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Investigation of D'stresen Rail Neutral Temperature Measurement System

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Summary

Transportation Technology Center, Inc. has conducted an extensive investigation of the rail neutral temperature (RNT) measurement system known as D'stresen. D'stresen is a portable and nondestructive technique that does not require the rail to be cut, unfastened, or altered in any way as part of the measurement process and is based on the unique concept of a rail mounted tune bar (TB) that senses small changes in shaker induced rail rotational deflections and relates these changes to the RNT.

Because of the inherent variability of track conditions that can affect the small amplitude vibration of the rail, D'stresen should be considered as an estimator rather than a direct measurement of RNT. It is felt that an accuracy of $\pm 15^\circ\text{F}$ or better can be achieved in most cases, and that D'stresen can be a useful tool to characterize RNT conditions, if used carefully.

The measurement process involves a rail mounted variable speed shaker inducing small-amplitude rail deflections that excite vibration of the TB and place it into resonance at a discrete frequency. The peak TB resonant amplitude is recorded along with the rail temperature; RNT is calculated from the two measured parameters.

The measurement hypothesis assumes that the recorded TB amplitude changes at a linear rate with changes in the rail temperature/thermal force and the *maximum* amplitude occurs at the RNT. This maximum amplitude referred to as the *B#*, is the zero-force reference that allows calculation of the RNT from any measured TB amplitude and is an assumed constant in the equation.

Modeling and field measurements confirmed that thermal forces can influence the rail torsional stiffness and inhibit the shaker's ability to rotate the rail through two mechanisms: (1) rail bending stiffness that is analogous to a tightening guitar string and only present when the rail is in tension and (2) contact forces generated between the rail base and lateral stops in the rail seat as the rail is pushed and pulled in response to temperature changes. The analytic and experimental data indicated that bending stiffness is the dominant mechanism for straight rail with elastic fasteners and, in this configuration, the system will not measure compressive rail forces. The data further showed that the rail seat mechanism allows the system to sense changes in rail compression, particularly with a curved rail in tie plates.

Implementation guidelines, aimed at maximizing the accuracy and reliability of the technique, were developed and include recommendations for acceptable track conditions, measurement procedural guidelines, and operator guidelines.



INTRODUCTION

The Transportation Technology Center, Inc. (TTCI) has investigated a RNT measurement technique known as D’stresen that is relatively new to North America.

The ability to measure RNT enhances management of longitudinal thermal forces in continuous welded rail and the prevention of forces that are damaging to the rail and track structure. It is generally agreed that an ideal RNT measurement is one that is portable and easy to use, is not affected by rail or track properties/conditions, and can measure absolute thermal force nondestructively. However, because none of the proven technologies currently in use fully meet these criteria, investigation and development of innovative RNT measurement systems has been a core objective of the Rail Stress Management Strategic Research Initiative. The D’stresen system is highly portable and the measurement process is completely nondestructive.

SYSTEM AND MEASUREMENT DESCRIPTION

System components attached to the rail include a variable speed shaker clamped to the railhead, a tune bar (TB) consisting of a C-clamp with a cantilevered beam and accelerometer attached, and a magnetic rail temperature sensor. Other components include an interface box with signal conditioning that controls operation of the rail mounted components, 12-volt batteries and a direct and alternate power inverter for system power, computer with data acquisition and analysis software, and a 65-foot-long cable connecting the interface box to the rail. The system is highly portable and can operate from the back of a pickup truck or SUV-type vehicle.

Figure 1 illustrates and explains the measurement process.



Figure 1. D’stresen Measurement Process

1. The shaker induces sinusoidal rotational deflection of the rail as its speed ramps from 0 Hz to 90 Hz.
2. The rail deflection excites vertical vibration of the TB placing it into resonance at a discrete frequency within the swept frequency range.
3. The larger the shaker induced rail deflection amplitude, the higher the TB peak resonant amplitude.
4. The data acquisition system records the TB peak amplitude ($A_{measured}$) and rail temperature, and RNT is calculated from the two measured parameters.

Measurement Hypothesis

As Figure 2 shows, calculation of the RNT is based on the hypothesis that (1) the $A_{measured}$ value increases linearly as tensile and compressive forces approach RNT and (2) the *maximum* $A_{measured}$ value occurs with rail at RNT. This value is referred to as the background number (B#). The B# is essential as it provides the zero-force reference from which an absolute thermal force can be determined.

The system calculates RNT from the B# and the rate of change of the $A_{measured}$ value with temperature (A_{slope}). A_{slope} is basically the TB’s sensitivity to changing rail temperature and thermal forces. Because $A_{measured}$ values increase as the rail temperature approaches RNT, A_{slope} is positive when the rail is in tension and negative when in compression. The measurement hypothesis also has the tension A_{slope} value as being half the compression value. Therefore, TB resolution in compression is twice that in tension, but as a single B# is used, the measurable temperature range in compression is half that of tension.

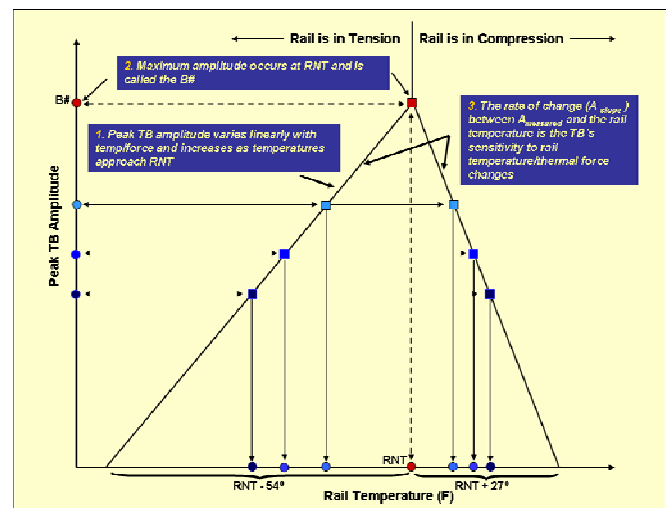


Figure 2. D’stresen Measurement Hypothesis

The B# and A_{slope} values are critical parameters that can be measured directly provided enough data is taken at a single location to capture the change from tension to compression. However, for D’stresen to be used as a single scan measurement, it is necessary for the B# and A_{slope} values to be assumed constants in the RNT equations. It is also important to note in Figure 2 that the same $A_{measured}$ value can be measured with the rail in tension and compression, and the operator must determine which is correct.

Validation of Measurement Hypothesis

Analysis and testing indicated that the very small amplitude rail deflections (generally less than 0.003 inch peak-to-peak) that excite the TB are highly influenced by changes in the rail torsional stiffness. At zero thermal force (RNT), the shaker works against the rail’s minimum torsional stiffness and is able to induce maximum deflections producing maximum $A_{measured}$ values (B#). As rail temperatures vary from the RNT, thermal forces inhibit the shaker’s ability to deflect the rail

through two mechanisms: (1) contact forces are produced as the rail base changes position in response to thermal forces and pushes against lateral stops in the rail seat and (2) tensile forces produce lateral and torsional bending stiffness in the rail that is analogous to a tightening guitar string. Bending stiffness may be the dominant mechanism, if the rail base is highly constrained as would be the case with elastic fasteners. However, compressive forces augment rail lateral and torsional bending which enables, rather than resists, the shaker's capacity to rotate the rail. This contradicts the measurement theory. Therefore, rail seat contact is the only mechanism affecting the torsional stiffness when the rail is in compression.

FIELD TESTS

A total of 202 measurements were taken at the Facility for Accelerated Service Testing and revenue service locations comparing D'stresen RNT values with baseline RNT data from strain gage sensors or the Verse® rail uplift device. The distribution of RNT variance, defined as the baseline RNT value subtracted from the D'stresen RNT value, for all measured locations, except tangent track with concrete ties and compressive rail forces, is plotted in Figure 3. As shown in Figure 3, D'stresen and baseline RNT values were within ±10°F of each other at 72 percent of the locations and within ±15°F of each other at 89 percent of the locations. If D'stresen is accepted as an estimator of RNT, rather than a direct measurement, the ±15°F variance may be considered to be an acceptable tolerance band, especially as the potential error of the baseline values could easily be ± 5°F or higher.

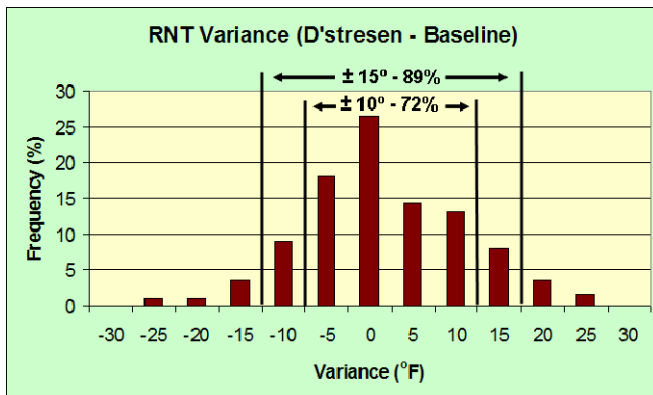


Figure 3. Distribution of RNT Variance for All Measured Data

The following is a summary of key test results:

- The test data was in agreement with the modeling conclusion that the TB does not sense compressive forces as assumed by the measurement hypothesis on tangent track where the rail base is highly confined in the rail seat, as is the case with concrete ties. The lack of TB response will cause D'stresen to calculate RNT values that are higher than actual.

- Compared to concrete ties, spiked rail on tangent track with the rail in compression produced favorable results with 95 percent of the D'stresen RNT data falling within ±15°F of the baseline data. This result suggests that the liberal rail seat clearances of tie plates allow sufficient rail base movement to respond to building compression.
- The TB responded positively to compressive forces on 2- to 6-degree curves, both spiked and elastically fastened rail, due to repositioning of the rail base in the rail seat that was enhanced by the curvature.
- Variability of the B# was apparent on concrete ties. When comparing D'stresen and baseline values, it was clear that different locations had different B#, including the high and low rails of curves.

The default B# being used for spiked rail on wood ties appears to be typical of mainline quality track.

IMPLEMENTATION RECOMMENDATIONS

Track Conditions

The track structure should be as uniform as possible. In addition, measurements should be avoided if any of the following conditions exist within 12 wood ties or 7 concrete ties on the TB side of the shaker:

- Thermite welds, rail joints, insulated joints, turnouts, open deck bridges, rail and highway crossings, rail mounted equipment, wayside detection equipment or any other track condition that will dampen or affect vibration of the rail.
- Ties or tie plates that are skewed to the point of the rail base binding on diagonal corners of the rail seat.
- Fouled ballast, mud pumping and/or evidence the track is pumping under traffic.
- Hanging ties, missing or improperly installed rail fasteners, rail not fully seated on warped or twisted ties, broken tie plates, missing and/or loose spikes, insulators not properly seated, evidence of ties moving in the ballast, or evidence of longitudinal rail movement.
- Use of the system is not recommended immediately after maintenance where the ballast has been disturbed.

Operational Guidelines

- Measurements should be taken with the TB on the field and gage sides of the rail in short time between the two readings to minimize changes in the rail temperature. The two readings should be averaged.
- A trained dedicated operator is recommended.
- The operator should pay close attention to the TB readings and watch the trend of the data with changing temperature. This will usually determine if the rail is in tension or compression and in some cases can give an indication of the actual B#. It is recommended that at least six locations within a distance of about 200 feet be measured over a temperature range of at least 10°F.

- The operator should closely monitor the RNT when measuring concrete ties on tangent track and be aware if values are increasing with increasing rail temperatures. This condition indicates the rail has gone into compression, and the RNT readings are in error.

POTENTIAL USE AND LIMITATIONS OF THE SYSTEM

Potential use of the D'stresen technology includes:

- General characterization of the RNT condition by taking measurements at approximate 100-foot intervals over track segments that are uniform in terms of components and condition. This approach takes advantage of the system's simplicity and ease of use and also allows accumulation of a dataset that is statistically robust. For example, a given territory can be divided into segments based on tie/fastener/ballast type, alignment, and grade and each segment measured at the 100-foot intervals. The objective is to determine the average RNT of the segment and to find any outlier locations where the RNT is too low or high. If needed, additional D'stresen testing or alternative testing with the Verse® or strain gage sensors can be performed at locations of selected interest or concern.
- Characterization of locations where the RNT is known or is thought to be low, including outlier locations from the general characterization. Typical sites would include plug rails installed at cold temperatures, locations where rail creep is evident, where curves have pulled-in, or derailment sites where significant amount of track was replaced in cold weather. Once again, it is recommended that at least six locations within a distance of about 200 feet be measured over a temperature range of at least 10°F to characterize a location and that this should be performed before the onset of warm weather.

- Characterize the RNT following CWR installation or surfacing/re-timbering maintenance by measuring at 100-foot intervals as above. Here, it is important to remember that recently disturbed ballast will affect the measurement accuracy, therefore, it is recommended to allow at least 100,000 gross tons of traffic (0.1 MGT) to accumulate between the rail installation and 500,000 gross tons (0.5 MGT) to accumulate between the surfacing/timbering maintenance and the measurement.

Basic limitations of the system:

- The TB cannot differentiate between tensile and compressive forces; therefore, operators must make the determination based on trends of the measurement results.
- There are no quick methods to verify the B# required to calculate RNT. The B# can only be verified by comparing the D'stresen data to a strain gage sensor, if available, or by taking sufficient data to define the B# experimentally.
- The concept is not valid for rail on tangent track that is fastened with elastic fasteners and is in compression.
- According to the measurement hypothesis, the measurable temperature range is limited to 54°F below and 27°F above the RNT.

CONCLUSIONS

The D'stresen measurement is based on the unique concept of a TB that senses changes in shaker induced rail deflections that are coherent with thermal rail forces. D'stresen is considered to be an estimator rather than a direct measurement of RNT due to the effects of track variability on the measurement accuracy. TTCI's investigation has shown the technology can be used to characterize RNT to within $\pm 15^\circ\text{F}$ or better of the actual RNT if used judiciously within the system's limitations.

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