |

TTCI has established correlation of ±10°F with strain gage or ambient rail temperature-derived RNT values as an acceptable criterion for RNT system evaluation. The range is considered adequate for a number of reasons, including the potential errors of the strain gage and rail temperature sensors and the practicality of needing a better correlation.

CONCLUSIONS

- MAPS-SFT system produced RNT results that were within 8°F of RNT values calculated from strain gages during HTL field tests and tensor applied load tests on worn RMSM head-hardened rail. The HTL tests were performed with the rail in tension and the rail tensor test represented system performance with the rail in compression. TTCI considers the correlation with the strain gage sensors as being sufficiently adequate to validate the MAPS-SFT measurement concept.
- The accuracy of the measurement technique, however, relies on the rail vertical/longitudinal residual stress relationship being adequately characterized and residual stress calibration lines being developed for the rail types being tested.
- The system hardware is well designed, quick and easy to set up and move, can be used on electrified railways and is robust and well suited to the North American environment. The measurement software and touch screen interface are well developed and intuitive.
- As tested, the system required a minimum of eight measurement scans, each taking 4 minutes, to produce a single RNT value. However, MAPS Technology Ltd is working to cut the measurement time in half by reducing the scan time to 2 minutes.

REFERENCES

1. Eckold, G. January 2008. "Measure the Stress." *The Chemical Engineer*, UK.
2. Hayes, A. and G. Eckold. June 2009. "MAPS-SFT – A New Approach to the Management of Stress Free Temperature in CWR." *10th International Conference Railway Engineering*, London.

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