Development of Nonconventional Tie and Track Structure Inspection Systems

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During the last decade research has focused on new and improved track inspection techniques to define the conditions of the track structure and its key components. Among the areas of focus for this research have been inspection of the strength or load-carrying ability of the track structure and inspection of the cross-ties and cross-tie/fastener systems. The results of two cooperative research and development programs in this area performed by Burlington Northern Railroad and Tiescan, Inc., a joint venture company consisting of ZETA-TECH Associates, Inc., Holland Company, and De Beer Applied Research Company, are presented. The two research programs are as follows: the development and implementation of the Track Strength Analysis and Recording system, a hi-rail-based system for the measurement of track strength (gage strength under applied load) and track geometry, and the development and implementation of the Tiescan wood cross-tie inspection system, a continuous wood tie condition measurement system. In the case of both systems a research concept was taken and transformed into a prototype production inspection system. Both systems are currently undergoing final system shakedown and validation.

The concept of the measurement of the strength or load-carrying capacity of the track, and in particular the gage strength or gage restraint of the track, was originally introduced as part of the Association of American Railroad's (AAR's) Track Strength Characterization Program in the late 1970s (*1*). As part of that program a system for the continuous in-track measurement of track strength was first demonstrated by using a specially developed research vehicle dubbed the *Decarotor* (*2,3*). The Decarotor was developed for use in evaluating the gage strength of the track and identifying weak points in the track. Tests with this system showed that under controlled loading conditions, that is, significant lateral and vertical loads applied to the railhead, the deflection of the track, and specifically, the gage widening under these loads, serves as a direct indicator of track gage strength. Furthermore, under properly defined levels of loading, this testing does not cause permanent damage to the track structure (*2,3*).

The success of the Decarotor tests led to the development of second- and third-generation test systems. The Volpe Transportation Systems Center (VTSC) developed a gage-spreading split axle for measuring rail restraint (*4*). AAR followed with their Track Loading Vehicle (*5,6*.).

VTSC's Gage Restraint Measurement System (GRMS) uses split axle technology coupled with an instrumented wheel set to apply and measure vertical and lateral loads on the railhead. This axle is mounted in a standard truck assembly on an open-top hopper car that operates in a train consisting of a locomotive, the hopper car, and an instrumentation/support car. An exception report is generated onboard the car, and a tie renewal recommendation is made after the test. To date GRMS has more than 8,047 km (5,000 mi) of production testing, during which the system performed consistently and accurately (*4*).

AAR's Track Loading Vehicle (TLV) was developed as a research platform to study the effects that dynamic track loads have on track and track components (*5,6*). Forces are measured by using an instrumented wheel set mounted in a load bogie under a rebuilt locomotive frame. The TLV is placed in consist with a locomotive and an instrumentation/support car.

These research and development activities by AAR and VTSC have shown that gage loading systems can be used to accurately measure the ability of track to resist gage widening forces. Gage strength measurements have been used to locate potential derailment conditions, assess fastener strength, and prioritize tie renewals. Recognizing these benefits, Burlington Northern Railroad (BN) commissioned the development of the Track Strength Analysis and Recording system (TSAR) from Tiescan, Inc., a consortium comprising of ZETA-TECH Associates, Inc., Holland, Inc., and De Beer Applied Research Company. This system was designed as a production track strength and track geometry measurement system mounted on a hi-rail vehicle to facilitate movement across the BN system.

DESCRIPTION OF TSAR

TSAR is composed of a test platform, a track loading axle, track geometry instrumentation, and an integrated software analysis and reporting system. The test platform is a three-axle, 18-kg (20-ton) truck equipped for highway and hi-rail travel (Figure 1). While on rail the vehicle has a gross weight of 22,679 kg (50,000 lbs) on two axles. The rear axle (split axle) provides propulsion and braking, applies up to 5,443 kg (12,000 lbs) of lateral load per rail and 6,803 kg (15,000 lbs) of vertical load per rail, and measures loaded gage (Figure 2). The vehicle measures both track geometry and gage strength while moving forward at speeds of up to 40 kph (25 mph) on track with curvatures of up to 12 degrees. Results are output on a chart recorder (Figure 3), which displays both track geometry and track strength (gage restraint or reserve) on exception reports, and data are also continuously stored onboard the vehicle.

Although most geometry and gage restraint testing to date has focused on heavy test vehicles with axle loadings comparable to those of heavy-axle-load freight equipment, hi-rail types of vehicles offer a degree of flexibility and ease of use that make them attractive. By combining both sets of capabilities, track strength measurement and track geometry measurement, on a single vehicle, increased flexibility in testing and improved use of expensive resources have been achieved. Ownership and operating costs are

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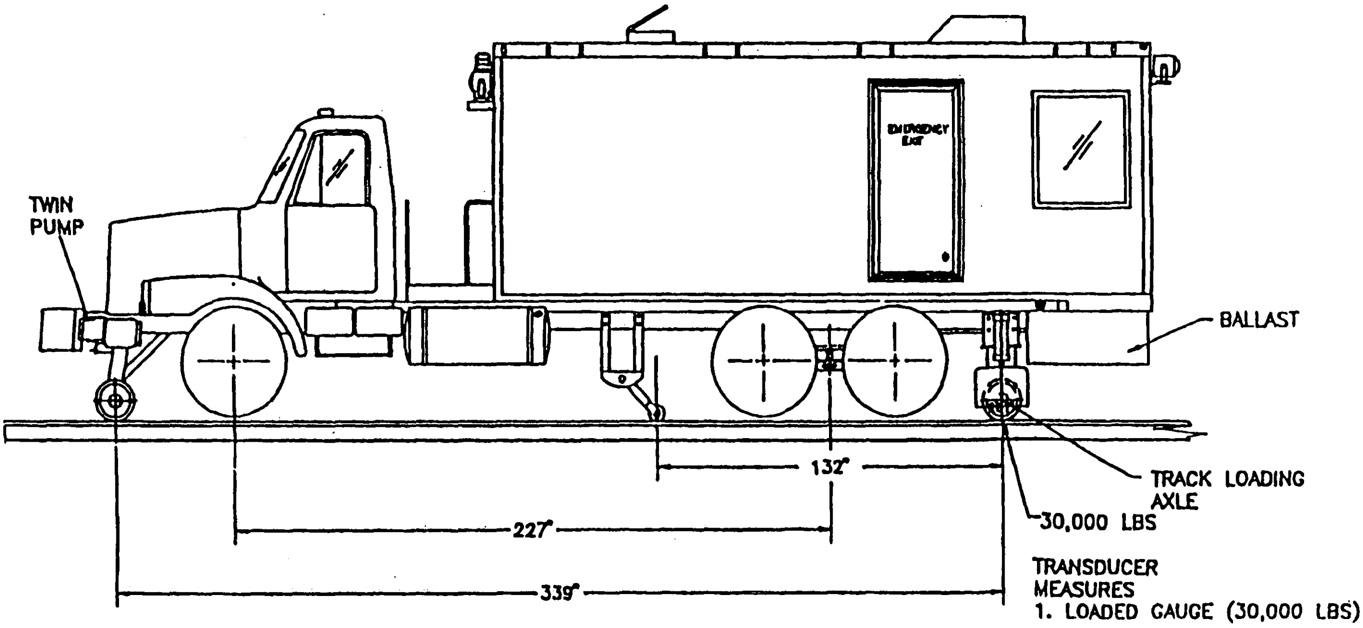

FIGURE 1 Track strength analysis and recording (TSAR) system.

much lower than those for conventional systems because of the elimination of a locomotive, a train crew, and a second test vehicle.

The part of TSAR software that controls the hydraulic system also monitors the lateral-to-vertical ratio to prevent wheel climb derailments. In addition, positive mechanical controls prevent wide-gage derailments. Despite these safeguards if the vehicle derails it has a mechanical device to keep the vehicle on track, prevent damage to the load axle, and facilitate rerailing.

Appendix A presents a detailed set of performance specifications for TSAR.

Geometry Measurement System

The system is equipped with full-wavelength-range responsiveness for all parameters. This in turn permits accurate calculation of defects, particularly chord offset defects, such as those used in current regulatory and railroad standards.

Track geometry measurements include the following:

- Unloaded gage: contact system that measures the distance between rails at 1.59 cm (0.625 in) below the top of rail.
- Loaded gage: uses track loading axle the same way that the unloaded gage uses it to make measurements.
- Alignment: contact system based on asymmetrical chord offset measurement; difference between consecutive midordinate measurements on a 19-m (62-ft) chord.
- Left and right profile: absolute vertical deviation from 19-m (62-ft) chord along the centerline of the left and right rail heads.
- Cross-level: absolute deviation in elevation between the two running rails.
- Curvature: the degree of the central angle subtended by a chord of 30 m (100 ft) on the centerline of the track.
- Twist: the absolute deviation in cross-level over a 3-m (11-ft) chord calculated from cross-level measurements.

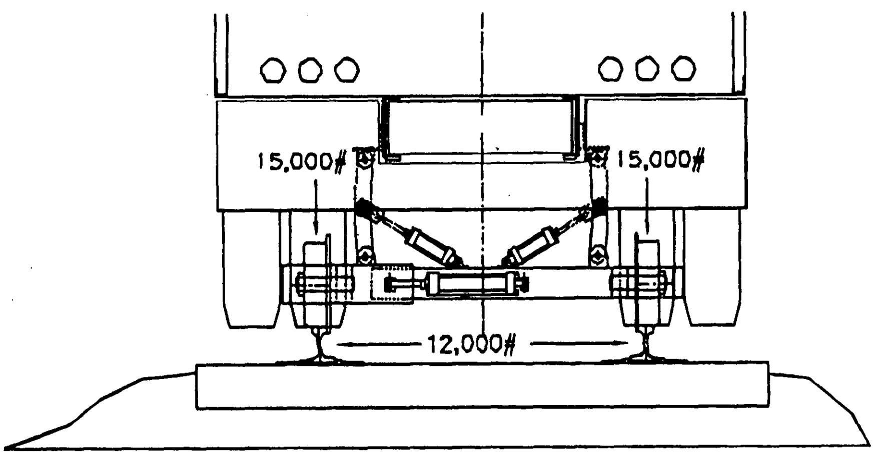

FIGURE 2 Split axle view of TSAR test vehicle.

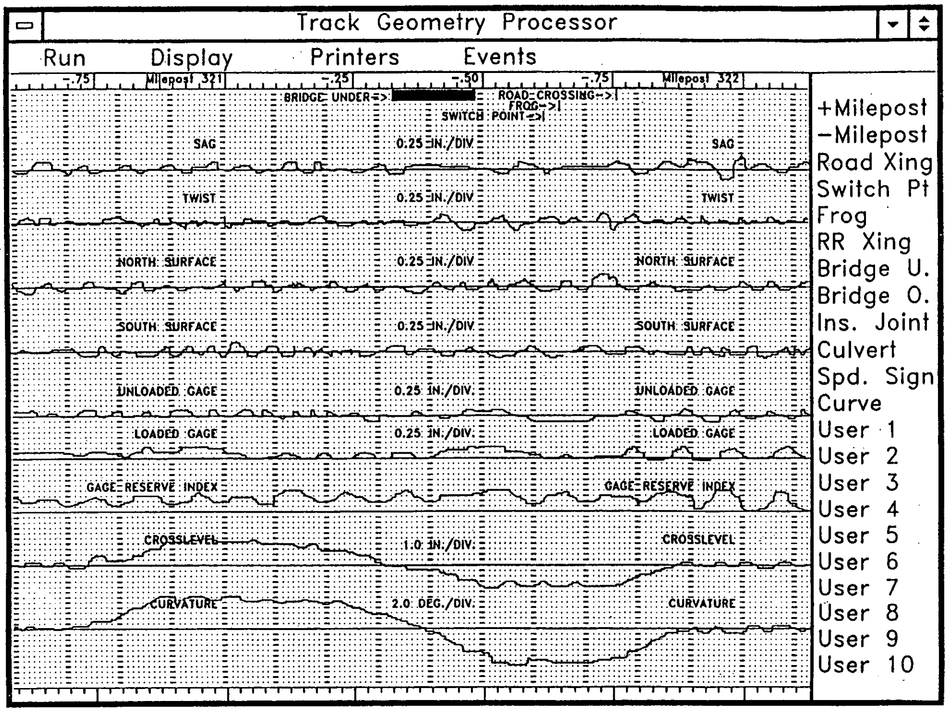

FIGURE 3 Track geometry processor.

• Warp: the absolute deviation in cross-level over a 19-m (62-ft) chord calculated from cross-level measurement.

TSAR Gage Restraint Measurement System

Since TSAR is a hi-rail system, proper definition of the track strength loading values was essential to ensure that the correct level of lateral and vertical loading was applied to the track to get a meaningful and useful track strength response. To define this level of loading the fastener loading severity value S approach, developed by AAR (*7*), was used to properly assess the effects of combined lateral and vertical loadings on tie/fastener strength and to define the TSAR loading requirements. The value S is used to determine minimum and maximum acceptable levels of vertical and lateral loading and is defined as

$$S = L - cV$$

where

S = fastener loading severity value,
L = applied lateral load,
V = applied vertical load, and
c = frictional resistance of the rail/fastener system (usually taken to be 0.4).

Figure 4 shows the loads applied by TLV, GRMS, and TSAR relative to theoretical thresholds for friction, wheel climb, and track damage. The size of each circle represents the degree of variation in dynamic load for each system. Tie/tie plate friction forces will not be overcome at L/V values less than 0.4 and on good track at a value of 0.5 (*7*), whereas rail roll will occur when the L/V ratio is on the order of 0.6 or greater (*8*). However, excessive L/V values, that is, values greater than 0.8, could result in wheel climb derailments, with L/V values of >1.25 posing a significant derailment risk. Furthermore, track damage could occur when S is greater than 10 kips. As can be seen in Figure 4, maximum TSAR loads of 15 kips vertical and 12 kips lateral are within the parameters needed to safely measure gage restraint.

Since the tests used to determine rail restraint must be carried out at a load level that does not damage the track an extrapolation of the measured result is required to determine whether the track is strong enough to prevent wheel drop under extreme loading conditions. The formulation used by TSAR was developed by VTSC (*4*) and is defined in terms of the projected loaded gage (PLG) or the gage reserve. In the case of the former, PLG is defined as follows:

$$\text{PLG} = G + A[g - G)]$$

where

PLG = projected loaded gage,
G = unloaded gage as measured cm (in.),
g = measured loaded gage cm (in.), and
A = extrapolation constant multiplier dependent on the test loads applied and the critical loads assumed.

FRA is currently proposing track performance regulations requiring that the computed PLG24 as defined here be less than 150 cm (59 in.) at any location. At locations where PLG24 exceeds 150 cm (59 in.) operations must not exceed 16 kph (10 mph) until action that increases the restraint capacity has been taken. This approach has been incorporated within the TSAR analysis software package.

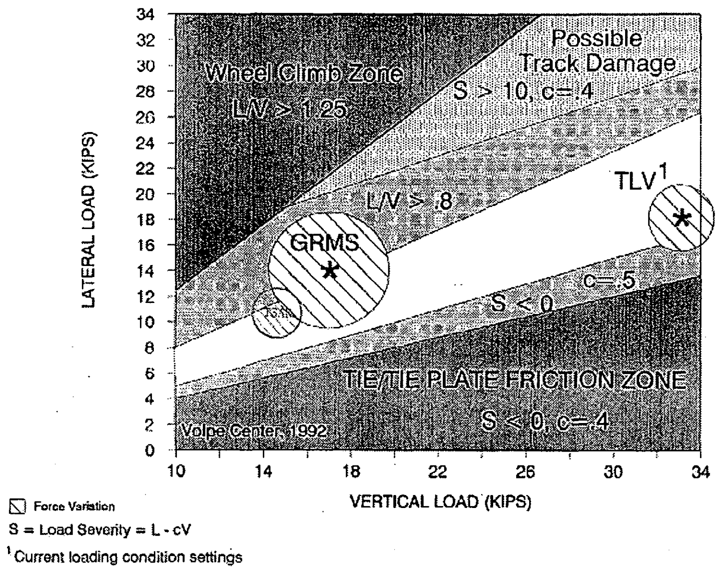

FIGURE 4 Track strength measurement system design criteria.

Exception Reports

TSAR outputs a defined set of exception reports based on current BN track geometry (and defined track strength) standards. In addition, the system will paint the track either red or yellow at locations where measured geometry and track strength parameters exceed the preset thresholds.

Reports and Data Handling

All raw and processed data are stored on an IEM optical (compact disk) disk storage device and are output to one of two Hewlett-Packard Series III laser printers. The reports generated include a strip chart, an exception report, and a curve report. The exception report lists red and yellow exceptions by number, type, magnitude, and location. The curve report summarizes the exceptions found in each curve along with recommendations for maintenance. The strip chart is a plot of the measured values for alignment, gage, left and right rail surfaces, cross-level, and twist. Locations of events, such as mileposts, road crossings, and bridges, are marked by the driver and are shown on the strip chart. Examples of the integrated track geometry and track strength strip chart report are presented in Figure 3.

VALIDATION TESTING OF TSAR

By mounting a split axle type of system on a hi-rail vehicle TSAR represents a new application of proven technology. The major difference between conventional split axle systems and TSAR is a reliance on a single axle to move the vehicle, support the vehicle's weight, and apply lateral loads. As with any new system there are bugs to be worked out, identified, and resolved before revenue testing.

To debug the system and evaluate its performance a series of shakedown tests were performed, first at BN's yard in Chicago, Illinois, and subsequently at AAR's Transportation Test Center (TTC) at Pueblo, Colorado.

The tests on BN revenue trackage in Chicago encompassed a limited amount of performance testing at speeds of up to 40 kph (25 mph) and with various *L/V* ratios. BN contracted with AAR to instrument a section of track with strain gages for split axle calibration. Strain gage testing was done both statically and dynamically, and geometry measurements were used for calibration to manually measured perturbations.

The objectives of the testing at TTC are as follows:

1. Perform static and dynamic tests to validate the calibration of the geometry measurement system and split axle.
2. Operate the TSAR on a TTC perturbed track section to verify geometry, track strength, and performance criteria against TTC's EM80 and TLV vehicles.
3. Train BN operators while in a nonrevenue environment.
4. Provide TSAR calibration data to AAR for use of TSAR vehicle on joint research projects by BN and AAR including AAR Heavy Axle Load Studies.
5. Perform repeatability tests on geometry and gage restraint.
6. Perform lateral track strength comparison tests with other gage measurement devices or by measuring rail displacement under load.

These tests are under way, and BN revenue service testing is expected to commence upon successful completion of these tests. It is expected that the TSAR vehicle will be used to measure track strength on primary or secondary lines for evaluation of tie and fastener conditions. In addition, the TSAR vehicle will provide a supplemented track geometry measurement capability, particularly on those lines that receive limited (or no) coverage from the current BN track geometry cars.

Tiescan Wood Cross-Tie Inspection System

Accurate measurement of the condition of wood cross-ties has been a major area of research for many years and was the last area of the track structure for which effective measurement techniques were not available. Rather, railroads have relied on visual inspection of the cross-ties by tie inspectors.

However, recent research under the sponsorship of BN has led to the development of the Tiescan (patent pending) wood cross-tie condition measurement system. This system relies on sonic compression and tangential waves that are transmitted through the wood (Figure 5). The speed of propagation and the degree of signal attenuation give a direct indication of the condition of the wood and its degree of deterioration from both mechanical and environmental degradation modes.

The Tiescan system consists of a transmitter unit and a separate receiver unit that are used to measure the condition of the wood in the zone between the transmitter and the receiver. Thus, when applied across the rail seat of the cross-tie a transmitter would be placed on one side of the tie plate and the receiver would be placed on the other side, as illustrated in Figure 5. The corresponding sonic waves propagate under the tie plate in the zone of the wood material that is most susceptible to degradation in the tie (Figure 5). Note that this zone under the rail seat is the primary location of tie failure for in-service cross-ties. Both rail seats are tested to fully inspect a cross-tie in the field.

Field Evaluation of Tiescan System

With the support and sponsorship of BN the Tiescan system has been implemented as a continuously moving measurement system that can test cross-tie condition at a speed of 3 kph (2 mph). To date, several sets of field tests have been carried out. These have included tests on the BN main line near Sandpoint, Idaho, a BN secondary main near McBride, Missouri, a yard track near Chicago, Illinois, and a main line track near Galesburg, Illinois.

Initial testing with the hand-held system and a manual test fixture addressed the ability of the Tiescan system to measure tie condition in a field environment.

During the Sandpoint, Idaho, tests in August 1990, 220 cross-ties were inspected on the BN main line, with a measurement taken on each side of the tie across each rail seat. Independent of the Tiescan measurement, a separate analysis of tie condition was performed by a BN tie inspector (*9*).

In addition to the basic tie condition tests, 21 of the tested ties were also checked to determine the repeatability of the test, with separate measurements again taken for each side of the tie. Thus, a total of 42 tie half measurements were repeated, with the repeat measurements taken approximately 30 min after the original measurements. Repeatability was very good, with a repeatability rate of approximately 85 percent.

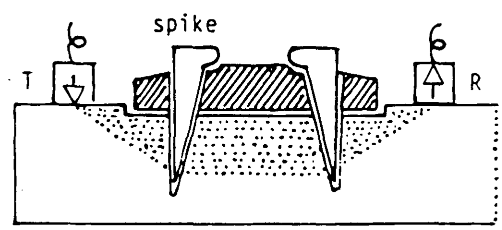

FIGURE 5 Tiescan signal and sonic wave path under rail seat of wood ties (T = transmitter; R = receiver).

Of the 220 ties tested, 57 ties were marked for subsequent follow-up inspection (at the tie plant). Many of these 57 ties were ties for which the condition found by the tie inspector and that found by the measurement system were different. All 220 ties were removed from the field by a P811 within a period of 4 weeks after the completion of this inspection and were shipped to the BN Tie Plant at Spokane, Washington, for follow-up study. As part of the follow-up study these ties were treated as follows:

1. The ties were cut into three segments, with the outside segments containing the full rail seat and tie plate area.
2. The outside segments were retested by using the Tiescan apparatus with a couplant to ensure sonic connectivity.
3. The segments were then cut in half at the center of the rail seat area, and a detailed visual inspection was performed.
4. The BN tie inspector performed a second tie condition inspection after the ties were cut.

Of the total population of 220 ties, there was approximately 82 percent agreement on tie condition (good or bad) between the BN tie inspector and the Tiescan system on the basis of field observations only. However, when the inspector was allowed to view sectioned ties (at the plant) agreement increased to 93 percent.

A second set of field measurements of wood cross-ties were carried out on BN near McBride, Missouri, in April 1991. In these tests a total of 201 ties were inspected, with a measurement taken on at least one side of every tie (*10*).

The site selected was directly ahead of a BN tie gang that was in the process of removing ties already marked as having to come out. Thus, the ties measured by the Tiescan system were compared with the ties marked by the BN system's tie inspector as either requiring replacement or as being allowed to remain in track.

The tie measurements were taken on two separate sites and were predominantly hardwood ties with a mixing of gum, oak, and other species. The conditions of all ties were evaluated in the field by a BN tie inspector, with an immediate definition of a good or no good tie by the Tiescan system. Of the 201 ties tested, five were sectioned in the field for further study.

Of the ties evaluated approximately 90 percent of the Tiescan results agreed with the decision of the BN tie inspector. However, for approximately 8 percent of the ties (or 15 ties) disagreement between the sonic measurement and the BN tie inspector was found.

Most of these ties represented ties that the Tiescan measurements showed to be no good but that the railroad inspector determined should be allowed to remain in track. For example, one such tie, Tie 69, was removed and sectioned for follow-up examination. After sectioning, this tie was found to have severe decay to the point that after sectioning, one side of the tie segment collapsed because of the lack of strength (decay).

The results of both the Spokane and McBride field tests of BN ties and comparison of those results with the results of a railroad tie inspector showed that between 85 and 90 percent agreement could be obtained between the Tiescan measurements and the tie inspector on a consistent basis. They also indicated that the Tiescan system has the ability to quantify a range of tie conditions and to obtain a quantitative indication of the conditions of individual ties (*11*).

Furthermore, the system showed the ability to be calibrated to different tie inspectors (or tie conditions) by varying the threshold levels and acceptance criterion. This would correspond to variations between inspectors and to different tie condition requirements for different types of track, that is, main line versus branch or yard track.

Continuous Track Testing

Following the initial testing, which concentrated on the ability of the system to evaluate tie condition, the research focused on the capability of continuous testing of track. To develop such a system the transducer shoes were replaced by transducer wheels and the system was mounted in a hi-rail drawn inspection cart. In addition, automated signal processing was developed and used in a real-time data processing and recording mode.

The inspection cart was designed to permit continuous low-speed testing (between 1 and 5 kph) (1 and 3 mph) of the wood ties. The cart measures both rails at the rail seats of the ties and is pulled along the track by a hi-rail vehicle. All of the Tiescan electronics except for the processing computer are mounted on the cart; the processing computer is located in the cab of the vehicle. A paint spray system is incorporated. The system marks all ties that exceed a predefined threshold level. In addition, a permanent record is kept of the condition of each tie together with a per kilometer (mile) summary of the number of bad ties in that kilometer (mile). Note that the threshold limits are variable and can be calibrated to a tie condition range as defined by the user. The measurement transducer wheels are mounted in protective shoes to provide for continuous contact on the tie.

After a series of initial development and calibration tests in Cherry Hill, New Jersey; Mississauga, Ontario, Canada; and Chicago Heights, Illinois, a shakedown test of the full cart system was performed on BN track at Galesburg, Illinois, in the summer of 1993. The results of those field tests showed that continuous measurement of tie condition was feasible in the speed range of 1 to 3 kph (1 to 2 mph). The system showed itself to be capable of recording the full range of tie output signals and to continuously monitor the output of the Tiescan transducers while moving at a continuous speed. The actual measurements taken during these tests are undergoing final data processing and analysis.

Several design modifications were identified during this test to ensure a more rugged field system and to allow for production testing of ties in the field. These modifications are being made to the prototype cart and are expected to be deployed in the fall of 1995. When fully implemented the Tiescan system will be used to accurately identify poor ties for replacement as well as to provide engineering personnel with accurate information about the distribution of good and poor ties on individual line segments.

SUMMARY

With the growing awareness of the need for accurate measurement of the conditions of the track structure and its key components, research has focused on filling in the missing pieces in the track inspection arsenal, particularly those relating to the ties and fasteners. To fill this gap BN and Tiescan, Inc., have developed and implemented a set of nonconventional track inspection systems aimed specifically at this area of the track structure.

The hi-rail-based TSAR is intended to be a production version of earlier research systems and is aimed at testing the gage strength of the track on a regular and continuous basis.

The hi-rail-pulled Tiescan cart is similarly intended to be a production test system for wood cross-ties, an area in which previous inspection techniques have been found to be ineffective. The sonic technology-based Tiescan system has been found to be effective in identifying degraded or failed wood cross-ties and is being implemented as a commercial wood tie testing system.

In both cases, the development of this class of inspection technology will help railroads identify weak spots in the track structure, thus reducing derailments and, furthermore, will help railroads more efficiently and effectively plan their track maintenance to minimize their maintenance of way costs while maximizing the effectiveness of their maintenance dollars.

APPENDIX A
Specifications
Hi-Rail Track Strength/Geometry Vehicle

1. Self-propelled hi-rail vehicle; gross weight on rail of 50,000 lbs on rail speed of up to 40 kph (25 mph).
2. Gage spreading axle; at one end of the vehicle (trailing end) gage spreading axle or buggy has capability of applying a constant lateral load of up to 5,443 kg (12,000 lbs) per rail and a constant vertical load of up to 6,803 kg (15,000 lbs) per rail. Vertical and lateral load levels are adjustable as required. Capable of testing curves up to 12 degrees.
3. Feedback system on gage spreading system to maintain applied lateral and vertical loads on loading wheels (axle) at speed of up to 40 kph (25 mph). System capable of necessary actual (dynamic) wheel/rail load at loading wheel (axle).
4. Loaded gage measurement system at loading wheel/axle. Calculation of Track Strength Index such as the Gage Restraint Index or alternate index as required.
5. Unloaded gage measurement system at opposite end of vehicle.
6. Conventional track geometry measurements at full range of operating speeds (up to 40 kph (25 mph)).
   - 6a. Lateral alignment measurement system (cord or accelerometer) based. Separate measurements for left and right rails.
   - 6b. Vertical profile measurement system (cord or accelerometer) based. Separate measurements for left and right rails.
   - 6c. Cross-level measurement.
   - 6d. Warp or twist measurement.
7. Complete hardware and software for computerized data analysis, processing, real-time reporting, and storage. This is to include
   - Exception reports for track geometry,
   - Exception reports for track strength,
   - Continuous recording of track geometry at 3-m (1-ft) intervals,
   - Continuous recording of track strength at 3-m (1-ft) intervals,
   - Continuous output of track geometry (strip chart),
   - Continuous output of track strength (selectable),
   - Storage of track geometry data via optical disk, and
   - Storage of track strength data via optical disk.
8. Paint spray system.

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Publication of this paper sponsored by Committee on Railway Maintenance.