TECHNOLOGY DIGEST
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Evaluation Results for Nayebi Wheel Profile Measurement System

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Summary

A system providing wayside measurement of flange wheel thickness, flange height, and degree of hollow wear has been demonstrated at up to 55 mph. The system, developed by Dr. Kambiz Nayebi for the Iranian Railway Research Center and the Iranian Railway Authority, was demonstrated in tests performed by Transportation Technology Center, Inc. The 'Nayebi' system uses machine vision technology including multi-camera, multi-laser imaging.

Data from the test runs was compared to reference values obtained from Miniprof™ profile measurements of the test wheels. Measurement accuracies required for "good" data points were based on specifications in AAR Interchange Rules (see Exhibit 1). Results from the evaluation show system accuracy to +/- 1/32 inch (1 mm) to be greater than 70 percent for flange thickness, 90 percent for tread hollow and 60 percent for flange height measurements. System accuracy within 1/16 inch (2 mm) of baseline values is over 90 percent for flange thickness and tread hollow and over 80 percent for flange height. Data consistency was high, with over 90 percent of the measurements within plus or minus 1 millimeter of the average parameter value.

Although the Nayebi system was able to produce the raw images of the wheels immediately after train passes, all image files collected during testing required manual post processing to provide wheel parameter information.

The basic elements of the Nayebi system were installed on the Railroad Test Track (RTT) at the Federal Railroad Administration's Transportation Technology Center (TTC), Pueblo, Colo. Since system components were not environmentally protected, testing occurred only under dry weather conditions. Additionally, all test runs were made in low-light conditions since system performance, as installed for testing, was affected by bright ambient and reflected light. The evaluation included 17 test runs at speeds varying from 5 to 55 mph.

This test was performed as part of the Association of American Railroads' (AAR) Strategic Research Initiatives (SRI) Program.

Suggested Distribution:

- ❏ Mechanical
- ❏ Planning & Analysis
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- ❏ Safety

Work performed by Transportation Technology Center, Inc.
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INTRODUCTION AND CONCLUSIONS

North American railroads commit considerable resources for inspecting railcar wheels to identify those that need maintenance or replacement. Even so, only about 5 percent of the total North American railcar wheel population is inspected annually. An automated wayside system that reliably measures key wheel profile parameters would significantly increase the number of wheels inspected annually and considerably reduce the impact on railroad operations of wheels with out-of-tolerance profile parameters (condemnable).

During the weeks of August 12 & 19, 2001, TTCI installed and evaluated a dynamic wheel profile system provided by Dr. Kambiz Nayebi. The 'Nayebi' system uses machine vision technology, including multi-camera, multi-laser imaging, to measure wheel flange height, flange thickness, and tread hollow. Although not setup for this test, tread thickness can be measured with the addition of another camera and laser.

Results from the evaluation show system accuracy to +/- 1/32 inch to be greater than 70 percent for flange thickness, 90 percent for tread hollow and 60 percent for flange height measurements. System accuracy within 1/16 inch of baseline values is over 90 percent for flange thickness and tread hollow and over 80 percent for flange height

Repeatability (or consistency) analysis of the system indicates that over 90 percent of the measurements are consistent to within plus or minus 1 millimeter of the average of all measurements. The standard deviation is 0.78 millimeter (0.03 in.) for flange thickness measurements, 0.47 millimeter (0.018 in.) for flange height, and 0.21 millimeter (0.008 in.) for tread hollow. Results were consistent from 5-55 mph.

Although the Nayebi system was able to produce the raw images of the wheels immediately after the train pass, all image files collected during testing required manual post processing to provide wheel parameter information.

All test runs were made in low-light conditions since the system, as installed for testing, was susceptible to bright ambient and reflected light.

SYSTEM REQUIREMENTS

Specifications set forth in AAR Interchange Rules require wheels to be measured within specific tolerances. If a railroad, which interchanges cars with others, is to use a wheel profile measurement system to enhance its conventional, manual inspection methods, then that system must be able to measure wheels to the same degree of accuracy as would be expected through manual inspection methods. Thus, the AAR sponsored SRI evaluations determined whether wheel profile measurement systems are able to measure wheels to the accuracies specified in Exhibit 1.

Flange height was measured from the tapeline of the tread to the top of the flange. Flange thickness was measured at a point 10 millimeters (0.39 in.)above the tapeline of the tread. Tread hollow was measured across the width of the tread

Exhibit 1. Dynamic Profile Accuracy Requirement

Parameter	Accuracy (in.)	Accuracy (mm)
Flange Height	+/- 1/32	+/- 0.80
Flange Thickness	+/- 1/32	+/- 0.80
Rim Thickness	+/- 1/32	+/- 0.80
Tread Hollow	+/- 1/50	+/- 0.50

SYSTEM DESCRIPTION

The system was developed and provided by Dr. Kamibiz Nayebi. It is designed to perform a wheel profile measurement using a multi-camera, multi-laser imaging system. After the pictures are taken, two sections of the wheel are reconstructed from the corresponding images in real coordinates. Later, the two sections are combined to a single profile using the calibration information. In the third stage, the combined profiles are used to compute four numbers for flange height, flange thickness, flange gradient, and tread hollowing. The fifth parameter, rim thickness, was not measured in this installation.

The system installed at the TTC was a prototype system not hardened for environmental influences. Exhibit 2 shows the lasers and camera installed on the inside of the rail as they were positioned for testing at TTC. Not visible in this photo is another camera that was placed on the outside of the rail. Two ties were spaced on approximately 30-inch (762 mm) centers and all components were placed within this spacing. All components were also placed a minimum of 2.5 inches (63.5 mm) below the top of the rail.

Images from passing wheels were collected and stored on a single desktop computer. It is not known if the same computer will be able to process the images and report wheel wear data, or if a separate system needs to be interfaced.

FIELD TEST EVALUATIONS

The system was installed at TTC on a long tangent section of the RTT. For this evaluation, the system was installed to measure wheel profiles on a single side of the test consist and wheel sensors were placed in such a way that test runs could only be made in a single direction.

TTCI = Transportation Technology Center, Inc.; AAR = Association of American Railroads

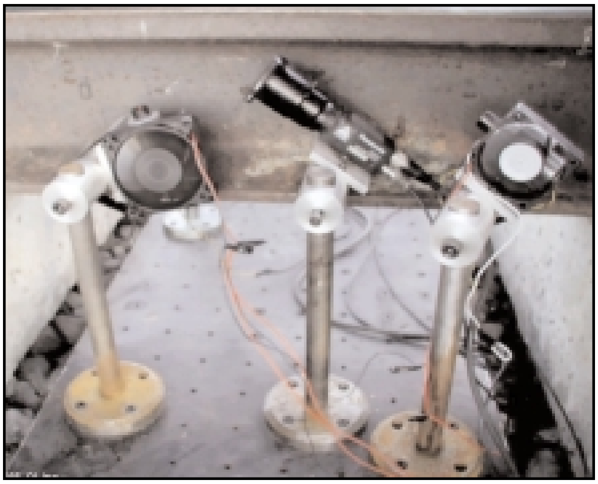

Exhibit 2. Nayebi System Lasers and Camera

The test consist was selected to provide a wide range of wheel conditions including wheel spacing, worn wheel conditions, and wheel diameter. Two axles with machined 2-millimeter hollow treads were also included. One four-axle locomotive and six cars were used for the evaluation. Speeds ranged from 5 mph to 55 mph in 10 mph increments. Six wheels on each side of the test consist were selected as test wheels. After two passes, at each speed, the train was turned and two more passes made at each speed. Seventeen test runs were made.

DATA ANALYSIS

Previous investigations under this program have shown there can be slight variations in parameters around the circumference of a wheel. Since the exact location of every measurement taken by the test system was not known, baseline measurements were taken on all test wheels with the MiniProf wheel profile gage at four locations, approximately every 90 degrees around the circumference of the wheel. The four measurements were averaged and used as a target value for comparison. The variation, if any, was added to the target value along with the accuracy tolerances in Exhibit 1 to give a tolerance band within which each measurement from the test system was required to fall in order to be considered an accurate measurement. The limits of this range are termed upper and lower bounds. Exhibit 3 shows an example of the performance for the Nayebi system for Wheel 8 flange thickness measurements made over nine test runs. The horizontal axis shows the test run number while the vertical axis displays the measured flange thickness in millimeters.

This figure demonstrates two analysis results. First, the total range for an acceptable measurement for Wheel 8 is +/- 0.92 millimeter (0.063 in.), which is larger than the +/- 0.8 millimeter accuracy specified. This indicates that the variation in flange thickness, around the circumference of this particular wheel, was 0.24 millimeter (0.009 in.). Half the variation was added to the accuracy requirements to define the acceptable measurement range for this particular wheel. Second, out of nine test runs eight of the measurements were within the accuracy band giving an 89 percent accuracy rate for Wheel 8 flange thickness measurements.

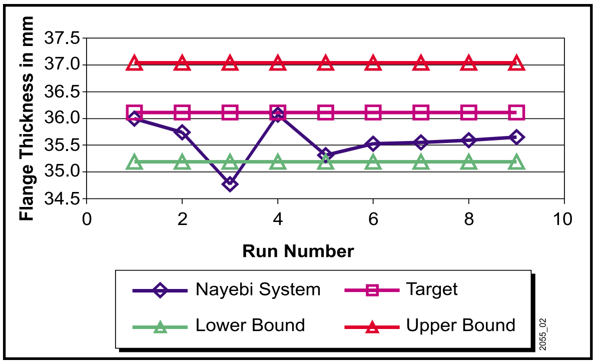

Exhibit 3. Wheel 8 Flange Thickness

RESULTS

Exhibit 4 summarizes the accuracy of the Nayebi system for this evaluation. The values indicate the percent of system measurements that were within +/-1/32 inch and +/- 1/16 inch of the baseline measurement.

Exhibit 5 shows the accuracy data curve for all parameters. The curve was calculated by plotting the absolute values of the target value deltas (difference between baseline & measured values). The horizontal axis represents the delta of the baseline target value and the measured value. The vertical axis represents the percentage of delta values that were greater than the associated horizontal axis values. The vertical grid lines at 0.8 millimeter and 1.6 millimeters are 1/32 inch and 1/16 inch, respectively. The curve of the graph does not match exactly to the numbers in the exhibit due to the wheel variations described above.

Exhibit 4. Nayebi System Accuracy

Parameter	Accuracy +/- 1/32"*	Accuracy +/- 1/16"*
Flange Height - (Sh)	59%	83%
Flange Thickness - (Sd)	72%	91%
Tread Hollow - (Hd)	81%	100%

* +/- half the range of the variation around the circumference of the wheel

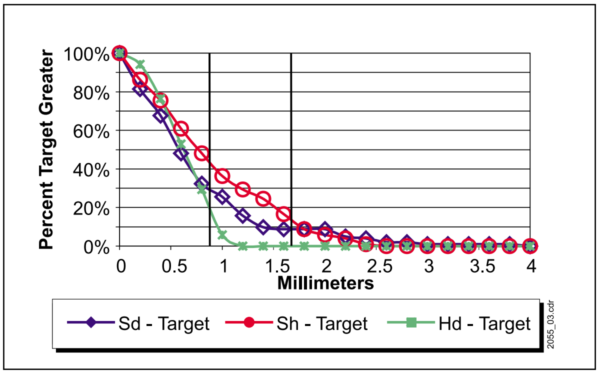

Exhibit 5. Nayebi System Accuracy

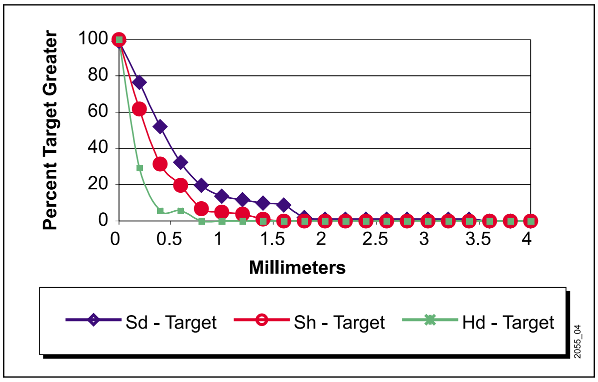

Exhibit 6. Nayebi System Repeatability

Another concern with dynamic wheel profile systems is their ability to measure each parameter of the same wheel consistently over several train passes. Data from this evaluation was analyzed to determine the repeatability of the system independent of accuracy. All measurements of a particular wheel were averaged, and the deltas from the individual measurements from that particular wheel were calculated. The standard deviations were then calculated to determine the consistency and repeatability of the system.

Repeatability (or consistency) analysis of the system indicates that over 90 percent of the measurements are consistent to within plus or minus 1 millimeter of the average of all measurements. Exhibit 6 shows the consistency of the Nayebi system for each parameter. The curve was calculated by plotting the absolute values of the target value deltas (difference between the average measured value & actual measured value). The horizontal axis represents the delta of the average system measurement value and the actual measured value. The vertical axis represents the percentage of delta values that were greater than the associated horizontal axis values. The standard deviation measurements are 0.78 millimeter for flange thickness, 0.47 millimeter for flange height, and 0.21 millimeters for tread hollow.

Although the Nayebi system was able to produce the raw images of the wheels immediately after train passes, all image files collected during testing required manual post-processing to provide wheel parameter information for the test runs. To handle the potential volume of information a dynamic wheel profile system is capable of providing, a production system should be able to handle all calculations without human intervention.

Accuracy and repeatability results for the system are independent of speed, as the system consistently measured all profiles through the complete speed ranges of the test, including the highest speed of 55 mph.

DISCUSSION

A positive attribute of the Nayebi system is that it does not require any significant track structure modifications to install. All components can be installed between two ties spaced a maximum of 32 inches on center.

Another positive aspect of the system is its repeatability and its capability to operate at speeds as high as 55 mph. Throughout testing and subsequent analysis, the system demonstrated a high degree of repeatability regardless of speed. Also, the system captured images for all wheels on every train pass.

An apparent limitation to the system, as tested at TTC, was its susceptibility to bright and/or direct lighting. A commercial installation might require the use of a screen to block or reduce direct bright lighting.

Other issues that should be addressed are: (1) The system has not yet demonstrated a real- or near real-time automatic processing ability. Each image captured during testing required manual processing to report wheel measurements; (2) The system is not yet interfaced with a car identification system; (3) The system needs to be hardened for environmental considerations.

Note: Please contact Scott Gage at (719) 584-0585 with questions or comments about this document.
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