TECHNOLOGY DIGEST
Timely Technology Transfer

Rugged Transducers for Measurement of Angle of Attack and Lateral Railhead Displacement,

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TD 92-010

Summary

Angle of attack and railhead displacement provide indications of poorly tracking vehicles. The Association of American Railroads has developed techniques for measuring angle of attack and lateral railhead displacement using new, rugged transducers capable of withstanding revenue service railroad environments. With the new measuring techniques, extended monitoring of angle of attack and railhead displacement is possible. Existing transducers are fragile and, therefore, do not permit long term monitoring.

The new transducers were installed in track at the Transportation Test Center, Facility for Accelerated Service Testing, Pueblo, Colorado. Tests showed that both performed acceptably for several passes of an 85- car test train. The new angle of attack measurement is accomplished using strain gages on the web of each rail, and the new railhead displacement measurement uses strain gages applied to an elastic fastener on the gage side of the rail. Both systems are sufficiently accurate to provide an indication of poorly tracking vehicles, although they are not as accurate as the fragile transducers which may be used for recording short term measurements.

In conjunction with vertical and lateral rail force circuits, a wayside detector for poorly tracking vehicles could be developed using the new transducers.

Association of American Railroads
Research and Test Department
August 1992

TECHNOLOGY DIGEST
August 1992

INTRODUCTION AND CONCLUSIONS

In order to monitor vehicle behavior at particular locations, it is desirable to measure angle of attack (AOA) and lateral railhead displacement along with vertical and lateral rail forces. Existing transducers for measurement of AOA and railhead displacement are fragile and intended only for short term installations. Consequently, rugged transducers have been developed by the Association of American Railroads to measure angle of attack and lateral railhead displacement. These transducers are suitable for long term installation at revenue service sites. Their accuracy is sufficient to identify vehicles which have a high potential of causing excessive damage to the track structure. The AOA transducer uses strain gages applied to the web of the rail, and the railhead displacement transducer uses strain gages applied to an elastic fastener. Both could be incorporated into a remote monitoring station.

ANGLE OF ATTACK MEASUREMENT

The new AOA measurement technique is capable of measuring within about 3 or 4 milliradians, which is sufficient to determine whether or not a truck is warped excessively. This measurement is accomplished by means of strain gage circuits attached to the webs of each rail in a fashion similar to the proven vertical force strain gage circuits. The gages may be protected using the same waterproofing techniques and protective covers used for vertical and lateral rail force circuits. While this new technique is not as accurate as the existing laser-based AOA measurement system, it is much more durable and well suited to long term revenue service applications. The existing system can still be used for short term operation.

The new technique was tested at the Transportation Test Center's Facility for Accelerated Service Testing (FAST). Strain gages were installed on both rails in a 5-degree curve. The laser-based angle of attack measurement system was installed in the same crib in order to provide comparison data. Data was collected during normal operation of the FAST train. The train had 5 locomotives and 85 cars, and operated at 40 mph.

Exhibit 1 compares the strain gage-based AOA measurements with the existing laser-based AOA measurements. It should be noted that the laser-based measurements themselves are not without error. It is seen that there is a reasonable correlation between the two systems, with a higher amount of scatter using the strain gage technique. As is expected for vehicles negotiating a 5-degree curve, most of the data for the trail and lead axles, respectively, is clustered near zero and 5 milliradians.

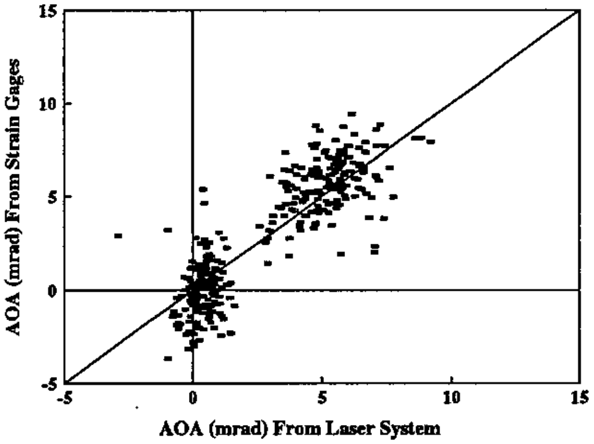

Exhibit 1. Comparison of AOA Measurement Techniques

The strain gages are arranged to measure vertical shear force in the web of each rail. The signal from this circuit exhibits a sharp zero crossing as a wheel passes through the circuit. By comparing zero crossing times for the two rails, the AOA is calculated using the train speed. Since the rails are subjected to longitudinal movements caused by both train traffic and thermal loads, a dynamic reference must be established for each train pass. The reference is based on the assumption that trailing axles tend to have zero AOA. Using the average of the trail axle time differences as a base line, the AOA is calculated for each passing axle. It is estimated that the two primary sources of the difference between this measurement and the laser-based system are longitudinal rail movement beneath the train and variation in train speed. With further refinement of the analysis software, it may be possible to correct for variations in train speed. It is recommended that the AOA circuit be installed in the center of the crib. If the circuit is installed too close to one of the ties, the sensitivity of the circuit zero crossing location to wheel position may be reduced, causing an underestimation of the actual AOA. The test circuit was implemented at FAST by splitting a typical vertical bridge circuit to create two separate AOA circuits in the same crib. A loss of sensitivity was noticed in one of these circuits, and it appears to be due to the proximity of the circuit to a tie.

A 512 Hz sample rate was found to be sufficient for the 40 mph test train speed. Data was sampled at rates ranging from 512 Hz to 8,000 Hz. The higher sample rates resulted in a negligible improvement in accuracy of the data. Filter cutoff frequencies ranged from 120 Hz up to wide band. No significant differences were noted due to the variations in filter cutoff frequency within this range. It is recommended for general use, a filter cutoff frequency of less than half the sample rate be used to eliminate alias in the signal.

LATERAL RAILHEAD DISPLACEMENT MEASUREMENT

A rugged lateral railhead displacement transducer has also been developed. Like the new AOA system, it is suitable for application in revenue service sites and for long term installations. It also can be used as part of an unattended remote monitoring station.

The measurement is accomplished by applying strain gages to a Safelok elastic fastener installed on the gage side of the rail. Both "fingers" of the fastener are gaged, with both gages wired into the same circuit in order to get an average signal.

This technique was tested at FAST in a 5-degree curve with concrete ties. The concrete ties were already equipped with Safelok fasteners. The concrete ties at this site previously had experienced about 237 MGT of heavy axle load traffic. Both the field and gage side clips of the low rail were strain gaged. The gage side clip experienced much higher levels of strain, as would be expected for rail rotation.

This strain gage output signal can be correlated with the lateral railhead displacements measured during the calibration process, as shown in Exhibit 2.

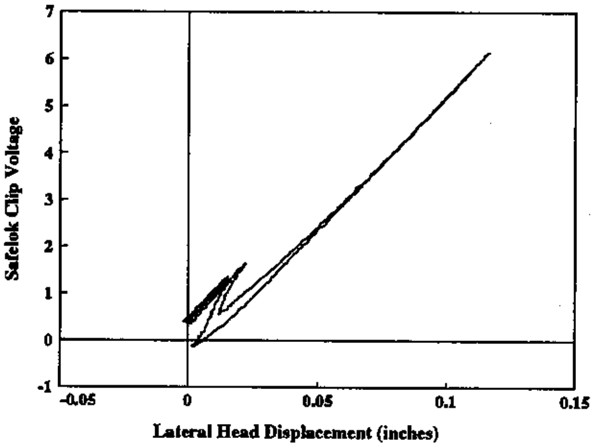

Exhibit 2. Calibration of Elastic Fastener for Lateral Railhead Displacement

During the calibration process, railhead displacements were measured using Linear Variable Differential Transformers. The small amount of nonlinearity at the beginning of the curve is due to compression of the tie pad as a 40 kip vertical load was applied. This compression causes a small amount of clip deflection, with little or no lateral railhead displacement. The amount of crosstalk is small enough to have no significant effect on the measurement of displacements under train traffic.

Exhibit 3 shows the lateral railhead displacements, measured using the elastic fastener, for a portion of a train pass. Note the deflection wave which precedes the arrival of a leading axle of a truck. A typical trail axle, which is applying little or no lateral force to the railhead, actually restrains the rail from overturning. This phenomenon is evident in that the deflection rapidly drops to near zero with the arrival of a trailing axle. The magnitudes of the deflections measured agree well with previous FAST data as well as model predictions.

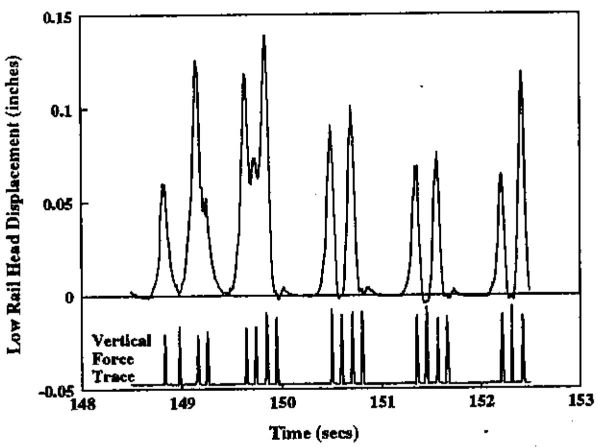

Exhibit 3. Selected Time History of Railhead Displacement

The signal from a strain gaged elastic fastener can also be related to the applied overturning moment during calibration. Exhibit 4 shows the relationship between signal voltage and overturning moment. The curve is nonlinear and contains some hysteresis. It should be noted that this calibration was performed for a lateral to vertical force ratio (L/V) from 0.0 to 0.5. For larger values of L/V, the curve may change significantly as the rail begins to rotate about the field side corner of the rail. Nonetheless, a reasonable estimate of the overturning moment can be obtained for lower values of L/V.

In theory, if all the overturning moment is generated by a single wheel and the applied vertical and lateral loads are known, it should be possible to calculate the position of the applied vertical load relative to the center of the railhead. In practice, however, the calculation of contact position is very sensitive to errors in measured lateral load and overturning moment. Usually, more than one wheel contributes to the overturning moment. However, an attempt was made to determine the contact position, but the errors due to the nonlinearity and hysteresis in the overturning moment calibration, as well as error in the lateral rail force circuit, led to unacceptable error in the calculated position value.

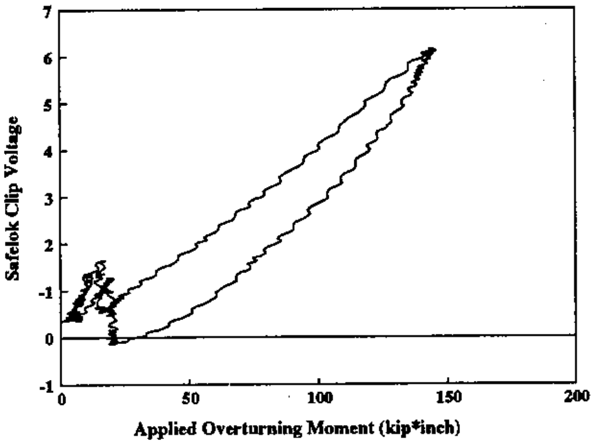

Exhibit 4. Fastener Response to Applied Overturning Moment

The strain gages must be applied to the Safelok clip after the clip has been installed on the rail. Once a strain gaged fastener has been removed, it cannot be reinstalled. The large amount of fastener strain required to provide toe load is sufficient to damage the strain gages; therefore, the gages must be installed after the fastener is installed in track. Similarly, once a strain gaged clip is removed from track, the strain gage may be damaged by the large amount of strain released.

Note: Contact Duane E. Otter at (719) 584-0594 with questions or comments about this document.