TECHNOLOGY DIGEST

Timely Technology Transfer — 01-003

Detection of Occurrence of Track Buckling Using Fiber Optic Technology

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Summary

A series of tests by Transportation Technology Center, Inc. (TTCI) has determined that optical fiber systems installed on the rail can, under controlled research conditions, successfully detect track buckling. The potential use of optical fibers in detection of track buckle was first realized from the laboratory experiments conducted at University of Illinois - Urbana Champaign under the research technology scanning initiatives of TTCI and the Association of American Railroads. The principle involved is that any change in the curvature of a rail can be indicated by the change in the amount of light transmitted through an optical fiber cable firmly attached to the rail. This change in light can then be measured as a change in voltage by means of specialized equipment. These tests were performed by installing optical fiber cable on a 540-foot-long segment of rail at the Facility for Accelerated Service Testing (FAST). Track buckles were developed by pulling the rail laterally at two locations using mechanical means. There was no train presence in the optical fiber circuit during the track buckle test. Findings of this investigation included:

- Signal processing techniques allowed differentiation between train presence and actual track buckling conditions, while avoiding false buckle signals from track thermal “breathing” movement.
- To evaluate the practicality of the technique for revenue service, long-term fiber durability tests under field operational and track maintenance conditions are needed.

The fiber optic technique could be potentially useful in detection of track buckles in critical areas such as bridge approaches, special track work, curved track with previous buckling problems, softer roadbed conditions, and areas difficult to electrically insulate. Optical fiber systems may also be applicable for the detection of train presence, or truck hunting.

Suggested Distribution:

- ❑ Maintenance of Way
- ❑ Planning & Analysis
- ❑ Track Maintenance
- ❑ Safety

Work performed by TTCI Transportation Technology Center, Inc.
a subsidiary of the Association of American Railroads

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INTRODUCTION

For the past two years, TTCI has been evaluating and optimizing the design of optical fiber measurement systems for the detection of buckled track. From initial studies by TTCI and the University of Illinois - Urbana Champaign (UIUC) to the field tests at FAST, the optical fiber technique has shown potential. The work described herein is a direct result of previous successful laboratory experiments conducted at UIUC as part of the initial phase of investigation, which has been documented in a previous research summary.[1]

The intent of this phase of buckle detection development was to select an optimum signal-processing algorithm to interpret signals transmitted by optical fibers and verify performance through full-scale tests. Simple data processing methods led to the development of a system capable of detecting buckled track. The design of hardened systems for commercial applications is ongoing.

BACKGROUND

The potential use of optical fiber to detect changes in rail curvature was first investigated from the research technology scanning initiatives of TTCI and AAR at UIUC. Optical fiber has a characteristic that attenuates light transmission along its length as a result of fiber curvature. This small change in light transmittance can be measured as a change in voltage using a specialized set of photo transmitter and receiver units. The corresponding small change in voltage, although measurable, presented problems in its separation from stochastic “extraneous” noise sources making track buckling detection less precise than required. The first objective then was to optimize selection of optical fiber design and signal processing algorithms.

Fibers are available in a multitude of configurations and diameters, and as such required a host of laboratory experiments to verify the best design for this unique application. The fiber ultimately chosen was the multi-mode fiber, which is larger in diameter than single mode fiber, but still quite small, measuring only 17 microns or the diameter of a human hair. Other differences include specialized jacketing construction around the glass fiber.

Although fiber selection was optimized, voltage signals produced by rail curvature changes were still too small to be relied upon for effective track buckle detection. Additional data post-processing was developed to accentuate the signal amplitude to sufficient levels above ambient and train handling noise generation sources. It was found that advanced signal processing techniques developed by TTCI provided the necessary resolution, and so were implemented as part of the field evaluation system. Implementation of proper digital filters minimized track induced noise from passing trains, which might be confused with a track buckle, while at the same time preserved slower transients identified with buckling behavior. For much slower track movement normally identified with track breathing (thermal expansion and contraction), the differential algorithm worked as an attenuator because of the nature of differentiation, which is sensitive to only rate of change and acts like a high-pass filter that allows only the higher frequency behavior to be considered. This final recipe of optimal fiber, signal differentiation and filtering was assembled as a system and installed at FAST for subsequent field demonstrations.

FIBER OPTIC SYSTEM

The optical fiber system shown in Exhibit 1 was installed at FAST for long-term evaluation, which included tests for weathering, passing train presence noise discrimination, and track buckle detection. The system consisted of fiber applied to one of the rails by epoxy, the laser beam transmitter unit at one end, and the receiver unit that receives the light signals at the other end of the circuit connected to the data acquisition unit. The strength of signal is affected by any change in the curvature of the fiber attached to the rail. Track buckle signals have lower frequencies than train noise and higher frequencies than thermal breathing.

Continuous monitoring of signal strength can give an indication of any change in track geometry such as a buckle or a loss of signal due to a broken rail or fiber. At this installation, it was found that applying the fiber to rail using epoxy resin is durable, but a combination

Transmitter Unit Receiver Unit

Exhibit 1. Optical Fiber System for Detection of Track Buckle

TTCI = Transportation Technology Center, Inc.; AAR = Association of American Railroads of porous tape with epoxy together would be an improvement. Other ideas for improvement of fiber application included the fabrication of fiber-embedded elastomeric type substrates glued or otherwise fastened to the rail. These tests have not evaluated whether it is feasible to maintain such a system under actual field operational and maintenance conditions.

FAST Experiments

The first phase of testing at FAST investigated the actual amplitude and frequency content of optical fiber signals generated by passing trains. Quantification was important to the definition of optimal post-processing algorithms. The optical fiber test section, which measured 540 feet long, produced the signals during 40-mph FAST train operation over the test section. Exhibit 2 shows the noise signal that has been differentiated and filtered. Since track buckling occurs at a much slower rate, higher frequencies associated with train noise are filtered out of the signal while lower frequency track buckling events are not. From successful results of these tests, the next phase of testing was actual track buckle detection.

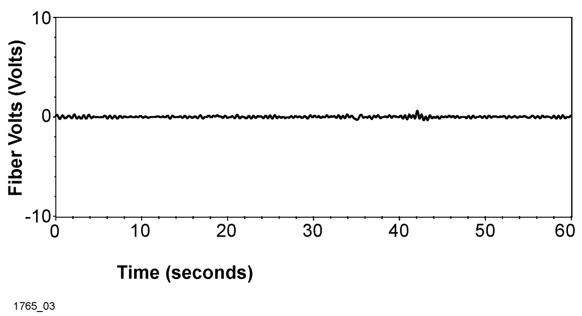

Exhibit 2. FAST Train Consist – Differentiated Filtered and Fiber Signal (at 40 mph)

To produce a track buckle, a test day was chosen with hot ambient air temperature to facilitate mechanical action and more easily produce a buckle. Mechanical action was provided by a bulldozer attached via a cable to the underside of the rail using a specialized adapter plate. From knowledge of buckling behavior, guidelines were set for operation of the bulldozer with the goal of producing a buckling rate of 5 to 6 inches in between 1 and 2 seconds. The track was buckled once at each of two locations to provide some variation in application of buckling load and to determine if the same optical fiber would detect both buckles. Photos of the resulting buckled track are shown in Exhibit 3. Exhibits 4 and 6 show the deformation magnitudes and rates of displacement taken by string potentiometers at the apex of the buckle curvature. The rate and displacement values were a little larger than designed owing to the difficulty in precisely controlling the bulldozer.

Exhibit 3. Photos Showing Track Buckles

Mechanical track buckling produced the differentiated optical fiber signals shown in Exhibits 5 and 7. Comparing track buckle signals with train presence noise, the signal to noise ratio is nearly a factor of two. Track buckling at a slower rate would have produced similar results, as was verified from previous small-scale laboratory experiments. For test sections of this length, optical fiber systems appear capable of detecting track buckling.

However, for much larger sections of installed fiber, obfuscation of train presence noise will become more troublesome without additional signal processing. For longer track sections that span long consists, noise from train presence will be larger. Although filtering removes most of this noise, lower frequency components may still reduce the apparent signal to noise ratio. To mitigate these effects, consideration needs to be given to the duration of the track buckle signal as well as its magnitude. Track buckling takes place in a matter of seconds while consist presence takes much longer. To differentiate between the two, a simple moving time window could be applied and easily implemented.

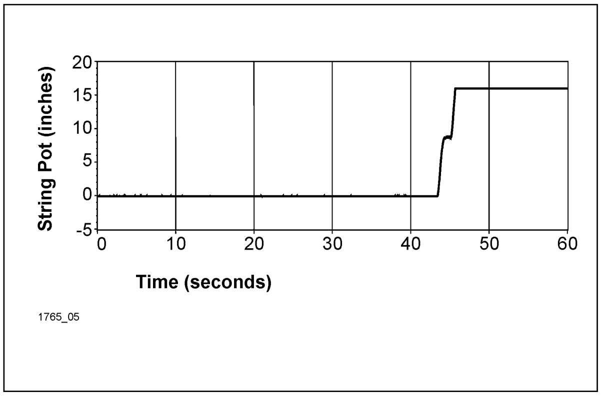

Exhibit 4. Track Buckle 1 — Displacement Potentiometer Response

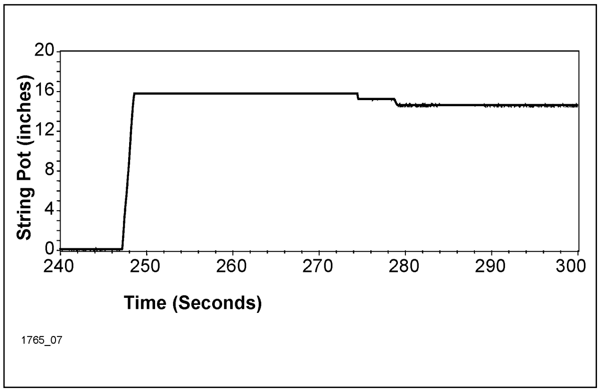

Exhibit 6. Track Buckle 2 — Displacement Potentiometer

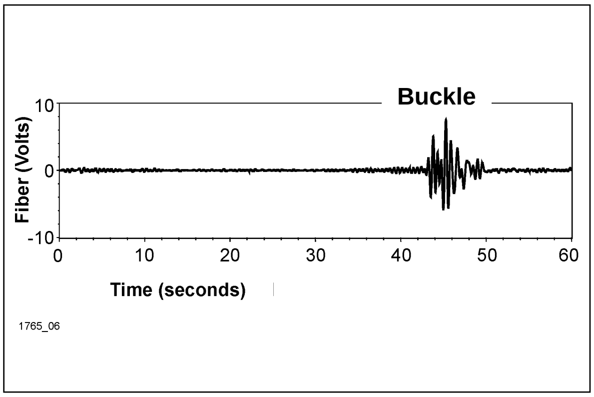

Exhibit 5. Track Buckle 1 – Differentiated Fiber Signal (at 40 mph)

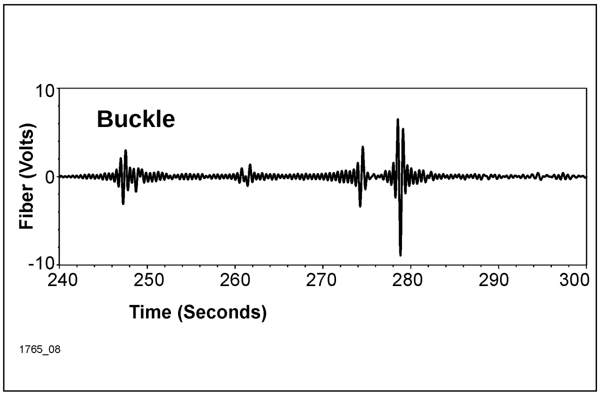

Exhibit 7. Track Buckle 2 — Differentiated Optical Signal (at 40 mph)

FUTURE WORK

For further refinement of the track buckle detection technique, the suggested future work should include methods of fiber application to rail and particularly to rail welds, and track buckle tests with a train in the circuit to simulate field events. This is to evaluate the time window, to identify track buckle signals in the presence of train noise, and to assess the effects of train speed. The system also needs to be evaluated to see whether it is practical to maintain under actual operational and track mantenance conditions.

REFERENCES

1. Schroeder, M.P., and Reiff, R.P., “ Evaluation of Fiber-Optic Method for Detecting Buckled or Broken Rail,” Association of American Railroads, Research Summary RS-99-003, February 1999

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A MORE DETAILED REPORT, WHICH MAY CONTAIN REVISED INFORMATION, MAY BE AVAILABLE AT A LATER DATE THROUGH AAR/TTCI, PUBLICATIONS, P.O. Box 79780, BALTIMORE, MD, 21279-0780.