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Wayside rail traffic monitoring with angle-of-attack measurement system

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Abstract

An angle-of-attack measurement system was developed for permanent unattended track side operation. Rail traffic monitoring with the system has enabled detection of trucks in need of repair. A truck inspection station on tangent track provides an efficient way of segregating poor performing trucks, reporting them to maintenance personnel, and of monitoring the effectiveness and the quality of the rehabilitating procedures. The data collected by a permanent monitoring station is a valuable source of information for development of maintenance policies.

1 Introduction.

Truck maintenance is an important area in railway operation. Current experience indicates that mileage-based maintenance is not efficient. Attempts to develop a maintenance planning tool based on a predictor of unacceptable truck dynamic performance, related to truck component wear, have not been successful. In 1993 an effort was initiated to detect trucks that displayed inadequate dynamic performance and, therefore, were the most likely candidates for repair. The wheelset angle of attack (AOA) was selected as a parameter reflecting performance of a railway truck; an Angle-of-Attack Measurement System suitable for a Wayside Truck Monitoring Station was developed as the initial phase of this effort.

2 History of development.

Fig.1 shows the definition of the AOA, the angle between the track radial line and the axle of the wheelset. The importance of measurements of the AOA when studying dynamic performance of a railway truck is well documented, see Refs. 1 and 2 as examples.

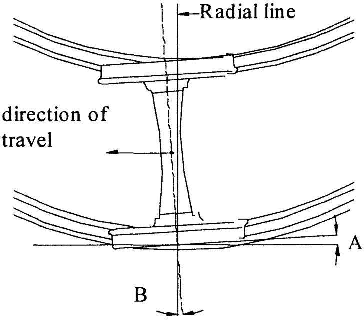

Figure 1: Definition of the Angle of Attack.

The first AOA measurement system was developed at CPRS almost two decades ago. This system was used exclusively as a research tool as it was a delicate instrument not designed for permanent unattended operation. Over the last 15 years, the system was improved with several modifications including:

- implementation of a real time data processing micro computer with on line reporting,
- replacement of the expensive HeNe lasers with solid state infra-red technology
- migration of the interface and software to a portable PC.

These modifications made the system more reliable and easier to deploy, but the system's configuration prevented it from being used in a Wayside Truck Monitoring Station (Ref. 3).

The original CPRS AOA measurement system employed three optical transducers, each of which consisted of an emitter and a detector. The emitter produced a narrow collimated light beam. The detector collected the light from the emitter but ignored the ambient light. In the transducer configuration shown in Fig. 2 the two light beams (emitters 1 and 2) were aligned to coincide with the radial line of the curve and were parallel to the top of the rails. The third light beam (emitter 3) was placed parallel to the line of the other two beams. All three light beams were positioned to just "skim" the heads of the rails. The three transducers were attached to a base installed under the rails between two adjacent ties. A wheelset passing over the transducers interrupted the light beams and generated a rectangular pulse from each detector.

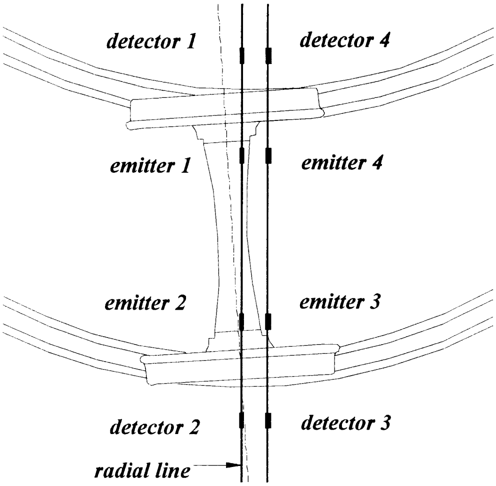

Figure 2: Original CPRS AOA measurement system configuration

The angle of attack of the passing wheelset was calculated using the measurements of the time differences between the centers of the pulses from the detector. Objects other than the wheels, such as flying debris, stones, sand pipes, interrupting the light beams could affect the measurement.

Successful measurements relied heavily on the accurate alignment of the assembly in relation to the radial line of a curve. Elaborate precautions had to be taken to prevent even very small displacements of the assembly from its precise position of alignment. This condition was very difficult to maintain in a railway environment. Strong impacts, vibrations generated at the wheel/rail interface, movements of track maintenance vehicles, accumulation of snow and ice, flying debris were detrimental to the AOA measurement. Alternative transducers that could detect the passage of a wheel were evaluated to replace the optical transducers (Ref. 4). These included:

- eddy current proximity transducer;
- strain gauge transducers;
- electromagnetic wheel sensors.

None of these were found to be sufficiently accurate to be considered for a permanent AOA system. In order to implement an AOA measurement system capable of prolonged unattended operation, a conceptual change was required.

It would be necessary to redesign the system so that the optical transducers could be moved away from the rails and out of reach of loose or dragging equipment from passing trains.

3 "Direct" Measurement of AOA.

Advances in optical transducer technology allow "direct" measurement of the angle between a wheel and a rail. This method, Ref. 5, provides a measure of the angle between the wheel itself and the rail, angle A in Fig. 1, not the angle B between the wheelset axis and a line perpendicular to the rail at the point of measurement (a radial line for a curve) as in the original system. Fig. 3 illustrates the concept of the "direct" method. An optical rangefinder, positioned at a safe distance from the rail on the field side of the track and aimed above the rail, scans passing wheels. The position of the rangefinder relative to the track is similar to that of a hot wheel detector. An X-Y point is created by measuring the wheel's longitudinal position in the field of view (the X coordinate) and the distance to an illuminated spot on the wheel surface (the Y coordinate). As the wheel passes the rangefinder, a set of X-Y coordinates of the wheel surface is generated.

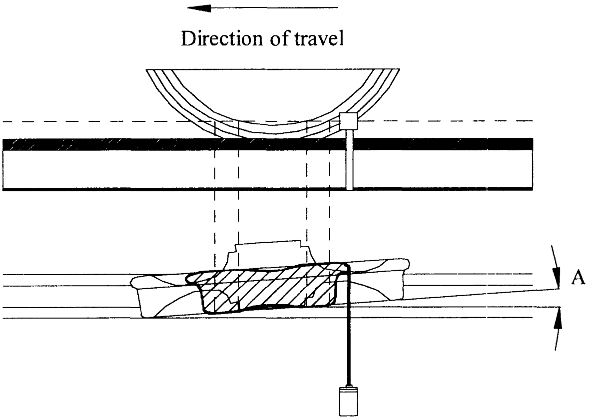

Figure 3: “Direct” measurement of AOA.

The shocks and vibrations typical for a trackside environment do not affect the measurement results. Any misalignment with the radial line translates into an AOA scale factor error approximately proportional to the cosine of the offset angle. (An error of 1% would require an offset angle of over 8 degrees which is easy to detect). This quality enables the use of the "direct" method for both

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a Wayside Truck Monitoring Station as well as a portable system which can be quickly deployed at a test site without an elaborate alignment procedure. The AOA measurement system used for the Wayside Truck Monitoring Station is composed of three modules:

- optical assembly
- signal conditioning assembly (SCA)
- data acquisition and processing computer (DAPC)

The optical assembly is housed in a weather proof enclosure that is positioned approximately 1.4 m (54") from the field side of the head of the high rail. Because the alignment of the optical assembly with the radial line of the curve is not critical, the optical assembly is very easy to install. The enclosure is equipped with heated windows that allow operation of the device at temperatures down to -40 C degrees. The signal conditioner assembly and the data acquisition and processing computer are located in a signal bungalow nearby the optical assembly.

The rangefinder is implemented with a laser based triangulation system. A passing wheel is illuminated by a laser; the position of the light spot is detected by a line scan video camera. Given the geometry of the optical system, the distance to the spot on the wheel surface is computed. The rangefinder is not an "off the shelf" unit but is assembled from commercially available components and custom made precision machined parts.

To process the video signal produced by the line scan camera, a specially modified interface board is used (Modular Vision Systems LaserVision Profile Board). The board resides in a standard IBM compatible personal computer. The LaserVision Profile Board determines which illuminated pixel represents the centroid of the laser spot, independent of the amplitude of the return signal. Because of the geometry of the rangefinder, the function relating the range information to the position of the illuminated pixel is slightly nonlinear. A lookup table linearizes and scales the data generated by the Laser Vision Board.

The signal conditioner assembly houses the interfaces of the wheel detectors, line scan camera and laser diode to the data acquisition and processing computer. The interfaces are implemented on Eurocard format printed circuit boards. The data acquisition and processing computer is an 80486 ISA bus computer host with a LaserVision Profile board, a timer counter board and an internal modem. The signal conditioner and the computer can be configured either for a portable application or for a permanent rack-mount installation.

4 Data Analysis and Reporting.

On-line wheel image analysis is performed to clean the raw image and to identify the rim portions of the profile. Then, areas at the bottom of the image corresponding to the wheel rim are identified. These horizontal segments belong to a flat annular rim surface lying in a plane at right angle to the wheel axis. The orientation of this surface in relation to the rail tangent is of course equivalent to the angle A (see Fig. 1), i.e. the angle-of-attack. Computation of the complete set of angles is performed for each wheel entering the measurement window. The final analysis of the complete set of angles, related to a passing train, identifies and reports wheelsets with abnormal behavior.

The results of the computations do not depend on the precise measurement of time intervals as in the old AOA measurement systems. Image processing compensates for sporadic noise and loss of signal due to flying debris or inadequate wheel surface reflectivity. This method of measurement and computation of the AOA has proven to be very robust and well suited for the railway environment.

The "direct" measurement method also allows for computation of another parameter of the dynamic performance of a truck: the tracking error. The tracking error is defined as the difference between the positions of the centers of the leading and the trailing axles of a truck in relation to the track center line, or any other line parallel to it. Ideally, the centers of the leading and the trailing axles of a truck, when moving on tangent track, should be aligned with the track center line. For this ideal condition, the tracking error is equal to 0. The AAR specification allows a possible maximum of 1 tape (3.18 mm or 1/8" on circumference) difference between wheels on the same axle. This difference between the wheel circumferences, at new wheel conicities of 1/20, can produce 5 mm (0.2") tracking error. The combined action of the worn wheel profiles and the rail head curvatures results in much higher effective conicities than 1/20, and, thereby, in much smaller tracking errors. Therefore, when a large tracking error is detected by the wayside station, it usually indicates a severely mismatched wheelset or another truck defect. Knowledge of the tracking error, in addition to the AOA, gives better insight into truck performance.

5 AOA measurements on tangent track.

A prototype system was tested in different weather conditions typical of the Canadian climate: snow, rain, wide ambient temperature range. The optics were also tested for any possible interference from direct sun or other sources of light. Finally, the system was tested on tracks with different geometry.

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The relevance of an AOA measurement system for monitoring the curving performance of railway trucks is reflected in many publications. Tangent track experience with AOA measurements is less known. There exists certain skepticism in relation to the repeatability of the AOA measurements on tangent track. On the other hand, tangent track monitoring does offer many potential advantages for wayside inspection, providing the measurements are accurate and repeatable. We decided to perform a long term field test of a prototype AOA measurement system to explore the feasibility of a Wayside Truck Monitoring station on tangent track. An AOA measurement system was installed at Ruby Creek, British Columbia in July, 1994 and was in continuous operation until November, 1995. This particular site is a well maintained section of tangent track adjacent to other wayside monitoring equipment, including an Automatic Equipment Identification system (AEI). Most of the trains passing by the station are loaded. The traffic is mixed: unit trains, mixed freight, intermodal, etc.

From the start of the wayside AOA monitoring it was observed that the dynamic behavior of the trucks was repeatable: the trucks monitored over a long time interval displayed the same AOA and the same tracking error each time they passed the wayside station. Noticeable changes in the parameters measured were typically attributable to changes in major truck components during maintenance at the shops.

The quality of the data collected with the Angle of Attack Measurement System enabled us to segregate trucks with an excessive AOA. In order to label these trucks as "bad actors" with certainty, the question still remained whether the AOA, repeatable in time at the point of measurements, were also sustained over a long distance. To answer this question we conducted a series of simultaneous measurements with the Wayside Truck Monitoring Station at Ruby Creek, B.C. and a portable AOA measurement system. The portable AOA measurement system is functionally identical to the one used for the Wayside Truck Monitoring Station, but is packaged for a quick installation.

The portable system was positioned on tangent track, 2.2 km away from the Monitoring Station. The data sets collected with the two measurement systems for one day of traffic were practically identical (Fig. 4). (The vertical shift between the two traces of the lateral wheel positions in Fig. 4 corresponds to the different stand-off distances of the stations 1 and 2 from the rail). The measurements indicate that the wheelset AOA registered by the wayside station is a permanent property of a truck and determine the truck performance along the route traveled. In order to validate this inference, another series of simultaneous measurements were carried out, but this time the portable system

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was located on a 2.5 degree curve, 11 km away from the Monitoring Station. Once again the data sets were highly correlative. (see Fig. 5).

The results of the measurements confirm the permanent character of a truck configuration detected by the monitoring station. The AOA expected when a conventional truck negotiates a curve becomes "biased" by the AOA measured at the location of the monitoring station. If the "bias" is in the direction of the curve, the truck approaches this curve "pre-aligned", in a manner similar to a truck curving, reducing the curving resistance. The "bias" in the opposite direction increases the angle-of attack (axles162, 166, 172 in Fig. 5) and, radial correspondingly, the curving resistance. In effect, it creates conditions similar to negotiating a sharper curve.

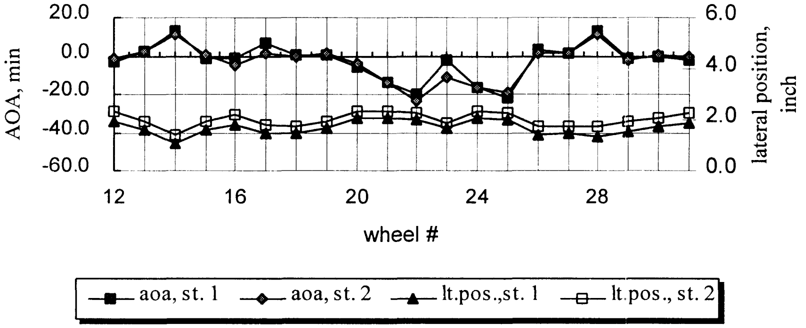

Figure 4: AOA on tangent track two stations 2.2Km apart.

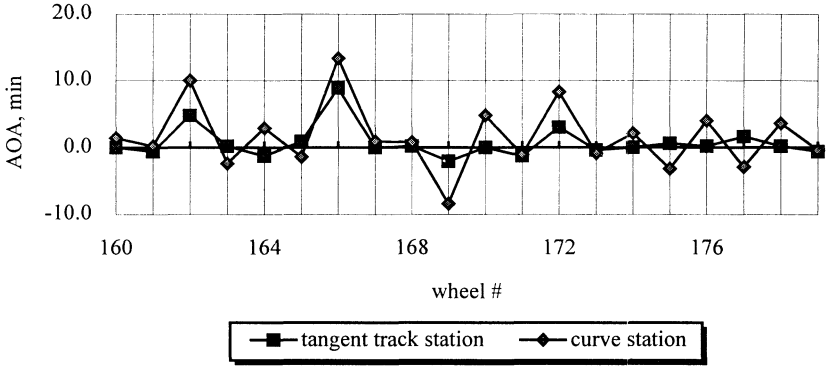

Figure 5: AOA on tangent track and 2.5 deg. Curve two stations 11Km apart.

6 Wayside Truck Monitoring Station.

Highly repeatable and accurate results, non-contact method of measurement with no need for periodic re-calibration, reliable performance of the AOA measurement system in adverse weather conditions present to a railway new opportunities in truck performance monitoring.

The Wayside Truck Monitoring Station, based on the AOA measurement system, can relate every wheelset AOA measured and a tracking error detected to a particular car, truck, and axle by using the data from the Automatic Equipment Identification System. Thereby, it is possible to identify trucks in need of maintenance and report them to mechanical personnel for follow-up procedures. It is also possible to trace the condition of each truck after maintenance to monitor the effectiveness of repair. Fig. 6 shows an example of a car before and after maintenance.

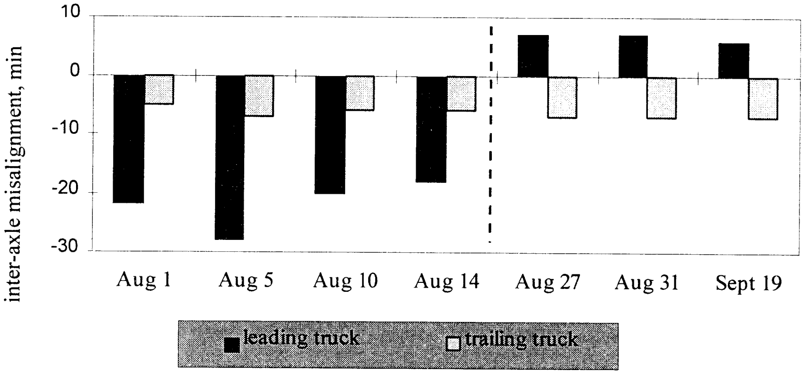

Figure 6: Inter-axle misalignment, coal car with DR-2 trucks, before and after wheelset 1 replaced on August 24.

The data collected by the wayside inspection station during a long time interval can be used to estimate the performance of the overall car fleet or a particular type of cars. Presented in Table 1 is an example of the data collected on a North American railroad during a period of a month .

A specific type of car can be analyzed separately. For example, the statistics for coal cars and for double stack solid drawbar cars is shown in Table 1 for comparison.

Table 1. Inter-axle misalignment (MA), coal cars and the rest of the fleet.

	coal car trucks	% in range	not coal cars trucks	% in range	double-stack, solid drawbar	% in range
Total number of trucks	3,506		10,654		414	
Trucks with MA less than 3.5 min	2,947	84.10	8,764	82.30	253	61.10
Trucks with 3.5 < MA <= 7.0 min	465	13.30	1,566	14.70	91	22 .0
Trucks with 7.0 < MA <= 10.5 min	64	1.80	258	2.40	29	7.0
Trucks with 10.5 < MA <= 14.0 min	19	0.50	44	0.40	16	3.90
Trucks with 14.0 < MA <= 17.5 min	9	0.30	8	0.10	11	2.70
Trucks with 17.5 < MA <= 21.0 min	1	<0.1	1	<0.1	7	1.70
Trucks with 21.0 < MA <= 24.5 min	0		5		3	0.70
Trucks with 24.5 < MA <= 28.0 min	1		1		3	0.70
Trucks with 28.0 < MA <= 31.5 min	0		2		0	
Trucks with MA > 31.5 min	0		5		1	0.20

Many researchers consider warped trucks that produce high gauge spreading forces on both wheelsets as a primary factor leading to the risk of derailment. A Wayside Truck Monitoring Station based on an Angle of Attack Measurement System makes it easy to identify warped trucks. Examples of warped trucks are shown in Fig. 7.

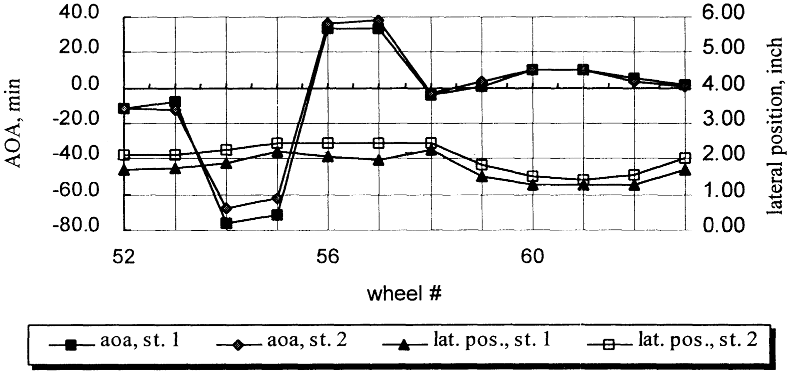

Figure 7: AOA on tangent track, two cars with warped trucks, two stations 2.5km apart.

7 Wayside Monitoring and Shop Repair.

Detection and identification of the trucks displaying abnormal behavior with help of the Wayside Monitoring Station provides an important input to maintenance planning. The maintenance budget can be better utilized when it addresses the trucks with inadequate performance in the first place.
An experimental exercise in detecting and rehabilitating defective trucks is described in Ref. 7. One truck with an excessive angle of inter-axle misalignment (12 min) and one warped truck (leading axle: 28.7 min and trailing axle: 24.8 min), as reported by the Wayside Monitoring Station, were inspected in the shop. This shop inspection had confirmed the presence of defects detected by the AOA system: the longitudinal clearance between thrust lugs and adapters was either close or at condemning limits, inter-axle lateral shift was attributed to a difference in wheel tape size, loss of stiffness of the friction wedge spring was responsible for truck parallelograming (warping).

Two successful modifications were performed in the shop. The thrust lugs of the truck with inter-axle misalignment were built up and adapters were changed to ensure that axles were aligned. Shimming had restored the friction wedges preload as a way to stiffen the truck to resist parallelograming.

8 Truck Misalignment and Operating Efficiency.

Given the statistics on the inter-axle misalignment of the fleet, one can estimate the losses in fuel and in additional wheel and rail wear related to this defect. The data presented in Table 1 illustrates that the great majority of the trucks of a sample railway travel with very small inter-axle misalignment (less than 3.5 min). The resistance to movement of trucks equipped with properly aligned wheelsets can be calculated by the Davis Equation which takes into account the effects of inherent resistance (truck bearings, suspension damping, aerodynamics, rolling resistance, etc.) and incidental resistance (grade, curve, acceleration). However, a small proportion of the trucks in our sample fleet (Table 1) remain misaligned while travelling, generate significant rolling resistance, and dissipate energy at the wheel / rail interface on tangent track as if they were on curves. There is not much test data available on the accurate evaluation of the rolling resistance of individual misaligned wheels. The AAR Report (Ref. 6), however, indicates that the rolling resistance is proportional to the angle of inter-axle misalignment (the Report recommends using 0.6 lbs/ton per milliradian, which is equivalent to 0.83 nt/t per minute of misalignment, as a coefficient of rolling resistance due to inter-axle misalignment for a conventional truck on tangent track). The rolling resistance coefficient is not linear at lower inter-axle misalignment. At low angles of misalignment the wheels of conventional truck may roll without flanging on the rail and, therefore, the increase in rolling resistance is relatively smaller than at higher angles. To simplify our discussion, we assume that for the majority of the trucks (84% in Table 1, with angles of misalignment less than 3.5 min) there is no additional rolling resistance. The rest of the truck fleet will generate additional rolling resistance on tangent track proportional to the distribution of the percentage of the misaligned trucks multiplied by the average angle of inter-axle misalignment in each range (as in Table 1). To overcome this increased rolling resistance, additional tractive effort is required, which, in turn, will require additional fuel consumption. Using this approach, it was estimated that a typical railway would require extra 20 million liters of fuel to overcome the effect of the inter-axle misalignment, given the conditions typical for North America, annual volume of traffic approximately 200 billion Gross ton-miles, and rolling stock conditions as in Table 1.

9 Conclusion.

A Wayside Truck Monitoring Station based on the Angle-of-Attack measurement system was installed in British Columbia in July, 1994 and has been in continuous operation since then. The data collected by the station is communicated via modem for analysis in Montreal. During this time the only maintenance required was the removal of weeds in front of the optical assembly.

The data collected in 1994-1995 indicates that current maintenance practice tends to treat the symptoms of the truck problems rather than getting to the problem's roots. It is frequently observed that trucks released from the shops after maintenance display high angles-of-attack. Many of these trucks have a history of excessive wheel wear. Changing a wheelset in many cases will not eliminate the problem, and the truck can be expected back to the shops for yet another premature wheel change. In the second half of 1995, a program was initiated to rehabilitate "bad actors" - the trucks detected by the wayside station. Visual inspection of the trucks with large inter-axle misalignment revealed truck defects responsible for inadequate performance. An effective procedure has been implemented to repair the defects.

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