

The U.S. Department of Transportation has established a goal to reduce the highway fatality rate to no more than 1.0 fatalities per 100 million vehicle miles traveled by the end of 2008. Each of the Department's highway safety agencies have individual reduction targets that will contribute to this 2008 target. Federal Motor Carrier Safety Administration's (FMCSA) aim is to reduce the large truck fatality rate by 41 percent from 1996 to 2008, to 1.65 fatalities in truck crashes per 100 million miles of truck travel.

The Office of Bus and Truck Standards and Operations, which produced this Tech Brief, develops and promotes national motor carrier safety program goals, priorities, and initiatives. It provides technical expertise and advice in the development and deployment of motor carrier safety programs, including the development of regulations. The Office determines national motor carrier safety operational program requirements, standards, and procedures for vehicle and roadside operations, driver and carrier operations, and bus safety.



U.S. Department of Transportation
Federal Motor Carrier Safety Administration

Office of Bus and Truck Standards and
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On-Board Sensors for Determining Brake System Performance

Project Funding

Under Section 5117 of the Transportation Equity Act for the 21st Century of 1998 (TEA-21), Congress required the U.S. Department of Transportation to "conduct research on the deployment of a system of advanced sensors and signal processors in trucks and tractor-trailers to determine axle and wheel alignment, monitor collision alarm, check tire pressure and tire balance conditions, measure and detect load distribution in the vehicle, and adjust automatic braking systems."

As a result of a comprehensive technology scan, as well as numerous interviews with key industry stakeholders such as truck manufacturers, fleet operators, suppliers, and regulators, a variety of research areas were identified, including the design, functionality, and performance of brake systems and brake sensors for commercial motor vehicle applications.

Background

The significant number of trucks operating on the highway with brake defects is a situation that has plagued the industry and law enforcement for years, despite attempts by many different groups to address the problem. Commercial vehicle inspection data shows that about 19% of all inspected vehicles – nearly one in five – were found to have one or more brake defects.* During Roadcheck 2002, a safety strike force activity combining the resources of FMCSA, the States, and Canadian Provinces, enforcement officials conducted a 72-hour intensive inspection of 49,032 vehicles in Canada, Mexico, and the United States from June 4-6, 2002. Enforcement officials placed 22.1% of the vehicles inspected out of service due to various defects and violations. Brake-related issues accounted for 53.3% of these vehicles being placed out of service.

It is understood that commercial vehicle braking system design and operation are directly linked to stopping distance, handling and, therefore, overall safety. Properly maintaining and performing brakes are clearly the driver's best ally in preventing and mitigating crash situations. Although vehicle defects on large trucks can rarely be pinpointed as the causative factor(s) in crashes, when defects do occur, faulty brakes tend to be at fault.

Optimally adjusted braking systems could help prevent or mitigate crashes even when the braking system itself was not the initial cause of the crash. Eliminating or mitigating key mechanical problems, including brake-related issues, would likely yield a significant reduction in the number and seriousness of injuries sustained in commercial vehicle-related crashes.

Study Objective

The overall objective of this research study was to document the performance and operational characteristics of leading-edge technological approaches to monitoring commercial vehicle braking systems. The study focused on the ability of the various sensors to detect abnormalities, defects, and/or misadjustments of the brake system.

*The Motor Carrier Management Information System (MCMIS) is operated and maintained by FMCSA. The MCMIS File contains the results of all driver-vehicle safety inspections of interstate commercial motor vehicles performed by States participating in the Motor Carrier Safety Assistance Program (MCSAP). In FY 2003, 2.9 million inspections of interstate vehicles were conducted.

The brake sensing technologies examined in this study included:

- Anchor strain measurement to determine brake force at each wheel,
- Air chamber stroke measurement to assess brake adjustment at each wheel,
- Wheel slip measurement (using wheel speed sensor data) to determine brake force at each wheel,
- Deceleration measurement to determine total vehicle braking force (limited results due to system software issues), and
- Temperature measurement to determine brake "work" or energy balance.

There are safety benefits associated with having a sensor or "sensor package" on-board the commercial vehicle that would objectively and accurately measure the stopping potential of the vehicle, and dynamically and continuously measure the actual braking force at each wheel. Such a system would potentially have three primary applications or benefits:

1. Warning the driver and/or maintenance personnel if braking ability degraded to an unsafe level – and help with diagnosis of the specific problem.
2. Providing information to enforcement personnel for use during roadside inspections.
3. Integrating brake performance-sensing technologies with an electronically controlled brake system (ECBS) in a "closed-loop" fashion. The brake force information might be used to balance the braking action at each wheel to improve service life, and/or provide an additional input for controlling braking action at each wheel during emergency situations.

Overview of Project Approach

The various sensor systems were installed on a conventional tractor-trailer combination vehicle and tested under controlled braking maneuvers on a test track. (All work was conducted at the Transportation Research Center (TRC) in Columbus, OH by Radlinski and Associates, Inc.) The output of the various brake sensor systems could then be compared on the same vehicle under identical testing conditions. This approach facilitated objective, accurate comparison of the sensors, and eliminated problems associated with test procedure repeatability when comparing different systems.

In addition, numerous industry stakeholders were contacted and interviewed during the study, including suppliers of the various technologies examined. The companies and individuals were extremely helpful in compiling the information contained in this report.

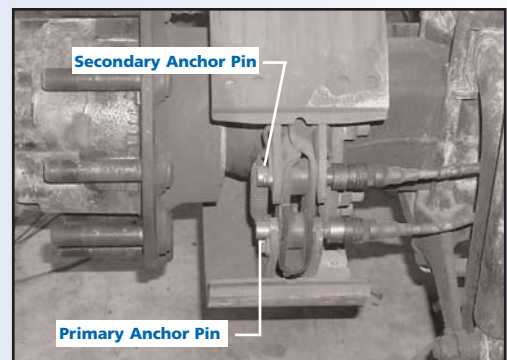
Summary of Results

The following are key observations and results from the testing of the aforementioned sensor technologies.

Anchor Pin Strain Gauges

Pre-production instrumented anchor pins (interchangeable with conventional S-cam brake anchor pins) fitted with strain gauges are capable of measuring the shear stresses applied to the anchor pins of the drum brake assemblies used on heavy-duty S-cam trucks and buses. Each anchor pin is fitted with two strain gauges orientated 90 degrees apart, in the "X" and "Y" direction. The test vehicle was equipped with four instrumented anchor pins, two on each of the intermediate axle brake assemblies (one on the upper/secondary and one on the lower/primary brake shoes).

- Track testing shows a highly predictable relationship between force data generated by instrumented (strain-gauged) anchor pins and the vehicle's deceleration rate. Instrumented anchor pin force is therefore an accurate measure of a vehicle's braking performance.
- Instrumented anchor pins can accurately detect brake deficiencies in specific (individual) wheel assemblies, including out-of-adjustment, disconnected, and/or oil-soaked shoe linings. They can also measure the effect of an out-of-adjustment brake on the other (properly adjusted) brakes on a vehicle. This capability lends itself for application to advanced brake balancing control schemes that may be possible with ECBS.

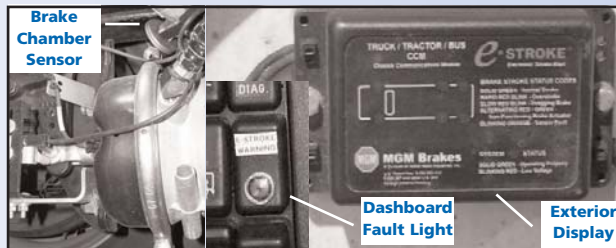


- Instrumented anchor pins can accurately detect even low brake forces. By resolving the resultant force into the "X" (friction force) and "Y" (normal force) directions, the instrument anchor pins can differentiate between an out-of-adjustment brake and a brake with oil-soaked shoe linings. With an oil-soaked lining, less force is generated in the "X" direction when compared to an oil-free lining. This capability could likely be leveraged to improve diagnostic efficiency and overall brake maintenance planning.
- Instrumented anchor pins performed reliably throughout the testing.

Stroke Sensors

The test truck was equipped with two commercially available stroke sensor packages and two laboratory-grade linear potentiometers mounted on the intermediate drive axle to measure stroke. Key observations and conclusions on the commercial brake stroke sensor packages, and on the utility of monitoring stroke in general, are as follows:

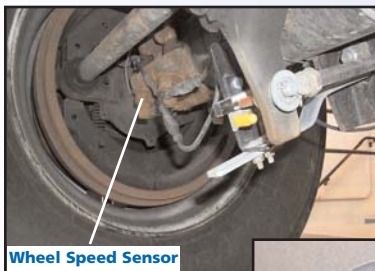
- Commercial brake chamber stroke sensor packages can detect brake deficiencies. Their accuracy varies depending on the load, deceleration rate, and type of brake deficiency. Both commercial systems tested had the most difficulty detecting brake deficiencies with the trailer unloaded and at low deceleration rates; however, both manufacturers state that these systems are intended to detect overstroke conditions during hard braking applications.
- In-cab displays featuring indicator lights for all ten brakes provide the driver with valuable real-time data on the overall condition of the vehicle's braking system.
- Unlike the instrumented anchor pins, brake stroke monitoring cannot differentiate between out-of-adjustment brakes and oil-soaked shoe linings. For example, with oil-soaked shoe linings, the linear potentiometers recorded an overstroke condition.
- The resolution and accuracy of stroke sensors make them well-suited for use in detecting brake maintenance needs and potential brake safety issues, but they are probably not appropriate for use in brake balancing systems.



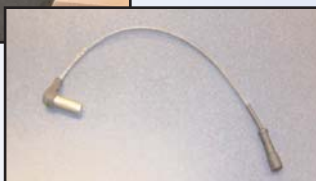
Wheel-Speed Sensors

Wheel-speed sensors are a standard component of anti-lock braking systems (ABS) used on heavy-duty trucks and buses. ABS wheel-speed sensors can be used to measure an individual wheel slip by comparing the calculated speed of each wheel to the calculated average for all wheels or to some other "actual" speed reference, such as a transmission signal or a contactless fifth wheel that measures ground speed.

- In general, ABS wheel-speed sensors are highly accurate and track closely with "actual" vehicle speed as measured by an instrumented fifth wheel.
- Wheel-speed sensors are sufficiently accurate to detect grossly out-of-adjustment and disconnected brakes. Wheel-speed sensors do not provide sufficient accuracy to detect brakes that are 1/8" or less beyond the readjustment limit.
- Wheel-speed sensors are sufficiently accurate to detect a problem due to oil-soaked brake linings. However, unlike instrumented anchor pins, wheel-speed sensors cannot differentiate between out-of-adjustment brakes and oil-soaked linings.



- Wheel-speed data broadcast on the J1939 network was significantly less accurate than data from actual ABS wheel-speed sensors.
- Although the wheel-speed sensor data broadcast over the J1939 network was less accurate than data from actual sensors, it was sufficient for detecting grossly out-of-adjustment, disconnected, and poorly performing brakes.



Researchers

This study was performed by Booz-Allen-Hamilton, Inc., McLean, VA, and Radlinski and Associates, Inc., Columbus, OH, by Robert M. Kreeb, Brian T. Nicosia, Douglas Skorupski, and Richard Radlinski. Contract No. DTFH61-99-C-00025.

Availability

The study final report (FMCSA-PSV-04-001), is available from the U.S. Department of Transportation and the National Technical Information Service, www.ntis.gov.

Key Words

Advanced sensor, brake, braking system, sensor study, signal processor

Notice

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Brake Shoe Thermocouples

Standard Type J thermocouples were installed and tested as part of this program. These tests had two objectives: (1) evaluate the thermocouples to determine whether they could reliably be used to detect brake defects, and (2) use the thermocouples to assist in evaluating the other sensor "packages". Thermocouples were mounted at varying depths within the shoe lining to test their sensitivity for determining brake deficiencies.

- Response time of thermocouples in general is not sufficient to detect brake problems during singular, discrete braking events.
- Because of the unpredictable variations in initial brake temperature, the comparatively slow response time of thermocouples, and the general inaccuracies inherent with thermocouples, their ability to detect and differentiate brake deficiencies during discrete braking events was found to be very limited.
- During the simulated mountain testing, temperature patterns were detected and used to identify various brake deficiencies.

Potential Sensor Applications

Several applications for the sensor technologies were identified during the study, and described in this section.

Brake Balance Systems

The instrumented anchor pins were proven to accurately detect brake deficiencies and provided sufficiently accurate data to measure the increase in work done by the remaining brakes on a vehicle. This makes them ideal for use in brake balance applications with advanced "brake-by-wire" technologies. In this application, brake pressure could be tailored to individual brakes based on brake force output readings. The benefits include increased brake life due to improved brake lining wear and the ability to perform minor brake adjustments in real time.

Wireless Transfer of Brake Data

Companies in the transportation industry market products capable of wirelessly transferring maintenance data from the vehicle to a central data processing computer in a maintenance yard. These systems are currently configured to wirelessly transfer engine and transmission fault codes, for example, from the vehicle's network. The information generated from the commercial stroke sensor packages and instrumented anchor pins could be broadcast to the vehicle's network and similarly transferred to the maintenance yard. The data could assist in improving vehicle brake safety, scheduling brake work, and tailoring brake rebuild schedules.

Improving Regenerative Braking in Hybrid Applications

Many hybrid propulsion manufacturers currently use an open-loop approach to combining regenerative braking and friction braking. The initial application of the brake treadle valve is regenerative. Exceeding a preset limit energizes the friction brakes. This open-loop control methodology results in an arbitrary amount of regenerative braking force being applied, and less-than-optimal energy being captured during a braking event. Instrumented anchor pins can measure the beginning of a friction braking application and its applied force. By factoring in this measurement data, regenerative braking algorithms can be "closed-loop" in nature. A closed-loop regenerative braking system, although still isolated from the service brakes, can optimize the braking energy recovered as well as reduce emissions, improve brake wear, and improve fuel economy.