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# DEVELOPMENT AND TESTING OF A STUCK BRAKE DETECTOR FOR WAYSIDE INSPECTION OF RAILROAD CARS

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16. Abstract

Stuck brakes and unreleased hand brakes can cause the wheels of moving trains to overheat and develop thermal cracks. A method of detecting stuck brakes by direct measurement of rail forces is described. An alarm criterion for longitudinal rail forces is discussed. The design and calibration characteristics of sensors capable of sufficient accuracy are described. An automatic signal processor and a voice synthesized reporting device for unattended operation are described. Laboratory and field test results are presented indicating the successful detection of stuck brakes with a projected false alarm rate of less than one per ten thousand axles. Suggestions for improving the durability of the prototype for long term service are given.

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# DEVELOPMENT AND TESTING OF A STUCK BRAKE DETECTOR FOR WAYSIDE INSPECTION OF RAILROAD CARS

## 1) EXECUTIVE SUMMARY

Freight cars with unreleased hand brakes, binding brake linkages or other mechanical malfunctions resulting in continuous brake drag pose a safety threat and economic burden to railroads. Continuous braking can overheat wheels and cause thermal stress damage. A broken wheel is one of the more common equipment related accident causes.

The only existing automated stuck brake inspection technology uses infrared sensors to detect hot wheels. The drawback of detecting stuck brakes by sensing hot wheels is that the wheels may have already sustained thermal damage in the process of becoming detectable. The object of the design and testing of the stuck brake detector was to determine if a stuck brake could be detected by directly sensing rail forces and, if so, could the device be made practical.

In order to prevent wheel damage, according to the Air Brake Association criterion, a force sensing stuck brake detector would have to alarm at 375 lb braking force per axle for trains traveling at up to 60 mph. A fundamental difficulty in measuring this small axle braking force is that the two wheel forces may be very large and oppositely directed. Axle torques due to slight differences in wheel rolling radii can cause a 375 lb axle braking force to be the result of the difference between a 4875 lb braking force at one wheel and a 4500 lb driving force at the other. Other practical difficulties to be overcome in the design of a wheel force transducer, which would replace short pieces of rail, are: force disruptions at the gaps between the sensor rail and running rails, cross axis influence of vertical loads 200 times the axle braking alarm threshold and variable thermal track forces.

The stuck brake detector was planned to have three principal elements as shown in figure 1. The tri-axial wheel force sensors are the first element. They would replace two small segments of rail about 1-1/2 ft long. These sensor rails would be mounted with a two inch stagger to sense the direction of travel of passing cars.

The second element converts raw sensor signals to meaningful messages. A processor capable of unattended operation would contain analog signal conditioning and a dedicated microprocessor with a ROM resident program. A compact unit, relatively inexpensive to reproduce and capable of running one dedicated task at a high computation speed would be required for practical application.

Message output devices constitute the third element. The voice synthesized 'talker' would be used to broadcast radio messages reporting axle numbers of stuck brakes, axle numbers of suspected intentional brake applications or a "no faults detected" message. A hard copy of wheel and axle forces for all axles would be printed after each train.

Since a previous attempt at stuck brake detection by force measurement had failed, it was decided to first develop the sensor rail in careful steps to confront the most intractable design problems right away. The first step was to examine the previous work. The low primary sensitivity and resolution of the displacement-driven transducer concept and its large, load position sensitive, cross-axis force sensitivity made the previous rail force transducers unable to resolve small brake forces from the background of extraneous influences.

The same sensor rail bodies were recognized as promising for triaxial force measurement by strain gage bridge techniques. Development and calibration of a strain-driven sensor rail was undertaken in the laboratory using a loading fixture with a full scale wheelset. The high primary sensitivity of the longitudinal force channel, the low crosstalk from vertical loads and the low sensitivity to wheel contact position appeared to be adequate for stuck brake detection.

A proof of concept test was undertaken at the Transportation Test Center (TTC) to determine if the promising laboratory performance of the sensor rails could be sustained under the dynamic loads of real rail vehicles. A powerful minicomputer operating in a high level language was used to perform the same type of real time processing expected of a dedicated microprocessor in later prototype form. The vertical load measurements agreed with static scales to within about 3%. The drag force measurements agreed well with the onboard brake force transducers of a special test car and with brake forces calculated from the cylinder pressures and linkage ratio for the same test car. Statistics gathered from repeated passes of a consist of heavy cars with carefully contrived truck defects (for worst case loads) indicated a false alarm frequency of less than 1 axle per 1000. Since problems involving the zero control circuit, hysterisis in brake forces due to water proofing adhesive and force disturbance at rail gaps were evident, improvements to reduce false alarms to 1 axle per 10,000 were considered readily achieveable.

The proof of concept test indicated that the probability of success justified the development of the self-contained processor and reporting devices appropriate to revenue service. The processor pictured in figure 8 combines the analog signal conditioning, including a successful zero control circuit, with a microprocessor and fast math coprocessor using a read-only memory chip (ROM) resident program suitable for long term unattended use. It operates a commercial 'talker' for voice reporting stuck brakes to the locomotive crew and control tower and produces a hard copy printout of wheel and axle forces. It is suitable for wayside installations similar to hot box detectors.

The final step in the development of the stuck brake detector was a field trial of the complete prototype system at the Richmond, Fredricksburg & Potomac Railroad yard in Alexandria, VA. The drag force measurement capability was demonstrated using a test consist operating over a range of braking levels and speeds. The device operated in routine service and successfully reported stuck brakes. The installation site had low vertical track stiffness with the short rails and joint bars, and as a result, the vertical load measurement repeatability was poorer than for the proof of concept installation at TTC. Two false alarms in service resulted from the wheel load of empty cars dropping below the 3000 lb wheel presence recognition threshold while on the sensor rails. A statistical analysis of routine traffic indicated that the goal of less than 1 false alarm per 10,000 axles as a result of random measurement error had been achieved.

The heavy traffic of the field trial revealed serious durability problems of the prototype sensor rails and joint bars that had not appeared during the proof of concept test. An improved installation method is proposed to eliminate joint bar fatigue and alleviate vertical load variability and loss of wheel presence recognition. The strain levels in the prototype sensor were so high that the adhesive bonds between the strain gages and the sensor rail body were subject to fatigue failure. Detail changes to the sensor rail body to reduce the stresses on the adhesive bonds without changing the successful measurement method or reducing its force resolution are proposed.

The early detection of stuck brakes by direct wheel force measurement was demonstrated to be a practical inspection technology to increase safety and decrease equipment losses.

## 2) INTRODUCTION

Freight cars with unreleased hand brakes, binding brake linkages or other mechanical malfunctions resulting in continuous brake drag pose a safety threat and economic burden to railroads. Continuous braking can overheat wheels and cause thermal stress damage. A broken wheel is one of the more common equipment related accident causes.

Inspectors look for extended brake cylinders and listen for brake squeal of departing freight cars, but stuck brakes escape these inspections often enough that some railroads use infrared hot wheel detectors along main lines. The drawback of detecting stuck brakes by sensing hot wheels is that the wheels may have already sustained thermal damage in the process of becoming detectable.

The object of the design and testing of the stuck brake detector was to determine if a stuck brake could be detected by sensing rail forces and if so could the device be made practical. A force sensing stuck brake detector could be placed at the exit or near the departure yard to locate stuck brakes before they could cause thermal damage. The inspection site would be chosen to avoid routine intentional brake applications, and the automated inspection could be combined with the visual inspection to facilitate remedial action.

## 3) THRESHOLD FOR STUCK BRAKE ALARM

In order to identify unsafe cars based on brake drag force measurements an alarm threshold is required. It must be low enough to protect against wheel damage yet high enough to prevent false alarms due to measurement error.

Freight car wheels are designed to be part of the braking system and they have the capacity to dissipate heat continually without damage at low levels of braking. The Air Brake Association[1] has

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[1] Engineering and Design of Railway Brake Systems, The Air Brake Association, Chicago, 1975.

published a rating of continuous braking capacity of freight car wheels. A 36 inch wheel is rated at 30 horsepower, which means that it can absorb and dissipate braking energy at that rate while maintaining a steady tread temperature (400°F to 600°F), which is below the damage threshold. The rating is expressed as an average braking power per wheel computed by dividing the total train braking power by the number of wheels. Since typical linkage variations would cause braking force variations of at least ±30%, the absolute rating for an individual wheel would be much higher than the train average rating.

Braking horsepower is the product of speed and drag force. Increasing the assumed speed reduces the drag force allowed by the safety threshold. The stuck brake alarm threshold was chosen to prevent brake drag in excess of 30 hp/wheel at 60 mph based on an axle drag measurement. The brake drag limit is therefore 375 lb per axle. It is certainly conservative, even for 33 inch wheels, because it is based on an axle average rather than a train average making the allowance for linkage variability unnecessary.

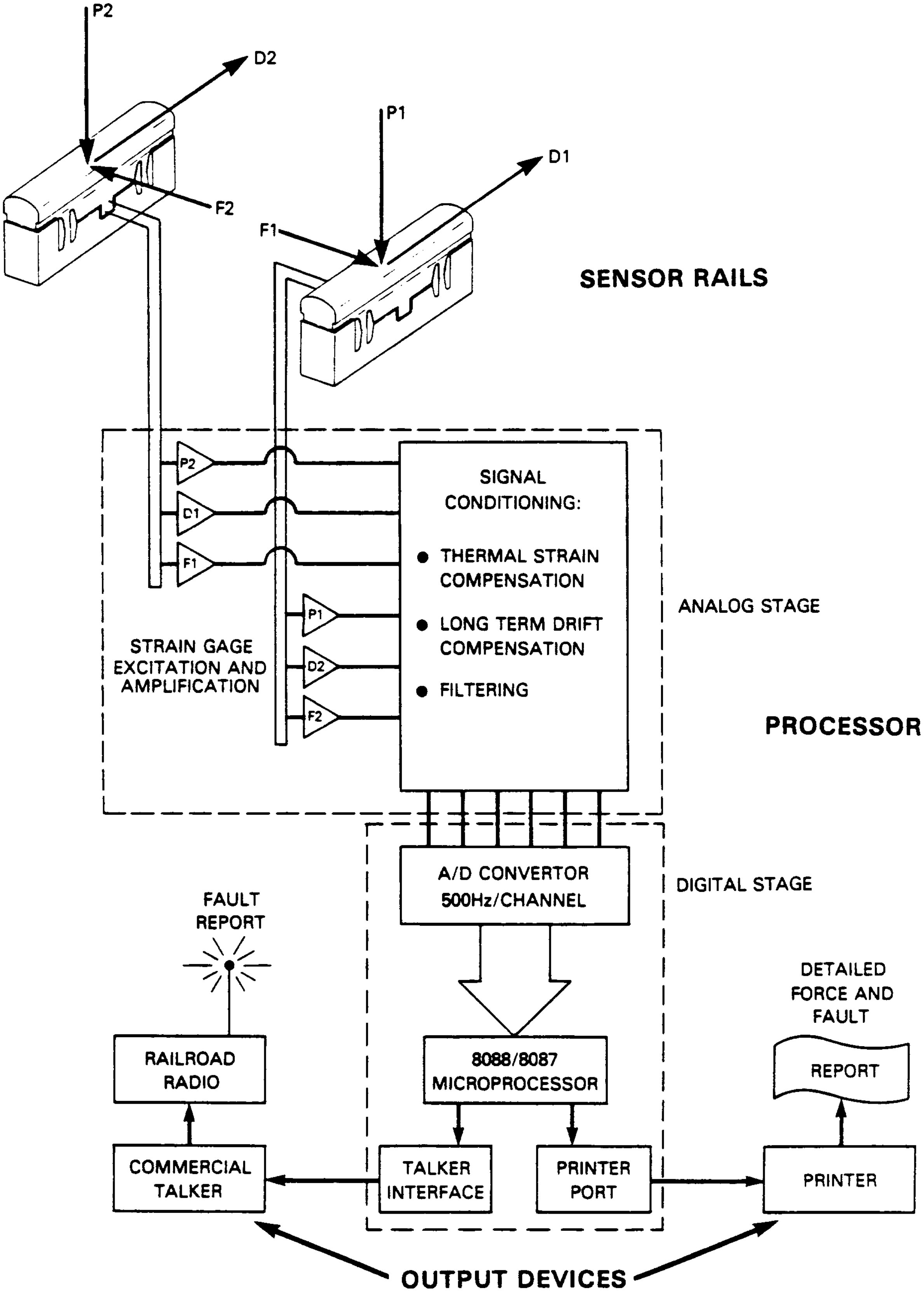
## 4) OVERVIEW OF STUCK BRAKE DETECTOR

The Stuck Brake Detector consists of three groups of components: sensor rails, processor and output devices. Figure 1 is a block diagram of the detector. The sensor rails are a pair of 18" long rail sections inserted into the running rails, each machined so that the wheel loads are supported by two vertical beams within the rail section (as shown in figure 2). Strain gage bridges on the vertical beams are used to sense longitudinal, vertical and lateral wheel/rail forces independently.

The analog stage of the processor powers the strain gage bridges, amplifies their low outputs and compensates for electronic drift and thermal track forces. The digital stage of the processor samples the rail forces while a wheel is passing, interprets the measurements and prepares the report. The processor computes the

Figure 1

# STUCK BRAKE AND OVERLOAD DETECTOR SYSTEM OVERVIEW



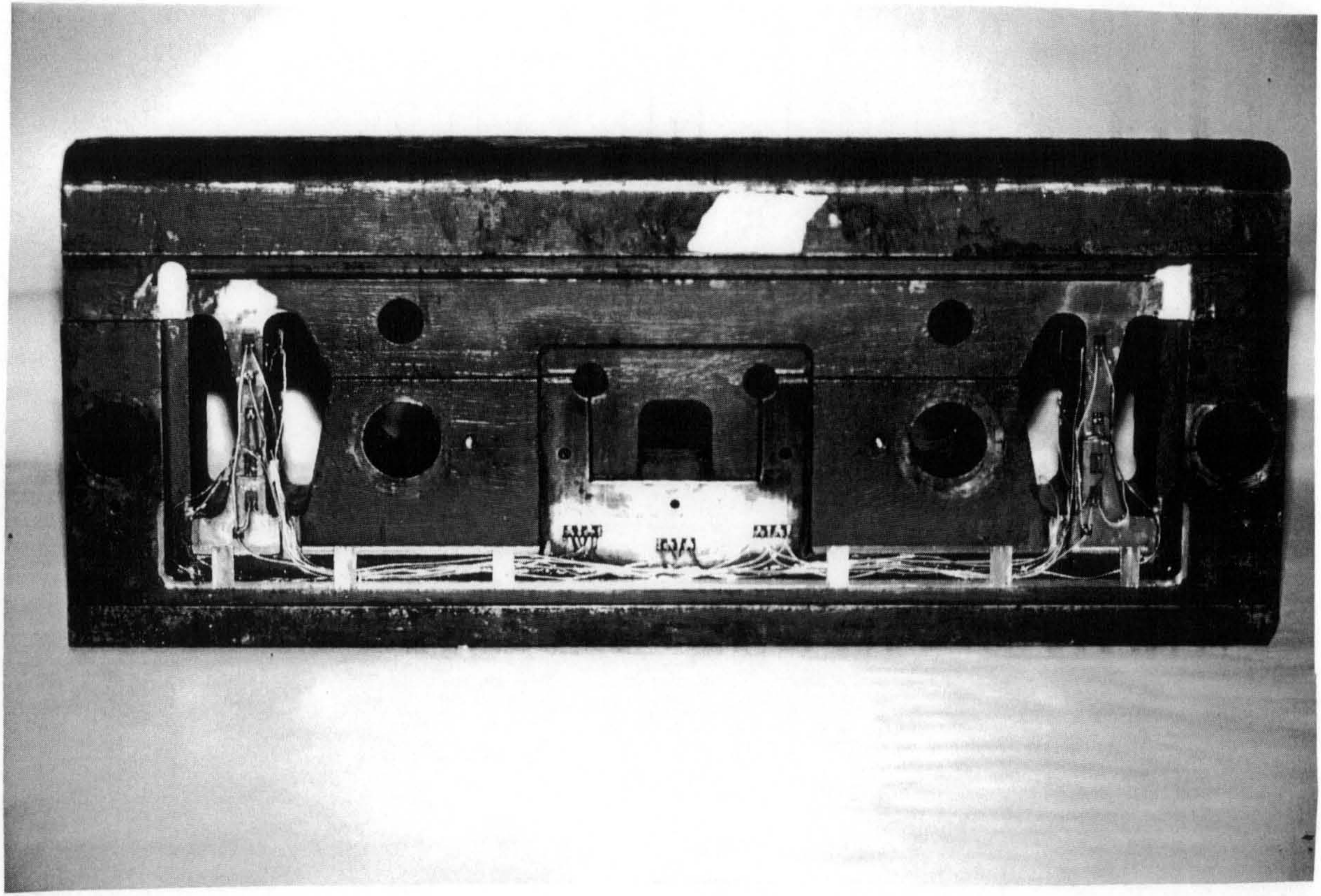


Figure 2. Sensor Rail with Strain Gages Exposed

length and direction of the train, the wheel forces and net axle forces, and the location of stuck brakes. It also determines probable intentional service brake applications and invalid tests caused by a train parking on the sensors.

The stuck brake detector can report by two output devices simultaneously. It uses a commercial voice synthesized talker and railroad radio to make a spoken report of stuck brake status and axle locations. And it reports the wheel and axle forces for each axle using a standard parallel printer for personal computers.

## 5. EXAMINATION OF PRIOR WORK

The stuck brake detector was not the first effort to measure longitudinal rail forces directly. Battelle Memorial Institute, the Association of American Railroads (AAR), and others, have attempted to measure longitudinal forces by strain gage bridges applied to ordinary running rails. The measurement of vertical and lateral forces at the running rail have been successful with that technique, but extremely low strain sensitivity and the inability to isolate the effect of other wheels have precluded the convenient wayside measurement of longitudinal wheel force.

The first effort to develop a longitudinal rail force sensor specifically for stuck brake detection was undertaken by Novatek Inc.[2] for the FRA. Their design featured a short sensor rail with a head supported by two vertical beams and a displacement transducer capable of measuring very small vertical and longitudinal displacements of the center of rail head. Their original installation used a single rail. It was tested and found to produce indications of large braking and driving force that could

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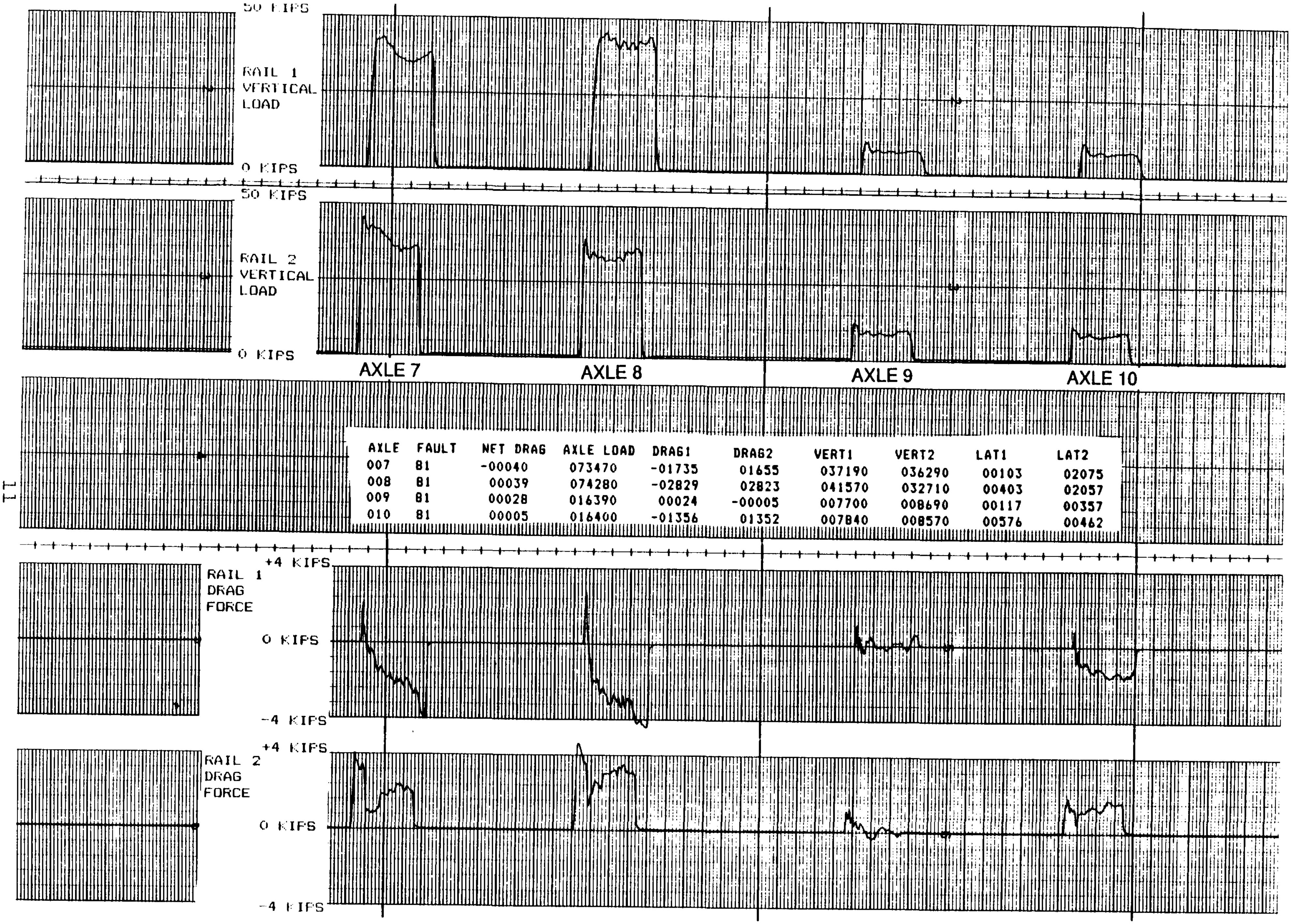
[2] Design, Fabrication and Evaluation of Prototype Brake Inspection Sensors, Spaulding et al, June 1980, U.S. Department of Transportation, Federal Railroad Administration Report No. FRA/ORD 80/20.

not be correlated to brake application. The researchers correctly reasoned that axle torques due to slight differences in the rolling radii of the wheels had created very large equal but opposite longitudinal forces masking the small braking forces. They improved their initial design by adding a second sensor rail but were still unable to resolve net braking forces well enough to detect stuck brakes.

Figure 3 is an example of an analog time history of wheel forces measured by the present sensors to illustrate the impossibility of braking detection with a single sensor. Time increases from left to right at 1/125 of a second per minor division with a train speed of about 8 mph. The rear truck of a heavy car followed by the front truck of a light car passes over the left and right sensor rails (rails 1 and 2, respectively). The vertical load traces at the top of the figure show sharp increases and decreases as the wheels roll over the 18 inch long sensor rails. The simultaneously measured longitudinal drag forces are shown on the lower traces. If a single sensor was installed in the left rail, large driving forces (negative drag forces) would be indicated for three of four axles. If a single sensor was installed in the right rail in this example large drag forces would be indicated. Actually, these axles were free rolling and the wheel forces were equal and opposite with significant torques in three of four axles. In order to recognize the true axle brake drag it is necessary to subtract the large driving force at one wheel from the large braking force at the other. Very accurate sensors to resolve the small difference between two large forces and a way of averaging the unsteady instantaneous longitudinal force measurements are required to measure net axle brake drag.

Because of the failure of credible attempts in the past to measure longitudinal track force and identify braking applications, the present device was developed and tested in stages. The previous transducer concept was examined to gain insight into the



| AXLE | FAULT | NET DRAG | AXLE LOAD | DRAG1 | DRAG2 | VERT1 | VERT2 | LAT1 | LAT2 |
|---|---|---|---|---|---|---|---|---|---|
| 007 | 81 | -00040 | 073470 | -01735 | 01655 | 037190 | 036290 | 00103 | 02075 |
| 008 | 81 | 00039 | 074280 | -02829 | 02823 | 041570 | 032710 | 00403 | 02057 |
| 009 | 81 | 00028 | 016390 | 00024 | -00005 | 007700 | 008690 | 00117 | 00357 |
| 010 | 81 | 00005 | 016400 | -01356 | 01352 | 007840 | 008570 | 00576 | 00462 |

FIGURE 3 -- EXAMPLE OF RAIL SENSOR MEASUREMENTS OF VERTICAL AND LONGITUDINAL WHEEL FORCES

problem, and the development of a better transducer was given the first priority. Unless a transducer of sufficient accuracy, cross axis insensitivity and wheel position insensitivity could be developed and demonstrated to detect actual brake applications, the design of an automated signal processor and reporting device would not be warranted.

## 6) DESIGN AND CALIBRATION OF WHEEL FORCE SENSORS

The original Novatek sensor rail was used as the starting point for the present wheel force sensor. Controlled wheel loads were applied to it using a full scale wheelset in a special loading frame in order to determine why it had not been successful. The longitudinal rail head displacements were measured with a very sensitive dial indicator (full scale ± .015") so that the best potential performance of the sensor could be evaluated independent of the performance of the particular displacement transducer. The basic longitudinal force sensitivity of the transducer body was 600 lb per thousandth of an inch deflection. A axle drag force at the alarm threshold of 375 lb would cause an average deflection of only 0.00031" per wheel superimposed on deflections of about ±.005" caused by moderate axle torques. The experiment also indicated that a free rolling wheel, loaded to 12-1/2 tons, traversing the sensor rail would produce a roughly sinusoidal crosstalk error with a peak to peak amplitude equivalent to 2200 lb of brake drag per rail.

Figure 4 shows the extreme influence of vertical load on the measurement of longitudinal force when the displacement sensing concept is used for the rail force transducer. The center of the sensor is 9 inches from the end of the 18 inch rail as represented by the horizontal axis of figure 4, and the crosstalk error due to a purely vertical load is given by the square points for the displacement-driven sensor at several wheel contact positions. The crosstalk error is less than 200 lb with the wheel centered over the sensor rail, but a load not centered between the internal railhead support posts causes a slight

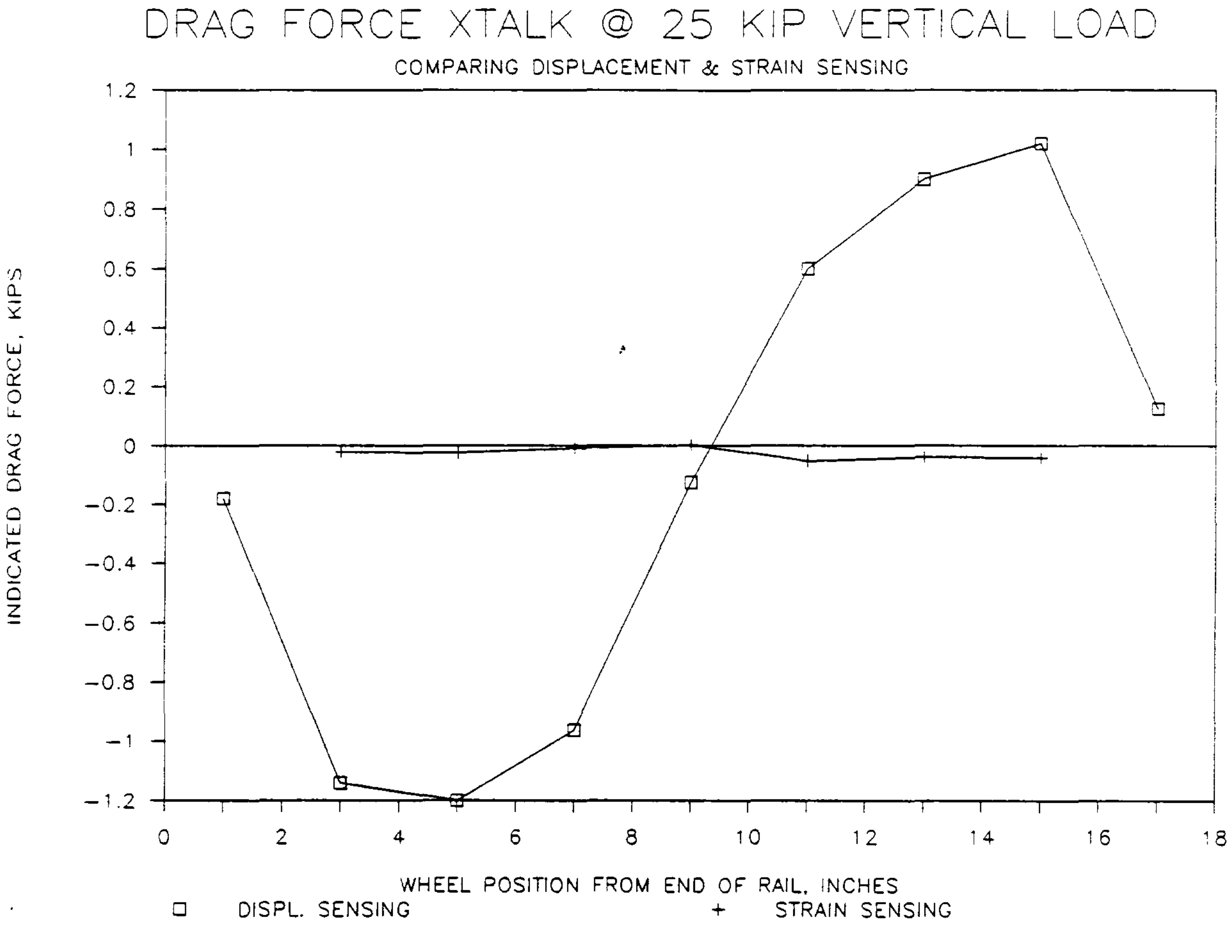

DRAG FORCE XTALK @ 25 KIP VERTICAL LOAD
COMPARING DISPLACEMENT & STRAIN SENSING
INDICATED DRAG FORCE, KIPS
1.2
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
−1.2
0
2
4
6
8
10
12
14
16
18
WHEEL POSITION FROM END OF RAIL, INCHES
□ DISPL. SENSING
+ STRAIN SENSING

Figure 4

railhead movement toward the near post. Since the longitudinal railhead movement is used to indicate brake drag force, fluctuations in the indicated drag force of more than ±1000 lb would result from a free rolling wheel crossing the transducer rail. When the two displacement-driven rail sensors were used to detect net axle braking drag, the combined fluctuation of ±2000 lb prevented the recognition of critical braking levels of only 375 lb. The excessive crosstalk ratio of the displacement-driven rail force transducer frustrated the earlier attempt at brake drag force measurements.

Although the displacement sensitivity of the sensor rail structure to longitudinal force was too low to warrent further development, its strain response to longitudinal and vertical loads was very high. The original sensor rail bodies which had been designed for displacement transducers were found to be excellent structures for the measurement of forces through strain gage techniques. Strain gage bridges were developed to measure longitudinal, vertical and lateral loads independently.

Strain gages are tiny foil grids made of an alloy which changes resistance when it is stretched or compressed. They are mounted on an insulated backing which is bonded with cyanoacrylate or epoxy adhesive to the surface of the object to be measured. Figure 3 shows strain gages and terminals bonded to the rail sensor body.

A tensile strain increases the resistance of the strain gage and a compressive strain decreases it. A strain gage bridge is simply a circuit with four strain gages (as shown in the example in figure 5) or a multiple of four (as used in the actual sensor rail circuits) with a constant voltage applied two opposite nodes and the output voltage measured at the other two nodes. Since the resistance of a gage varies by only about ±1% full scale, the differential unbalance voltage of the bridge circuit can be measured more accurately than the direct resistance change.

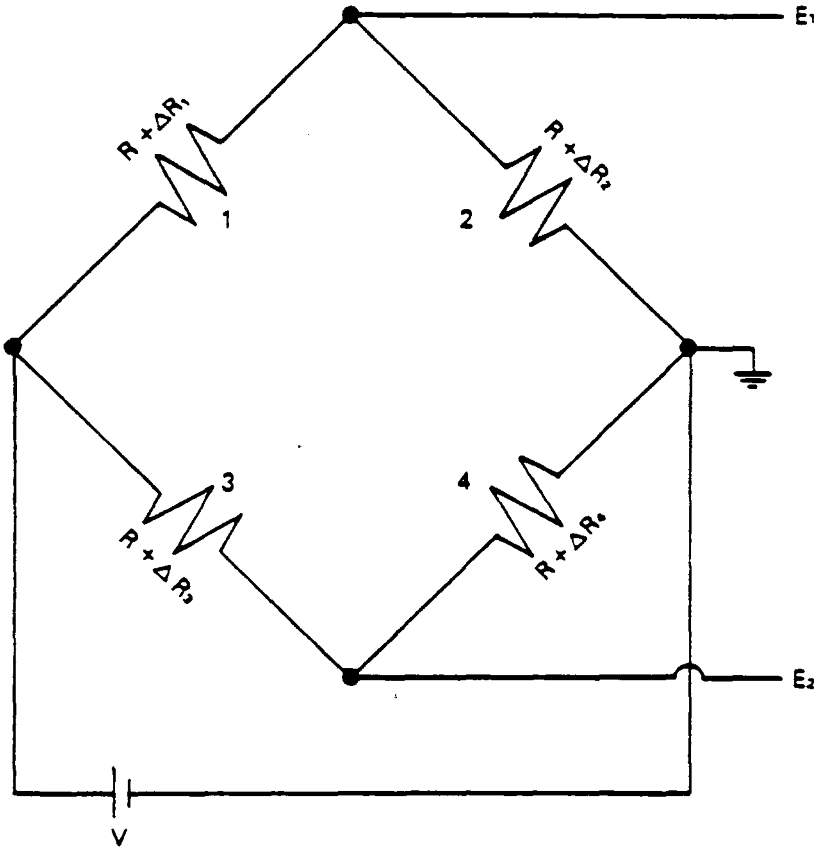


Figure 5A. Strain Gage Bridge Circuit with Four Gages

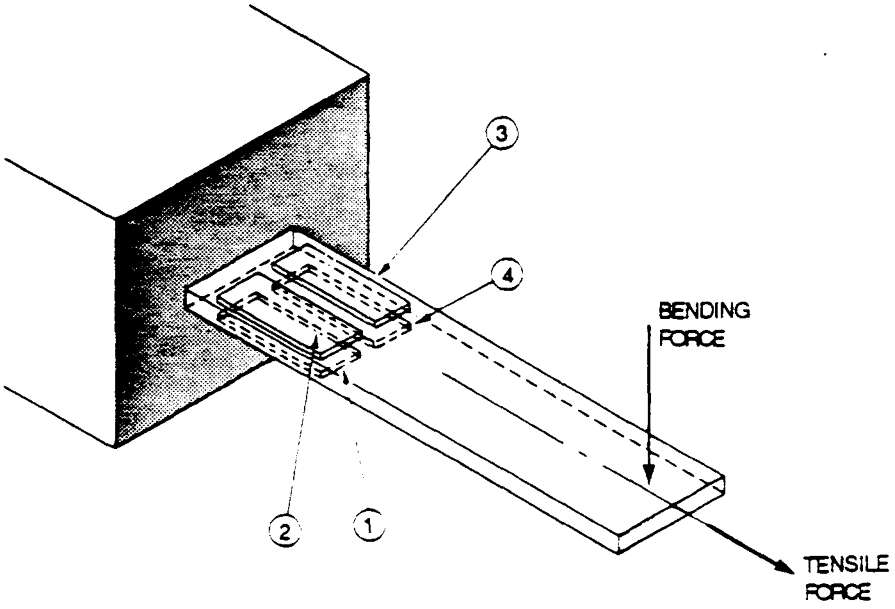


Figure 5B. Example of Strain Gage Bridge to Measure Bending Force and Eliminate Crosstalk From Tensile Force

Using the nomenclature of figure 5 it is evident tensile strains at gages 2 and 3 and compressive strains at gages 1 and 4 cause a positive output voltage. The output voltage,

$$V_o = E_1 - E_2 = \frac{VG}{4} (-\varepsilon_1 + \varepsilon_2 + \varepsilon_3 - \varepsilon_4)$$

where

$E_1$ and $E_2$ are the voltages at points shown in figure 5a,

V is the input voltage

G is the ratio of resistance change to strain (a function of gage, material and constuction), and

$\varepsilon_1 \ldots \varepsilon_4$ are the strains imposed on the gages.

A useful property of the bridge circuit is that it subtracts the strains at half the gages from the strains at the other half. The ability of the sensor rail to separate vertical, longitudinal and lateral forces was a result of this property. The design strategy was to choose strain gage locations where the strains due to the desired force could be maximized by subtracting negative compressive strains from positive tensile strains while the strains due to the cross axis forces could be cancelled by the inherent bridge subtraction.

The cantilever beam in figure 5b provides a simple example of the strategy. If the bending force is to be measured, gages 2 and 3 are placed on top of the beam and gages 1 and 4 are placed on the bottom at the same cross section. A bending force causes positive tensile strains at gages 2 and 3 and equal negative compressive strains at gages 1 and 4. The net bridge strain (i.e. $(-\varepsilon_1+\varepsilon_2+\varepsilon_3-\varepsilon_4)$) is therefore maximized at four times the absolute gage strain. A tensile force, however, causes equal tensile strains at all four gages and its crosstalk is cancelled in the net bridge strain.

The key to maximizing primary sensitivity while minimizing crosstalk of a force transducer is identifying the suitable gage locations (if they exist) or designing a sensor structure to have suitable gage locations. The sensor body for the displacment-driven sensor was recognized as having suitable strain gage locations on the two internal support posts for the above design strategy.

The trial strain gage bridge designs were evaluated and refined using a full scale wheelset in a loading frame. A longitudinal force measurement sensitivity of over 500 microstrain per kip (between 10 and 100 times the strain sensitivity of instrumented wheelsets) with a very low vertical load crosstalk of 0.1% or less was achieved. Vertical and lateral force measurement sensitivities of 33 microstrain/kip and 120 microstrain/kip respectively were achieved with a high degree of independence of wheel contact position and without significant crosstalk.

The crosstalk between vertical load and the indicated longitudinal drag force of the strain-driven rail force transducer is also shown in figure 4 for several wheel positions. The crosstalk is very low and it is uniform for wheel positions along the rail. The crosstalk and primary sensitivities in all three axes were designed to maximize uniformity for wheel positions along the rail and across the railhead so that simple automated data collection could be used. The average of samples taken by the analog to digital converter represent the wheel forces without the need to compensate for the wheel/rail position.

## 7) PROOF OF CONCEPT TEST

The strain gaged sensor rails were capable of very high resolution in the laboratory fixture, but a practical stuck brake detector would have to perform under severe field conditions. A typical threshold detection could have 4875 lb braking force on one rail and 4500 lb driving force on the other with vertical loads of 35,000 lb and lateral loads of 3000 lb applied simultaneously. Field loads would be highly dynamic in contrast to the static laboratory loads. In particular the entry and exit disturbances of longitudinal force shown in figure 3 were beyond the laboratory expectation. Impacts from slight vertical height irregularites and rail gaps and the transfer of forces at one wheel to the other through axle torque cause entry and exit spikes in the longitudianl wheel forces. They were especially pronounced during the eventual field installation at the Richmond, Fredricksburg and Potomac (R,F&P) Railroad. Locomotive drive forces, flexure of ties and running rails, effects of adjacent wheels, slack motion, rock and roll motion, thermal forces in the track, and moisture would be among the other practical obstacles to successful stuck brake detection. A practial detector operating automatically without human judgement of the force measurements, would rely on sensor design characteristics, signal conditioning and processing algorithms to distinguish brake drag from extraneous influences.

A complete breadboard stuck brake detector was built and tested to determine if the promising laboratory performance of the sensor rail would be adequate for practical application. A powerful minicomputer system was used to sample and compute wheel and axle forces. It allowed programming in a high level language to speed development, but the program structure was designed to simulate the capabilities of a small inexpensive microprocessor which would be required for a practical stuck brake detector. Signal conditioning boards for the strain gage bridges were designed which used bandpass filters to eliminate the slow drift of the force channels due to thermal track forces. And a very simple installation technique was designed using long joint bars and baseplates as shown in figure 6. The test was performed at the Transportation Test Center, Pueblo, Colorado, using a test train prepared and operated by AAR. A car was specially modified for independent braking control with on board brake drag and cylinder pressure instrumentation to determine the accuracy of the stuck brake detector. Cars with severely mismatched wheel diameters, skewed truck frames and a wide variation of load and speed were used to test the false alarm potential of the device.

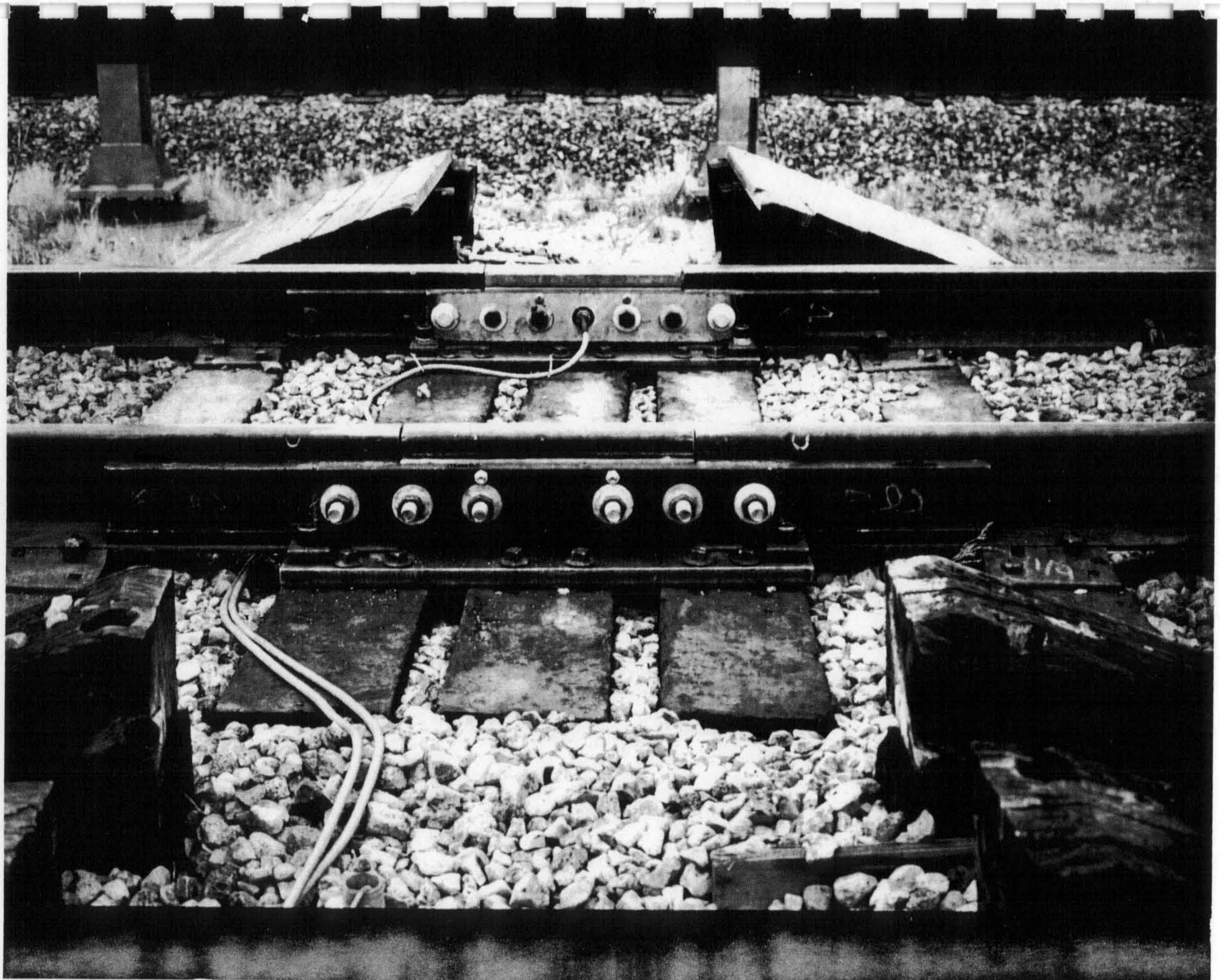


Figure 6. Sensor Rail Installation

The sensor rail installation was performed by three Test Center track men in about eight hours. Several problems were encountered during the initial test runs. The attempt to eliminate thermal drift by high pass filtering was unsuccessful, and it was abandoned for the test runs in favor of occassional zero adjustments. The drag force zeros were observed to shift slightly during the passage of a train, and it could not be remedied during the test. It was later determined that the waterproofing sealant would exert a 50-75 lb hysteresis after a deformation, which could be eliminated by a change in waterproofing technique. Vertical and longitudinal force impact spikes occurred as heavy cars rode over the gaps between the sensor rails and running rails. The computer program was successfully adapted to ignore entry spikes so that the test could proceed.

Table 1 compares the vertical loads measured by the breadboard stuck brake detector to the weights reported by the scales at the Transportation Test Center. The vertical force measurement of the sensor rails was satisfactory. The dynamic weighing agreed with the test center static scales to within about 3% or better for the passenger coach and test cars. There was no perceptible difference in performance between 10 and 20 mph with or without simultaneous braking force.

The brake drag force exerted by the special test car (DOTX-401) was measured in two ways. The cylinder pressure was measured for the computation of drag force from the linkage ratios and friction coefficient shown in figure 7. And, the brake hanger force was measured directly with a load cell. The brake hanger forces were consistently about 35% higher than the computed drag force which lead to the discovery that a component of the brake beam clamping force as well as the drag force was being carried by the brake hanger.

## Table 1

## COMPARISON OF VERTICAL LOADS MEASURED BY STATIC SCALES AND BY RAIL FORCE SENSORS

| | | | Vertical Rail Force from Sensors (~lbs) | | |
|---|---|---|---|---|---|
| Vehicle | Truck | Static Scales, Weight (~lbs) | 10 mph Unbraked | 20 mph Unbraked | 20 mph 50 psi Brake Cylinder Pressure |
| Locomotive | A | 118,050 | 113,577 | 109,487 | |
| | | | 113,162 | 107,655 | |
| | B | 119,450 | 114,747 | 111,762 | |
| | | | 112,750 | 108,810 | |
| Coach | A | 62,750 | 63,298 | 61,763 | |
| | | | 62,060 | 62,069 | |
| | B | 60,150 | 60,657 | 60,203 | |
| | | | 60,539 | 60,048 | |
| Car 401 - Load 1 | B | 24,850 | 25,492 | 24,097 | 24,827 |
| | A | 24,600 | 24,866 | 24,588 | 23,809 |
| Car 402 - Load 1 | B | 25,350 | 25,249 | 25,889 | |
| | A | 24,700 | 24,430 | 25,128 | |
| Car 401 - Load 2 | B | 44,050 | 44,530 | - | 45,549* |
| | A | 44,150 | 45,127 | - | 44,986* |
| Car 402 - Load 2 | B | 44,550 | 45,830 | - | |
| | A | 44,300 | 45,192 | - | |
| Car 401 - Load 3 | B | 62,900 | 64,798 | 60,586 | 61,879 |
| | A | 63,300 | 64,325 | 62,324 | 61,461 |
| Car 402 - Load 3 | B | 54,000 | 54,073 | 54,888 | |
| | A | 53,800 | 53,191 | 51,485 | |

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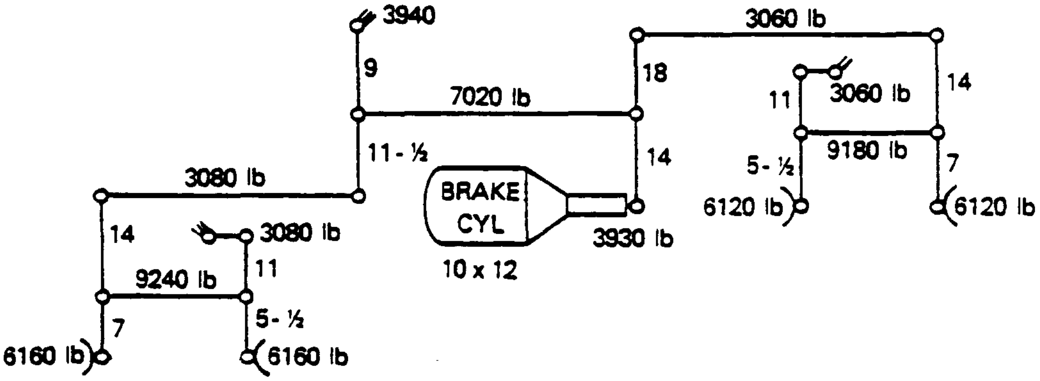
*10 mph

# DOTX-401 BRAKE SYSTEM ANALYSIS

LEVER DIMENSIONS — INCHES



CYL PRESSURE @50 psi

| BRAKE CYL PRESSURE | BRAKE CYL. FORCE | IDEAL BRAKE BEAM FORCE | IDEAL AXLE DRAG FORCE | |
|---|---|---|---|---|
| | | | 10 mph $\mu = .24$* | 20 mph $\mu = .19$* |
| 5 | 393 | 612 | 147 | 116 |
| 10 | 786 | 1224 | 294 | 232 |
| 15 | 1179 | 1836 | 441 | 348 |
| 20 | 1572 | 2448 | 588 | 464 |
| 25 | 1965 | 3060 | 735 | 580 |
| 30 | 2358 | 3672 | 882 | 696 |
| 50 | 3930 | 6120 | 1470 | 1160 |

* SOURCE: AIR BRAKE ASSOCIATION
$\mu$: Coefficient of Friction

Figure 7

A comparison between the stuck brake detector, the uncorrected AAR brake hanger load cell and the ideal computed drag force is given in table 2. The drag force measurement by the stuck brake detector at 10 mph was very satisfactory. It agreed with the computed brake forces and the adjusted brake hanger force measurements to within about 50 lb up to the alarm threshold and to within about 100 lbs at high axle drag forces up to 1500 lbs. The agreement between the stuck brake detector and the adjusted brake hanger force measurement was also good at 20 mph. The agreement with computed braking forces was poorer largely because the predicted decline in coefficient of friction with speed did not occur. The test runs were so short that it is doubtful whether any change in tread temperature as a function of speed occurred.

A consist of 12 loaded 100 ton hopper cars including some with skewed axles and mismatched wheels were driven back and forth over the stuck brake detector without braking to estimate its false alarm rate. No false alarms occurred in 10 passes (about 500 axles). A prediction of less than 1 false alarm per 1000 axles was computed from the measurement variation of the hopper car drag forces.

For the stuck brake detector to be practial, the false alarm rate should be less than one per 10,000 axles. This test indicated that only a 15% reduction in the standard deviation of drag force measurement would be required to meet that goal. The performance of vertical load measurement, drag force measurement and false alarm rate during this test strongly suggested that routine stuck brake detection could be achieved by the strain gaged sensor rail with a microprocessor controller.

## 8) DESIGN OF PROTOTYPE PROCESSOR

The proof of concept test indicated that the sensor rails were adequate for use in a prototype stuck brake detector (except for waterproofing technique), but a small inexpensive dedicated

## TABLE 2

## COMPARISON OF ONBOARD AND WAYSIDE MEASUREMENTS OF AXLE BRAKE DRAG OF DOTX-401 TO IDEAL COMPUTATION

| | | | | 6 Kip Vertical | | 11 Kip Vertical | | 15.5 Kip Vertical | |
|---|---|---|---|---|---|---|---|---|---|
| Speed (mph) | Dir | Cyl Pressure (psi) | Ideal Axle Drag (lb) | AAR Onboard (lb) | Wayside Detector (lb) | AAR Onboard (lb) | Wayside Detector (lb) | AAR Onboard (lb) | Wayside Detector (lb) |
| 10 | N | 0 | 0 | --- | 38 | --- | 73 | --- | 56 |
| 10 | S | 0 | 0 | 0 | 36 | 0 | 118 | 0 | 65 |
| 10 | N | 5 | 147 | --- | 111 | --- | 100 | --- | 105 |
| 10 | S | 5 | 147 | 130 | 105 | 50 | 187 | 70 | 112 |
| 10 | N | 10 | 294 | --- | 293 | --- | 235 | --- | 235 ** |
| 10 | S | 10 | 294 | 330 | 244 | --- | 309 | 300 | 265 ** |
| 10 | N | 20 | 588 | --- | 521 | --- | 681 | --- | 612 ** |
| 10 | S | 20 | 588 | 710 | 550 | 690 | 560 | 970 | 711 ** |
| 10 | N | 30 | 882 | --- | 809 | --- | 842 | --- | 992 |
| 10 | S | 30 | 882 | 1160 | 858 | 1140 | 829 | 1180 | 972 |
| 10 | N | 50 | 1470 | --- | 1460 | --- | 1563 | --- | 1396 |
| 10 | S | 50 | 1470 | 2000 | 1367 | 1920 | 1391 | 2030 | 1352 |
| 20 | N | 0 | 0 | --- | 75 | --- | --- | --- | -29 |
| 20 | S | 0 | 0 | 0 | 11 | --- | --- | 0 | 211 * |
| 20 | N | 5 | 116 | --- | 5 | --- | --- | --- | 32 |
| 20 | S | 5 | 116 | --- | 29 | --- | --- | 50 | 175 |
| 20 | N | 10 | 232 | --- | 292 | --- | --- | --- | 167 |
| 20 | S | 10 | 232 | 380 | 290 | --- | --- | 340 | 349 * |
| 20 | N | 20 | 464 | --- | 785 | --- | --- | --- | 604 |
| 20 | S | 20 | 464 | 790 | 646 | --- | --- | 790 | 624 |
| 20 | N | 30 | 696 | --- | 1125 | --- | --- | --- | 955 |
| 20 | S | 30 | 696 | 1270 | 973 | --- | --- | 1240 | 1000 |
| 20 | N | 50 | 1160 | --- | 1778 | --- | --- | --- | 1675 |
| 20 | S | 50 | 1160 | 2280 | 1696 | --- | --- | 2040 | 1388 |

*Obvious impact spike errors.

**Program modified to ignore impact spikes.

processor would be required for unattended wayside inspection. The analog strain gage conditioning would require a new strategy for eliminating long term zero drift and thermal track forces, but the strain gage excitation and amplification circuit used for the proof of concept test was adequate. The most stringent requirements on the microprocessor controller were:

(1) The ability to operate conveniently on decimal (floating point) numbers required for crosstalk correction and force scaling, and

(2) The speed to collect six channels of rail force data at 500 samples per second and to process them before the next axle strikes the sensor rail (about 4 ft of train movement at 30 mph).

The most powerful single board computer conforming to the economical 'STD' bus configuration was chosen. It used an 8088 microprocessor with an 8087 floating point math co-processor. A compatable A/D converter board, switch closure output board, and compact power rack were chosen in the popular 'STD' bus configuration. A circuit for zero drift compensation was designed to continually update the zero level except when turned off by a train crossing the sensor rails. New cards were designed to combine this zero control circuit with the previous strain gage amplifier and to fit in the same compact enclosure with the microprocessor cards. A streamlined program was written in 8086 assembly language and stored in a ROM (read only memory) chip. The inexpensive microprocessor system was able to match the stuck brake detection performace of a minicomputer costing 50 times as much because it was built to perform only one task without provision for general use.

As soon as power is turned on, the processor begins the background loop of looking for wheel presence. Upon recognizing a wheel, it computes the wheel/rail forces axle by axle and determines the direction of travel. As soon as it recognizes that the train has passed, it reviews the wheel forces to determine the location of stuck brakes, the location of axles with probable intentional brake applications, or the possiblity of computational errors causing an invalid test. It has been programmed to use a commercial hot box voice synthesized talker to broadcast voice messages of stuck brake detections, intentional brake applications, invalid test, or no faults detected. It also drives a printer to list the wheel forces of each axle for each train. It operates unattended and resets itself after power interruptions.

Figure 8a shows the prototype processor flanked by a commercial talker on the right and a personal computer printer on the left. Figure 8b shows the compact processor in more detail. The six identical boards on the right are the six channels of analog strain gage conditioning. The single board computer, the analog to digital convertor and the talker interface card are among the cards on the left.

## 9) Railroad Field Trial

A field trial of the prototype stuck brake detector under actual service conditions was performed with the generous support and cooperation of the RF&P Railroad at their Potomac Yard in Alexandria, VA.

The new prototype processor and talker were used with the sensor rails from the proof of concept test. A test site was chosen on the main south departure track near the area where visual stuck brake inspections are made. The sensor rail had been designed to fit 136 lb rail with a tall section height, but much shorter 130 pound PS rail was present at the test site. A new set of joint bars and baseplates were made to adapt to the obsolete 130 pound PS rail and the worn rail heads at the test site were built up to full height by welding. Figure 9 shows the railhead to the left built up with welding material to match the height of the sensor rail at the right. The wear pattern of the bottom picture of

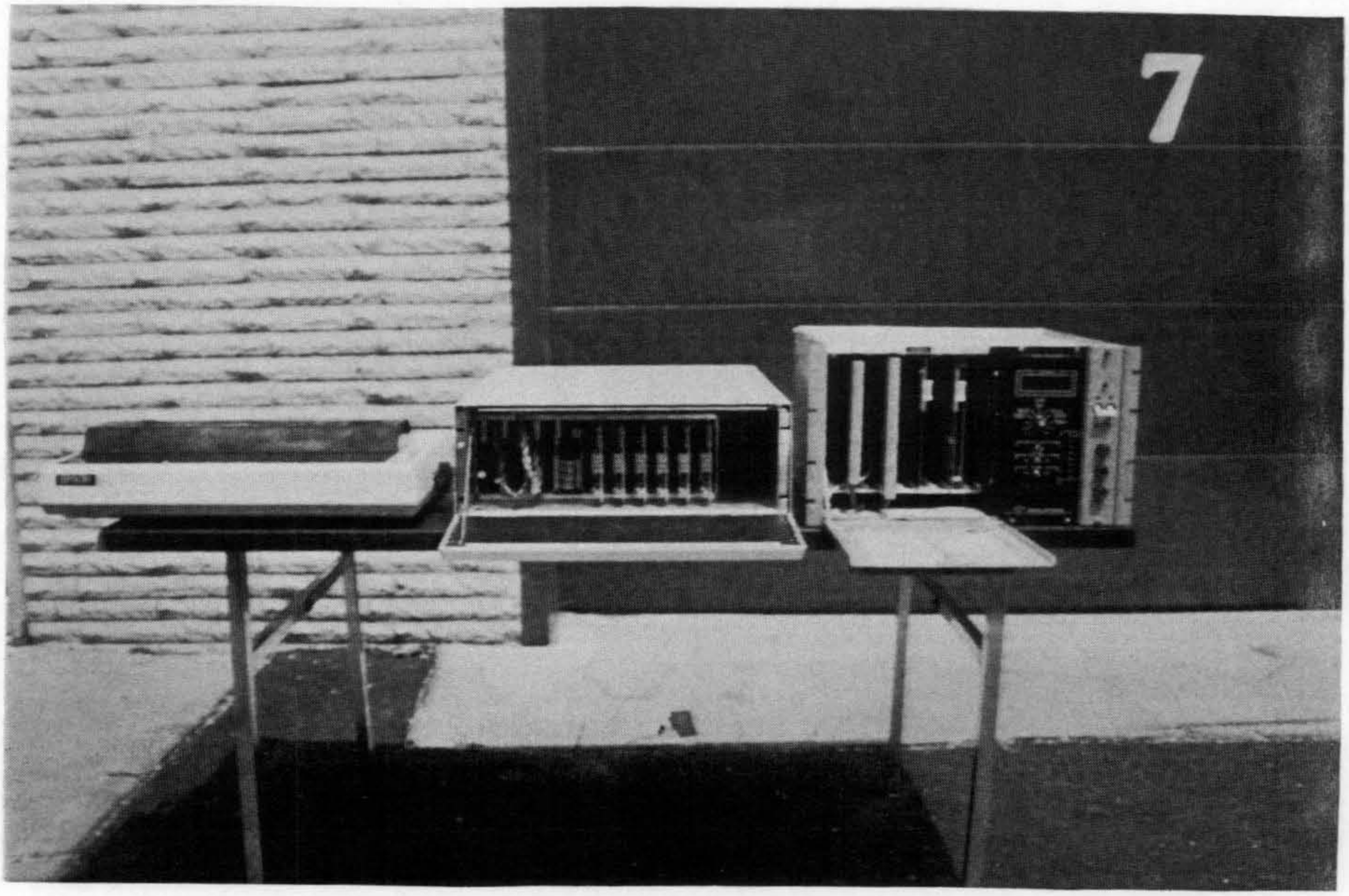


Figure 8A. Printer, Stuck Brake Detector Processor, and "Talker" (Left to Right)

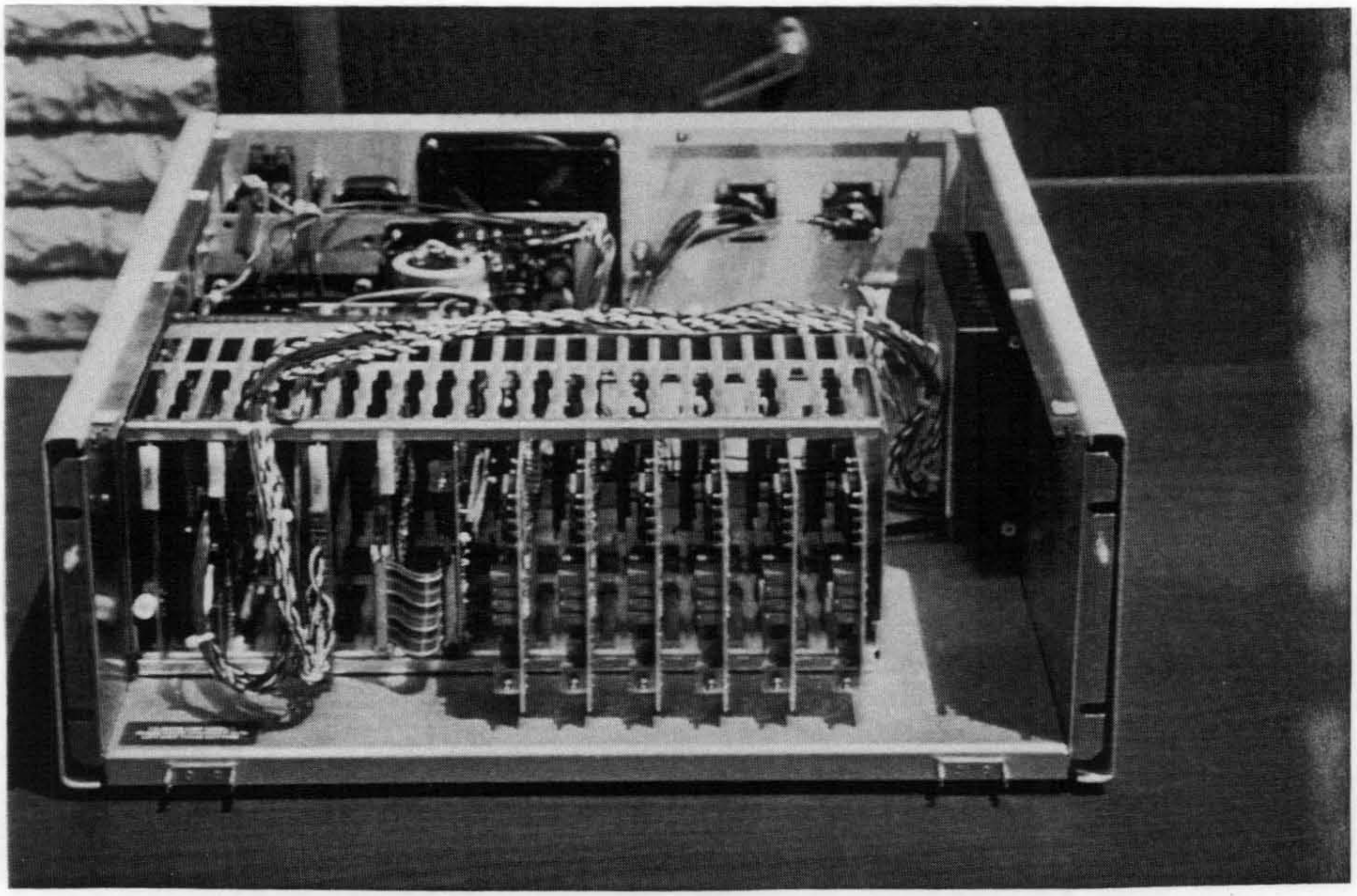


Figure 8B. Stuck Brake Detector Processor with Details Exposed

Figure 9. Sensor Rails Installed in Running Rails with Weld Restored Heads. (Sensor rail is at right, above, and at top, below.)

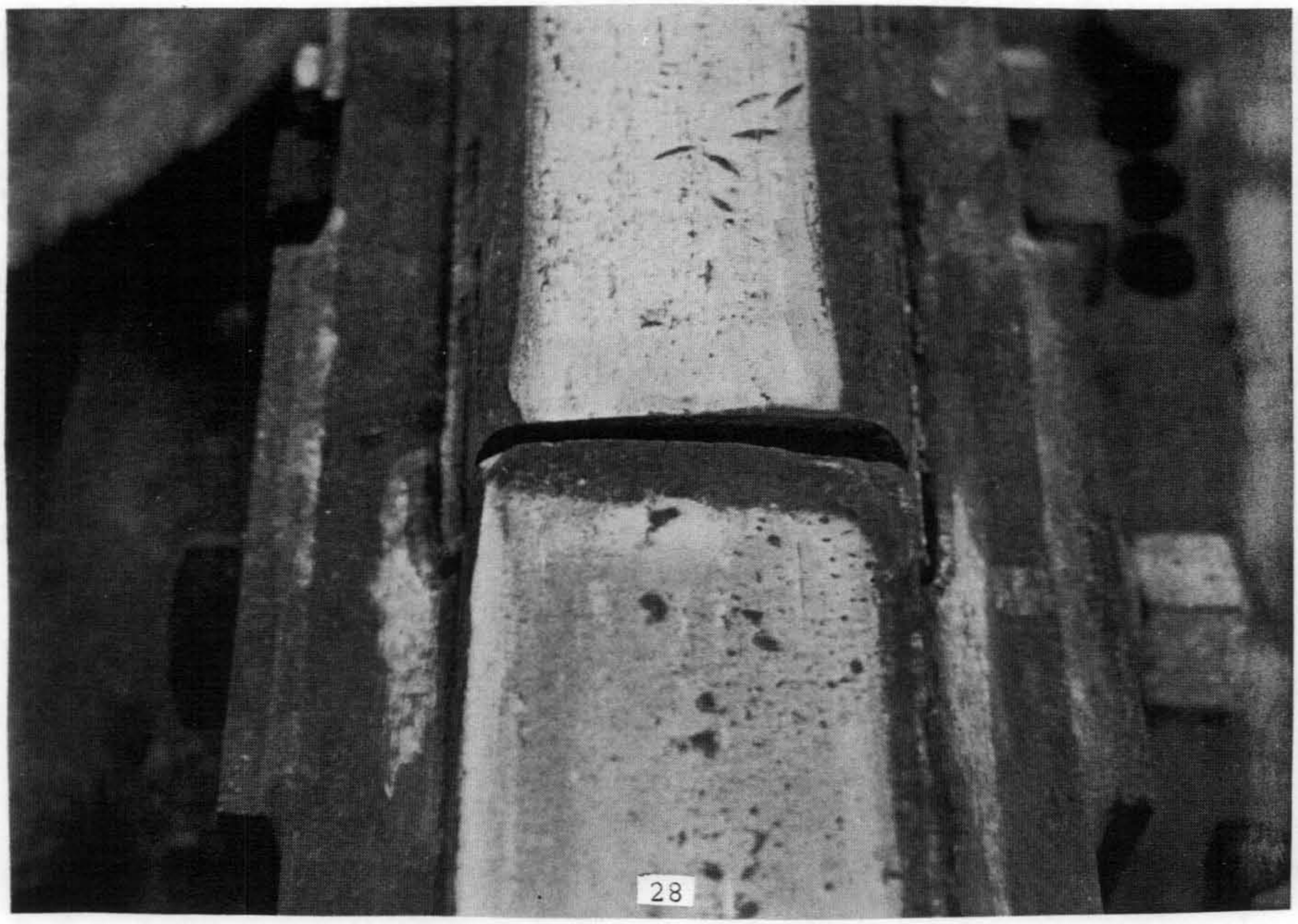


figure 9 indicates wheel impacts at the edge of the sensor (sensor is at the top of the figure). Although the welded rail initially matched the sensor height well, subseqent cold flow reduced its height enough that the wheel did not contact it near the gap. The joint bars for the 130 lb rail had been designed for a tighter fit than those of the proof-of-concept test to reduce changes in gap size with temperature changes. However, the combined effects of the cold flow and the reduced stiffness of the short rails and joint bars at the field test site lead to much greater entry and exit disturbances of wheel force measurements than had occurred with the prior 136 lb rail installation. It was also difficult to install the sensor rails with the correct stagger. One sensor rail is placed slightly ahead of the other to enable the processor to determine the direction of travel and the proper sense of driving and braking forces. But too much stagger is undesirable because it reduces the number of samples of simultaneous wheel forces. The independent installation of the two rail sections during the daily temperature cycle caused an installation with excessive stagger.

The stuck brake detector was to be operated for about a month to evaluate its performance before starting automatic alarm broadcasts to the control tower. During this time the false alarm rate would be studied and optimized through hardware corrections or software algorithms, as required, and a demonstration for the railroad officials would be held when the system was operating properly. The first broadcasts would be based on a 750 lb threshold to find unreleased hand brakes and avoid the possibility that false alarms could discredit the detector before the control tower operators learned its benefits. The 375 lb threshold would be introduced to detect more subtle brake malfunctions after the device was better understood by the users.

False alarms occurred during the initial evaluation because of the great entry and exit disturbances of longitudinal force shown in figure 3. Exit spikes in particular were more severe than expected from the proof of concept test. A software algorithm causing the processor to ignore the first 1/4 and the last 1/8 of the samples from the leading rail and the first 1/8 and last 1/4 from the trailing rail eliminated the apparent source of false alarms. The processor and output devices operated perfectly during extended use, and the strain gage excitation voltage, amplifier and filter gains and balances required no adjustments during the two months of operation. However, serious durability problems of the sensor rails also occurred. The traffic every day represented about three times the number of stress cycles endured during the whole proof of concept test. The first sensor failures were broken solder tabs on the strain gages which occurred soon after installation. They were identified as low cycle fatigue failures due to insufficient lead length between gages, and the sensor rails were rebuilt to eliminate lead wire strain. The next fatigue failures were cracks in the joint bars. The joint bars stresses were high because of the small section height, and cracks occurred in welds at stress raising discontinuities. Reinforcement plates and improvements in weld material and finishing technique were added to return the stuck brake detector to service. The detector stayed operational for several weeks while the software changes were made until another strain gage failure occurred at about 100,000 stress cycles. This failure was fatique of the strain gage adhesive and it was clear that the adhesive bond of the strain gages were going to fail one after another. The gage was replaced, but long term testing would not be possible because the sensor rails were not durable enough.

A special test consist was operated back and forth across the site to demonstrate the accuracy of the stuck brake detector in measuring various levels of service brake application and in spotting random hand brake applications. Table 3 lists the drag force meaurements for the 21 test runs with a locomotive and six cars. The axle numbers are grouped to distinguish the vehicles,

## Table 3

### DRAG FORCE MEASUREMENT SUMMARY - SOUTHBOUND

| RUN | 1 | 3 | 5 | 7 | 9 | 11 | 13 | 15 | 17 | 19 | 21 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DIRECTION | S | S | S | S | S | S | S | S | S | S | S | FREE |
| SPEED | 10 MPH | 10 MPH | 20 MPH | 25 MPH | 5 MPH | 10 MPH | 10 MPH | 10 MPH | 10 MPH | 10 MPH | 10 MPH | ROLLING |
| PSI REDUCTION | | 0 | 0 | 0 | 0 | 5 | 10 | 15 | 20 | 0 | 0 | AVG |
| AXLE # | | | | | | | | | | | | |
| 1 | -7691 | -2915 | -7025 | -6336 | -1095 | -1211 | -3695 | -2929 | -8015 | -1418 | -4425 | |
| 2 | -7210 | -2397 | -7150 | -5557 | -1144 | -1436 | -3683 | -2903 | -8015 | -1571 | -4071 | |
| 3 | -2215 | -2511 | -6924 | -6112 | -1030 | -488 | -3675 | -3057 | -8015 | -2814 | -4470 | |
| 4 | -987 | -2240 | -6495 | -6010 | -970 | -605 | -3619 | -3009 | -8015 | -2825 | -4013 | |
| 5 | 59 | 92 | 97 | 41 | 66 | 132 | 217 | 541 | 1562 | 32 | 19 | 58 |
| 6 | 81 | 82 | 27 | -40 | -13 | 90 | 184 | 360 | 1332 | -49 | -33 | 8 |
| 7 | 163 | 28 | 123 | 45 | -40 | 101 | 177 | 486 | 1481 | -29 | -20 | 39 |
| 8 | 7 | 43 | 66 | 2 | 39 | 113 | 264 | 385 | 1385 | 14 | 17 | 27 |
| 9 | ----- | ----- | -3 | 40 | 28 | 27 | 159 | 464 | 1524 | -15 | 0 | 10 |
| 10 | -96 | -91 | -29 | 184 | 5 | 65 | 215 | 631 | 1756 | -12 | 0 | -6 |
| 11 | 68 | 27 | -113 | -113 | 7 | 62 | 319 | 541 | 1605 | -12 | 13 | -18 |
| 12 | -11 | -86 | 58 | 123 | -13 | 20 | 228 | 631 | 1704 | 41 | -32 | 11 |
| | | | | | | | | | | | | 0 |
| 13 | -85 | -24 | 175 | -16 | 4 | 65 | 217 | 456 | 1380 | -24 | -79 | -7 |
| 14 | -76 | -172 | -18 | ----- | 15 | 115 | 332 | 768 | 1966 | 117 | -29 | -27 |
| 15 | -64 | 13 | -55 | 17 | 23 | 83 | 260 | 551 | 1633 | 84 | -26 | -1 |
| 16 | 1 | -104 | -79 | 35 | -11 | 76 | 222 | 679 | 1554 | 68 | -42 | -19 |
| 17 | -1 | 56 | 53 | -168 | 31 | 106 | 283 | 661 | 1511 | 4 | 20 | 47 |
| 18 | -14 | -19 | 58 | 55 | 39 | 214 | 474 | 955 | 2179 | 60 | -22 | 22 |
| 19 | 76 | 31 | -70 | -2 | 1 | -3 | 67 | 58 | 26 | 33 | 2 | 10 |
| 20 | -30 | 4 | 120 | 75 | 2 | 45 | 54 | 37 | 53 | -2 | -3 | 24 |
| 21 | -157 | -21 | -20 | 14 | -20 | 48 | 309 | 708 | 1621 | -44 | 1120 | -41 |
| 22 | -35 | -73 | -21 | 662 | -24 | 94 | 318 | 772 | 1608 | -9 | 1226 | 247 |
| 23 | 26 | -32 | -148 | 403 | 24 | 139 | 340 | 637 | 1551 | -17 | 1118 | 196 |
| 24 | -55 | 5 | 30 | -135 | -17 | 120 | 257 | 666 | 1533 | 7 | 1096 | -28 |
| 25 | -57 | -72 | -157 | -91 | -19 | 141 | 273 | 632 | 1664 | -55 | -84 | -76 |
| 26 | -46 | -95 | -81 | -7 | -7 | 253 | 399 | 672 | 1634 | -34 | -82 | -50 |
| 27 | -17 | -11 | -117 | 57 | 13 | 284 | 378 | 1016 | 1814 | -63 | -10 | -21 |
| 28 | -31 | 4 | 10 | 25 | -6 | 312 | 380 | 1024 | 1930 | -25 | -12 | -5 |

AVERAGE AXLE DRAG FORCE BY CAR #

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LOCO | -4526 | -2516 | -6899 | -6004 | -1060 | -935 | -3668 | -2975 | -8015 | -2157 | -4245 | |
| CAR 1 | 78 | 61 | 78 | 12 | 13 | 109 | 211 | 443 | 1440 | -8 | -4 | 33 |
| CAR 2 | -10 | -38 | -22 | 59 | 7 | 44 | 230 | 567 | 1647 | 1 | -5 | -1 |
| CAR 3 | -56 | -72 | 6 | 9 | 8 | 85 | 258 | 614 | 1633 | 61 | -44 | -13 |
| CAR 4 | 8 | 18 | 40 | 74 | 18 | 91 | 220 | 428 | 942 | 24 | -1 | 26 |
| CAR 5 | -55 | -30 | -40 | 236 | -9 | 100 | 306 | 696 | 1578 | -16 | 1140 | 14 |
| CAR 6 | -38 | -44 | -86 | -4 | -5 | 248 | 358 | 836 | 1761 | -44 | -47 | -38 |
| RUN AVG | -12 | -17 | -4 | 64 | 5 | 113 | 264 | 597 | 1500 | 3 | -20 | -1 |

## Table 3 (Continued)

### DRAG FORCE MEASUREMENT SUMMARY - NORTHBOUND

| RUN | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DIRECTION | N | N | N | N | N | N | N | N | N | N | FREE |
| SPEED | 10 MPH | 10 MPH | 20 MPH | 5 MPH | 5 MPH | 10 MPH | 10 MPH | 10 MPH | 10 MPH | 10 MPH | ROLLING |
| PSI REDUCTION | | 0 | 0 | 0 | 0 | 5 | 10 | 15 | 20 | 0 | AVG |
| AXLE # | | | | | | | | | | | |
| 1 | 367 | -488 | 442 | -1172 | -1414 | -1098 | -2826 | -5743 | -8015 | 291 | |
| 2 | -561 | -694 | -679 | -1045 | -1383 | -1450 | -3181 | -5731 | -8015 | -97 | |
| 3 | 1277 | -879 | 1767 | -1286 | -1207 | -1122 | -2858 | -5483 | -8015 | -494 | |
| 4 | -204 | -1137 | 276 | -1286 | -1326 | -1018 | -2662 | -5337 | -8015 | -499 | |
| 5 | 158 | 132 | 215 | 208 | 202 | 293 | 285 | 694 | 1178 | 45 | 160 |
| 6 | 54 | 93 | 46 | 75 | 89 | 163 | 183 | 511 | 1030 | 15 | 62 |
| 7 | 57 | -38 | 54 | 170 | 173 | 307 | 276 | 815 | 1475 | 98 | 86 |
| 8 | 111 | 170 | 77 | 190 | 236 | 327 | 254 | 722 | 1182 | 73 | 143 |
| 9 | ----- | -3 | ----- | 61 | 95 | 211 | 189 | 783 | 1375 | 993 | 31 |
| 10 | 36 | 62 | 31 | 91 | 86 | 237 | 252 | 802 | 1293 | 938 | 61 |
| 11 | 28 | 16 | 1 | 71 | 98 | 365 | 360 | 1061 | 1666 | 1306 | 43 |
| 12 | 44 | 45 | 11 | 94 | 99 | 156 | 292 | 725 | 1261 | 951 | 59 |
| 13 | 106 | 38 | 74 | 79 | 101 | 134 | 145 | 548 | 1105 | 18 | 69 |
| 14 | 12 | 0 | 0 | 107 | 96 | 270 | 260 | 941 | 1545 | 75 | 48 |
| 15 | 127 | 42 | 134 | 82 | 59 | 289 | 344 | 986 | 1664 | 26 | 78 |
| 16 | 17 | 61 | -115 | 61 | 48 | 95 | 204 | 601 | 1273 | 75 | 25 |
| 17 | -34 | 27 | 154 | 60 | 45 | 88 | 256 | 835 | 1263 | 13 | 44 |
| 18 | 84 | 136 | 59 | 159 | 167 | 338 | 508 | 1027 | 1615 | 212 | 136 |
| 19 | 136 | 41 | 190 | 104 | 124 | 113 | 65 | 105 | 122 | 93 | 115 |
| 20 | 52 | 93 | 39 | 99 | 81 | 122 | 119 | 137 | 141 | 107 | 79 |
| 21 | 263 | 52 | 171 | 93 | 85 | 170 | 261 | 680 | 1158 | 56 | 120 |
| 22 | 60 | 73 | 47 | 67 | 61 | 105 | 269 | 708 | 1231 | 28 | 56 |
| 23 | 106 | 52 | 142 | 118 | 62 | 236 | 338 | 740 | 1304 | 73 | 92 |
| 24 | 45 | 90 | 55 | 68 | 86 | 195 | 312 | 743 | 1314 | 94 | 73 |
| 25 | 94 | 96 | 201 | 96 | 86 | 299 | 284 | 783 | 1246 | 555 | 115 |
| 26 | 81 | 130 | 36 | 166 | 125 | 290 | 353 | 845 | 1363 | 707 | 108 |
| 27 | 67 | 101 | 116 | 102 | 119 | 415 | 342 | 836 | 1670 | 1012 | 101 |
| 28 | 12 | 35 | -18 | 80 | 79 | 353 | 315 | 869 | 1508 | 798 | 38 |

AVERAGE AXLE DRAG FORCE BY CAR #

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LOCO | 220 | -800 | 452 | -1197 | -1333 | -1172 | -2882 | -5574 | -8015 | -200 | |
| CAR 1 | 95 | 89 | 98 | 161 | 175 | 273 | 250 | 686 | 1216 | 58 | 113 |
| CAR 2 | 27 | 30 | 11 | 79 | 95 | 242 | 273 | 843 | 1399 | 1047 | 48 |
| CAR 3 | 66 | 35 | 23 | 82 | 76 | 197 | 238 | 769 | 1397 | 49 | 55 |
| CAR 4 | 60 | 74 | 111 | 106 | 104 | 165 | 237 | 526 | 785 | 106 | 93 |
| CAR 5 | 119 | 67 | 104 | 87 | 74 | 177 | 295 | 718 | 1252 | 63 | 85 |
| CAR 6 | 64 | 91 | 84 | 111 | 102 | 339 | 324 | 833 | 1447 | 768 | 90 |
| | 72 | 64 | 72 | 104 | 104 | 232 | 269 | 729 | 1249 | 348 | 81 |

and the southbound and northbound runs are separated to check for directional effects. A variety of speed and brake applications are represented. In runs 1 through 10 the cars were free rolling; the brake pipe reduction was increased for runs 11 through 18; and various hand brake application were made in runs 19 through 21. The vertical load measurements for the same runs are presented in table 4 in the same format.

The cars in the test consist were randomly chosen from those available in the yard at the time. The first car was a heavily loaded hopper car, but the others were empty, including several very light trailer haulers with nominal wheel loads of about 8000 lbs. The processor was programmed to recognize wheel presence at a 3000 lb threshold. The dynamic wheel load of several unloaded cars dipped below the wheel recognition threshold on several occasions at rail 1. The five dashes in table 3 represent occurrences of the right wheel load oscillating below the 3000 lb threshold causing an indication of two axles instead of one. During the 25 mph run 7, the right wheel loads of axles 22 and 23 did not complete the oscillation back to the higher load before crossing the sensor. Figure 10 shows that the wheel load was above the wheel presence threshold only while the entry impacts were occurring in the drag force channels. Since the processor only collects drag force data during wheel presence, the false alarms on the table were the result of processing only the entry spikes rather than steady state drag.

The lack of track stiffness particularly under the right rail sensor, increased the dynamic load fluctation which was already stimulated by the ramps formed by the railhead welds. The vertical load measurement was analagous to a person using bathroom scales in a moving elevator. The most direct use of vertical load information made by the brake drag force processing is to turn on and off the drag force sampling. The drag force processing algorithm was able to adequately calculate drag forces despite the vertical load oscillations except in rare cases when

# Table 4

## WEIGHT MEASUREMENT SUMMARY - SOUTHBOUND

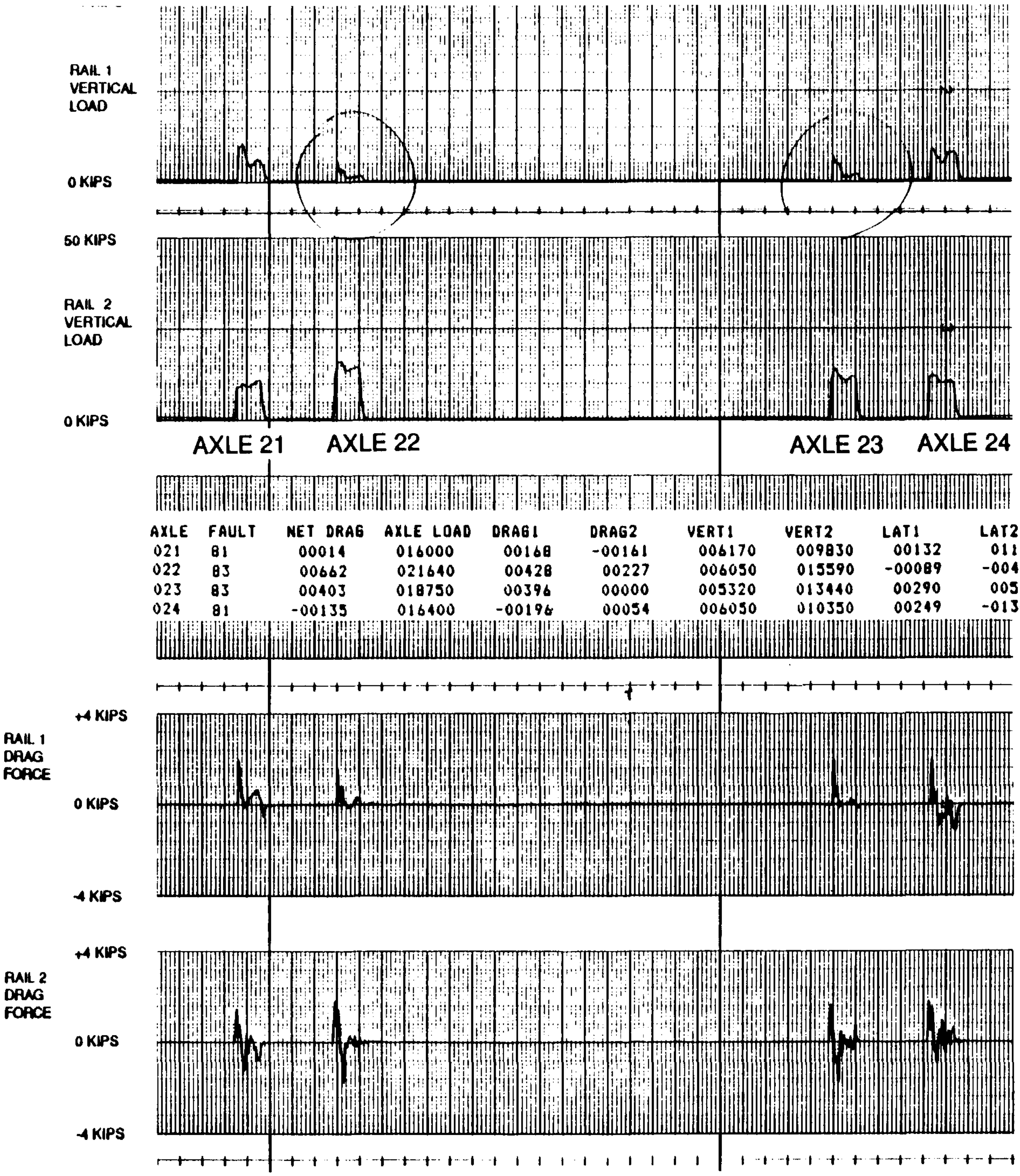
| RUN | 1 | 3 | 5 | 7 | 9 | 11 | 13 | 15 | 17 | 19 | 21 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DIRECTION | S | S | S | S | S | S | S | S | S | S | S | AVG |
| SPEED | 10 MPH | 10 MPH | 20 MPH | 25 MPH | 5 MPH | 10 MPH | 10 MPH | 10 MPH | 10 MPH | 10 MPH | 10 MPH | AXLE |
| PSI REDUCTION | | 0 | 0 | 0 | 0 | 5 | 10 | 15 | 20 | 0 | 0 | LOAD |
| AXLE # | | | | | | | | | | | | |
| 1 | 57530 | 61170 | 56820 | 60290 | 61920 | 63130 | 60590 | 61700 | 57950 | 61580 | 60720 | 60309 |
| 2 | 68400 | 64770 | 67860 | 65560 | 64990 | 64820 | 66450 | 65750 | 74840 | 66830 | 65750 | 66911 |
| 3 | 63200 | 65520 | 63420 | 64160 | 62360 | 66790 | 66210 | 65980 | 60270 | 62870 | 63620 | 64036 |
| 4 | 63730 | 66540 | 72090 | 70430 | 65030 | 63220 | 67860 | 67880 | 75490 | 66460 | 66720 | 67768 |
| 5 | 55220 | 54580 | 56500 | 55730 | 58460 | 53960 | 54380 | 55000 | 60010 | 58420 | 53900 | 56015 |
| 6 | 54460 | 53950 | 57320 | 57860 | 59890 | 54060 | 53780 | 56330 | 61190 | 59300 | 55640 | 56707 |
| 7 | 66480 | 68810 | 68520 | 72330 | 73470 | 72000 | 71050 | 74760 | 73290 | 75900 | 71570 | 71653 |
| 8 | 70360 | 72390 | 72010 | 71270 | 74280 | 72340 | 72990 | 73030 | 71730 | 73580 | 72030 | 72365 |
| 9 | ------ | ------ | 15470 | 15180 | 16390 | 16700 | 16570 | 17110 | 18040 | 16140 | 16740 | 16482 |
| 10 | 14720 | 14830 | 15190 | 17920 | 16400 | 16400 | 16440 | 16740 | 16860 | 16090 | 16620 | 16201 |
| 11 | 15870 | 16170 | 14550 | 15930 | 17060 | 17250 | 17240 | 17510 | 17790 | 16790 | 16830 | 16635 |
| 12 | 15330 | 15590 | 15050 | 15290 | 16970 | 17070 | 16380 | 16890 | 15840 | 16960 | 16670 | 16185 |
| 13 | 14880 | 14810 | 14130 | 15050 | 15570 | 15000 | 15820 | 16280 | 15860 | 15730 | 14570 | 15245 |
| 14 | 15730 | 16000 | 14920 | ------ | 16000 | 15380 | 15150 | 15660 | 14610 | 15910 | 15660 | 15502 |
| 15 | 13850 | 14190 | 13260 | 13780 | 14720 | 14820 | 15090 | 15620 | 15960 | 14730 | 14510 | 14594 |
| 16 | 14440 | 14880 | 12420 | 13390 | 15340 | 15250 | 15170 | 15000 | 13690 | 15010 | 15250 | 14531 |
| 17 | 18740 | 20110 | 17510 | 16690 | 20070 | 20340 | 20810 | 21100 | 20620 | 20100 | 20780 | 19715 |
| 18 | 18270 | 18790 | 18330 | 18380 | 20200 | 20530 | 19310 | 20630 | 19660 | 20580 | 19310 | 19454 |
| 19 | 19920 | 20730 | 17770 | 18250 | 19540 | 20610 | 20320 | 20350 | 19540 | 19610 | 20170 | 19710 |
| 20 | 18950 | 19520 | 18110 | 18230 | 19650 | 19810 | 19220 | 20730 | 19960 | 19790 | 19330 | 19391 |
| 21 | 17090 | 16570 | 15810 | 16000 | 16080 | 16400 | 16030 | 17110 | 17380 | 16220 | 16990 | 16516 |
| 22 | 14910 | 16550 | 16820 | 21640 | 15990 | 16420 | 16130 | 16350 | 15540 | 15890 | 15850 | 16554 |
| 23 | 16710 | 17010 | 14980 | 18750 | 16990 | 17170 | 16890 | 17890 | 17710 | 16620 | 17360 | 17098 |
| 24 | 16840 | 16720 | 13800 | 16400 | 16770 | 17010 | 16490 | 16630 | 16000 | 16510 | 15990 | 16287 |
| 25 | 16240 | 16830 | 12870 | 13930 | 16440 | 16960 | 16900 | 17270 | 17190 | 16480 | 16310 | 16129 |
| 26 | 14340 | 15650 | 13700 | 15580 | 15410 | 15540 | 14230 | 15810 | 14960 | 15580 | 14940 | 15067 |
| 27 | 15510 | 15350 | 12830 | 12130 | 15210 | 15580 | 15890 | 16420 | 16040 | 15310 | 15230 | 15045 |
| 28 | 14160 | 15580 | 12970 | 13960 | 14990 | 14740 | 13880 | 14660 | 13780 | 15260 | 14400 | 14398 |
| CAR # | | | | | | | | | | | | CAR<br>AVG |
| LOCO | 252860 | 258000 | 260190 | 260440 | 254300 | 257960 | 261110 | 261310 | 268550 | 257740 | 256810 | 259025 |
| CAR 1 | 246520 | 249730 | 254350 | 257190 | 266100 | 252360 | 252200 | 259120 | 266220 | 267200 | 253140 | 256739 |
| CAR 2 | 61074 | 61964 | 60260 | 64320 | 66820 | 67420 | 66630 | 68250 | 68530 | 65980 | 66860 | 65283 |
| CAR 3 | 58900 | 59880 | 54730 | 56152 | 61630 | 60450 | 61230 | 62560 | 60120 | 61380 | 59990 | 59729 |
| CAR 4 | 75880 | 79150 | 71720 | 71550 | 79460 | 81290 | 79660 | 82810 | 79780 | 80080 | 79590 | 78270 |
| CAR 5 | 65550 | 66850 | 61410 | 72790 | 65830 | 67000 | 65540 | 67980 | 66630 | 65240 | 66190 | 66455 |
| CAR 6 | 60250 | 63410 | 52370 | 55600 | 62050 | 62820 | 60900 | 64160 | 61970 | 62630 | 60880 | 60640 |
| TOTAL | 821034 | 838984 | 815030 | 838042 | 856190 | 849300 | 847270 | 866190 | 871800 | 860250 | 843460 | 846141 |

## Table 4 (Cont'd)

### WEIGHT MEASUREMENT SUMMARY - NORTHBOUND

| RUN | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DIRECTION | N | N | N | N | N | N | N | N | N | N | AVG |
| SPEED | 10 MPH | 10 MPH | 20 MPH | 5 MPH | 5 MPH | 10 MPH | 10 MPH | 10 MPH | 10 MPH | 10 MPH | AXLE |
| PSI REDUCTION | | 0 | 0 | 0 | 0 | 5 | 10 | 15 | 20 | 0 | LOAD |
| AXLE # | | | | | | | | | | | |
| 1 | 71480 | 66990 | 69640 | 67940 | 68180 | 67080 | 69030 | 73420 | 76340 | 66870 | 69697 |
| 2 | 60330 | 60760 | 59850 | 61800 | 61140 | 60540 | 58920 | 57490 | 57980 | 60830 | 59964 |
| 3 | 66630 | 65100 | 66180 | 66150 | 66410 | 65880 | 65930 | 69160 | 73900 | 64860 | 67020 |
| 4 | 60890 | 62120 | 62330 | 61980 | 61850 | 62380 | 63350 | 62690 | 62370 | 63260 | 62322 |
| 5 | 55370 | 56230 | 57410 | 59400 | 59480 | 59170 | 57840 | 58950 | 59330 | 57230 | 58041 |
| 6 | 53710 | 55440 | 55320 | 57550 | 57460 | 56620 | 57260 | 57960 | 59210 | 56290 | 56682 |
| 7 | 71090 | 71640 | 72050 | 75120 | 74520 | 74590 | 71780 | 74130 | 74440 | 71870 | 73123 |
| 8 | 69100 | 71150 | 67770 | 73240 | 72410 | 72610 | 71950 | 74940 | 76380 | 72020 | 72157 |
| 9 | ------ | 16200 | ------ | 16840 | 16680 | 16290 | 16370 | 15360 | 14370 | 15510 | 12762 |
| 10 | 14450 | 15680 | 14670 | 16650 | 16490 | 16330 | 17150 | 16520 | 17720 | 17180 | 16284 |
| 11 | 14890 | 16860 | 15030 | 17290 | 17400 | 17040 | 16750 | 16670 | 16320 | 16400 | 16465 |
| 12 | 14850 | 16050 | 15120 | 16700 | 16710 | 16870 | 16460 | 17440 | 17600 | 17060 | 16486 |
| 13 | 14880 | 15840 | 14310 | 16530 | 16550 | 16290 | 16210 | 16320 | 16050 | 16590 | 15957 |
| 14 | 14660 | 15030 | 14860 | 15990 | 15730 | 15370 | 15380 | 16070 | 17540 | 15520 | 15615 |
| 15 | 13590 | 15530 | 12710 | 15810 | 15730 | 15510 | 15380 | 15120 | 14990 | 15840 | 15021 |
| 16 | 13410 | 14730 | 12660 | 15480 | 15290 | 15480 | 15270 | 15930 | 16580 | 15120 | 14995 |
| 17 | 17710 | 21280 | 17160 | 21250 | 21270 | 20720 | 20330 | 20580 | 20180 | 20960 | 20144 |
| 18 | 18810 | 20080 | 17490 | 20210 | 20150 | 19800 | 19970 | 20500 | 20740 | 19520 | 19727 |
| 19 | 18720 | 20250 | 16520 | 20360 | 20380 | 20140 | 19830 | 20090 | 20050 | 20200 | 19654 |
| 20 | 18310 | 19060 | 17570 | 19770 | 20150 | 19730 | 19590 | 19650 | 19860 | 19790 | 19348 |
| 21 | 15370 | 16240 | 18660 | 16550 | 16990 | 16690 | 16210 | 16220 | 15750 | 16810 | 16549 |
| 22 | 15140 | 16060 | 15020 | 16270 | 16700 | 16590 | 16250 | 16990 | 17650 | 16480 | 16315 |
| 23 | 16730 | 16920 | 15010 | 17330 | 17610 | 17190 | 16880 | 16710 | 16470 | 17390 | 16824 |
| 24 | 15640 | 16650 | 14850 | 17010 | 17080 | 17120 | 16920 | 17950 | 18350 | 17420 | 16899 |
| 25 | 14840 | 15920 | 14480 | 16550 | 16770 | 16280 | 16020 | 16010 | 15710 | 16160 | 15874 |
| 26 | 15310 | 15240 | 14810 | 15270 | 15520 | 15650 | 15630 | 15980 | 16940 | 15590 | 15594 |
| 27 | 15960 | 15640 | 12740 | 16200 | 16460 | 15900 | 15730 | 15490 | 15070 | 16150 | 15534 |
| 28 | 14710 | 15000 | 13660 | 15490 | 15660 | 15580 | 15250 | 16100 | 16690 | 16220 | 15436 |

| CAR # | | | | | | | | | | | CAR AVG |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LOCO | 259330 | 254970 | 258000 | 257870 | 257580 | 255880 | 257230 | 262760 | 270590 | 255820 | 259003 |
| CAR 1 | 249270 | 254460 | 252550 | 265310 | 263870 | 262990 | 258830 | 265980 | 269360 | 257410 | 260003 |
| CAR 2 | 58773 | 64790 | 59610 | 67480 | 67280 | 66530 | 66730 | 65990 | 66010 | 66150 | 64934 |
| CAR 3 | 56540 | 61130 | 54540 | 63810 | 63300 | 62650 | 62240 | 63440 | 65160 | 63070 | 61588 |
| CAR 4 | 73550 | 80670 | 68740 | 81590 | 81950 | 80390 | 79720 | 80820 | 80830 | 80470 | 78873 |
| CAR 5 | 62880 | 65870 | 63540 | 67160 | 68380 | 67590 | 66260 | 67870 | 68220 | 68100 | 66587 |
| CAR 6 | 60820 | 61800 | 55690 | 63510 | 64410 | 63410 | 62630 | 63580 | 64410 | 64120 | 62438 |
| TOTAL | 821163 | 843690 | 812670 | 866730 | 866770 | 859440 | 853640 | 870440 | 884580 | 855140 | 853426 |



```
AXLE  FAULT   NET DRAG  AXLE LOAD  DRAG1    DRAG2    VERT1    VERT2    LAT1     LAT2
021   81       00014    016000      00168   -00161   006170   009830   00132    01106
022   83       00662    021640      00428    00227   006050   015590  -00089   -00475
023   83       00403    018750      00396    00000   005320   013440   00290    00545
024   81      -00135    016400     -00196    00054   006050   010350   00249   -01300
```

FIGURE 10 -- FALSE ALARMS DUE TO VERTICAL WHEEL LOADS BELOW THE WHEEL PRESENCE THRESHOLD

the wheel presence threshold assumption was violated. Since most departing revenue trains were fully loaded, unlike the demonstration consist, only two similar false alarms occurred in subsequent testing, but the vertical load measuring potential of the device cannot be exploited without greatly increasing the vertical stiffness of the installation. The dynamic car weights shown at the bottom of table 4 exhibit much greater variation than similar measurements in table 1 taken during the proof of concept test. The stiffer rails and sensor joint bars of the proof of concept test performed better, but the joint bar fatigue failures during the field trial indicate that a more fundamental improvement of installation method for sensor rails is required for useful service. An improved installation is discussed in the conclusions. The joint bar fatigue, false alarms from loss of wheel presence signal, and variability of load measurements would all be alleviated by the same installation improvement.

Returning to table 3, the average axle drag forces are uniformly low for the free rolling runs except for the false alarms at axles 22 and 23 for run 7 that have already been discussed. The average free rolling axle drag was -1 lb for southbound runs and +81 lb for northbound runs. The overall average was a very reasonable 40 lb with a ±41 lb variation representating the limits of the processing algorithm in dealing with differences in entry and exit spikes between directions of travel.

As the brake pipe pressure is reduced in steps, the drag force measurements increase as expected with agreement between directions of travel within about 20 percent. The differences between 5 psi and 10 psi reductions are not significant, reflecting the known characteristics of brake control valves. The braking force measurements increase rapidly for brake pipe reductions over 10 psi. The variations in brake force between axles, mentioned in the discussion of the alarm criteria, are evident at moderate braking force with an improvement in uniformity at higher brake forces. It is also interesting to note the locomotive driving force measurements for axles 1 through 4. They were typically very uniform except when the engineer was making a speed adjustment while crossing the sensor rails. The value -8015 lb, which represents the negative full scale limit of the A/D converter, was reported for both runs in which the locomotive was pulling cars under the heaviest service brake application. A car with totally inoperative brakes on one truck was discovered during this demonstration. Axles 19 and 20 are not braked even at the 20 psi brake pipe reduction.

During runs 19, 20, and 21, random hand brakes were set. A very light hand brake application was made on the third car during run 19. It loosened as soon as the train began to move, but the braking force of that car stands out in comparison to the others although the force is well below the alarm threshold. Heavier brake applications were set during runs 20 and 21 causing obvious alarms. The good brake drag measurement performance shown in the proof of concept test was demonstrated in the field installation, and the system was used to report stuck brakes in revenue service until another strain gage adhesive bond failed a few days later.

Although the formal revenue service test was abbreviated, sufficient measurements were made for a statistical estimation of false alarm probability. The only two false alarms in approximately 3000 nominally free rolling axles of revenue traffic were those due to the vertical load oscillating below the wheel presence recognition threshold as previously described. They were not random errors; they were deterministic and preventable by a specific action, in this case, a firmer sensor mounting design. Random errors are those caused by failures of the processing algorithm to compensate for impacts, axle torques, ballast pumping, instrumentation drift and other unpredictable effects which cause measurement errors distributed about the expected value (close to zero). For a 'Normal' distribution, a value 3.8 times the standard deviation statistic from the mean is expected to occur only once in more than 10,000 samples. Table 5

## TABLE 5
## STATISTICAL DISTRIBUTION OF MEASUREMENTS OF NOMINALLY UNBRAKED AXLES

|  |  |  |  |  | DRAG FORCE RANGES IN POUNDS |  |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DATE | RUN-DIR | AVERAGE | STD. DEV. | # OF AXL | <-200 | -200.-150 | -149.-100 | -99.-50 | -49..-1 | 0..49 | 50..99 | 100..149 | 150..199 | 200..249 | 250..299 | 300..349 | 350..399 |
| 11/3/86 | 1 -S | -42 | 59 | 350 | 6 | 13 | 24 | 101 | 131 | 62 | 10 | 2 | 1 | 0 | 0 | 0 | 0 |
| 11/4/86 | 2 -S | -56 | 58 | 176 | 1 | 5 | 34 | 56 | 56 | 16 | 5 | 3 | 0 | 0 | 0 | 0 | 0 |
| 11/4/86 | 3 -S | -70 | 52 | 134 | 2 | 4 | 27 | 61 | 28 | 9 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2/2/87 | 4 -S | -31 | 74 | 300 | 1 | 0 | 13 | 78 | 142 | 55 | 7 | 2 | 1 | 1 | 0 | 0 | 0 |
| 2/3/87 | 5 -S | -27 | 62 | 340 | 4 | 5 | 19 | 79 | 121 | 92 | 13 | 5 | 1 | 0 | 1 | 0 | 0 |
| 2/4/87 | 6 -S | 26 | 57 | 96 | 0 | 0 | 1 | 7 | 17 | 49 | 11 | 7 | 4 | 0 | 0 | 0 | 0 |
| 2/4/87 | 7 -S | 75 | 78 | 224 | 0 | 0 | 0 | 6 | 25 | 61 | 71 | 29 | 23 | 6 | 1 | 2 | 0 |
| 2/5/87 | 8 -S | 18 | 54 | 214 | 0 | 0 | 0 | 6 | 66 | 113 | 26 | 2 | 0 | 1 | 0 | 0 | 0 |
| 2/5/87 | 9 -N | 85 | 41 | 214 | 0 | 0 | 0 | 0 | 2 | 33 | 117 | 51 | 8 | 2 | 1 | 0 | 0 |
| 2/5/87 | 10-S | 7 | 52 | 114 | 2 | 0 | 0 | 6 | 35 | 56 | 12 | 3 | 0 | 0 | 0 | 0 | 0 |
| 2/6/87 | 11-S | -30 | 50 | 252 | 1 | 1 | 21 | 70 | 98 | 51 | 6 | 4 | 0 | 0 | 0 | 0 | 0 |
| 2/6/87 | 12-S | 22 | 50 | 74 | 0 | 0 | 0 | 6 | 16 | 30 | 18 | 4 | 0 | 0 | 0 | 0 | 0 |
| 2/6/87 | 13-N | 56 | 78 | 74 | 0 | 0 | 0 | 3 | 9 | 30 | 18 | 9 | 2 | 2 | 1 | 0 | 0 |
| 2/6/87 | 14-S | -52 | 44 | 164 | 1 | 2 | 14 | 73 | 59 | 11 | 3 | 1 | 0 | 0 | 0 | 0 | 0 |
| 2/6/87 | 15-N | 65 | 50 | 162 | 0 | 0 | 0 | 3 | 11 | 42 | 82 | 14 | 9 | 1 | 0 | 0 | 0 |
| CUMULATIVE |  | -4 | 77 | 2888 | 18 | 30 | 153 | 555 | 816 | 710 | 402 | 136 | 49 | 13 | 4 | 2 | 0 |

| WEIGHTED AVERAGE | POOLED STD. DEV. |
|---|---|
| -4 LB | 60 LB |

lists 2888 nominally unbraked axles (locomotive axles, the two deterministic false alarms and genuine stuck brake detections were eliminated); the grand average was -4 lb and the overall standard deviation of the entire sample was 77 lb. A histogram of the distribution of brake drag measurements in figure 11 shows that it conforms to the expected bell shaped curve of a 'Normal' distribution. The 375 lb alarm threshold was nearly 5 times the standard deviation from the mean. The design goal of less than one random false alarm per 10,000 axles was achieved.

The average and standard deviation of the measurements for each train are also given separately. Since the average shifted on 2/4/87 due to the A/D converter adjustment prior to the demonstration, the overall standard deviation includes the effect of the resulting slight level shift as well as a random variation. When the standard deviations of the individual train samples about their means are pooled, the random component of the overall standard deviation is estimated at only 60 lbs (the rest of the 77 lbs is due to the non-random level shift). The prediction of less than 1 false alarm per 10,000 axles remains consistent with any train mean and its standard deviation or the pooled standard deviation.

The brake drag measurements of routine traffic used in the false alarm analysis also includes some measurements of special interest. Table 6 summarizes these events. The previously mentioned two false alarms as well as one false axle count, all resulting from vertical load oscillations below the wheel presence threshold, are documented in table 6. A false axle count also occurred when the train identified as run 15R parked with one axle over the sensor rails. The voice syntheisized message reported the test as invalid to prevent an ambiguous broadcast.

The last column shows that 9 axles with stuck brakes were detected in one week of revenue operation. Runs 8R and 9R were

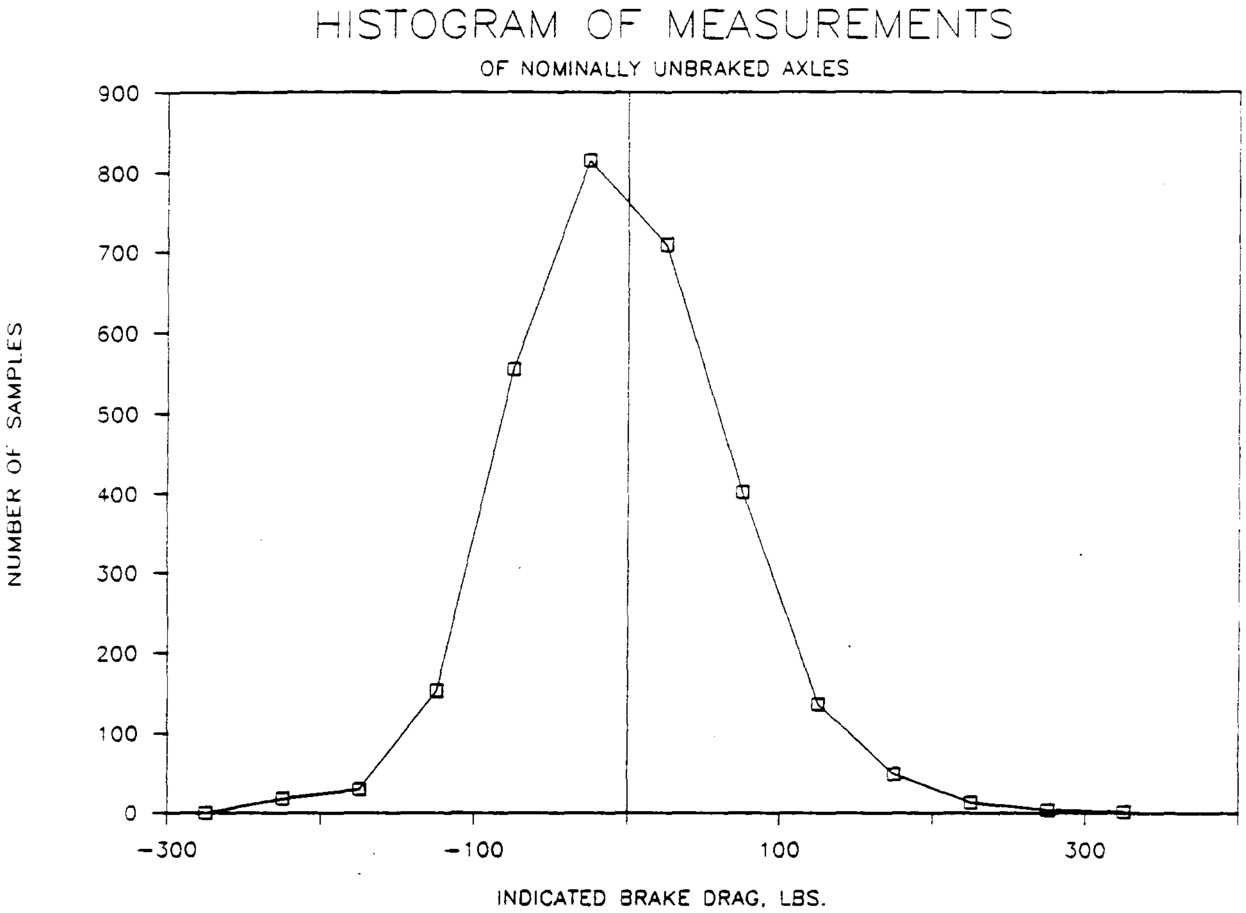

HISTOGRAM OF MEASUREMENTS
OF NOMINALLY UNBRAKED AXLES
NUMBER OF SAMPLES
900
800
700
600
500
400
300
200
100
0
-300
-100
100
300
INDICATED BRAKE DRAG, LBS.

Figure 11

## Table 6

## SUMMARY OF ROUTINE TRAFFIC TESTED FOR STUCK BRAKES

| Run | Date | # of Axles | False Alarms | False Axles | Stuck Brakes |
|---|---|---|---|---|---|
| 1R | 11/3/86 | 368 | 0 | 0 | 0 |
| 2R | 11/4/86 | 188 | 0 | 0 | 0 |
| 4R | 2/2/87 | 313 | 0 | 1(a) | 0 |
| 5R | 2/3/87 | 376 | 2(b) | 0 | 0 |
| 6R | 2/4/87 | 104 | 0 | 0 | 0 |
| 7R | 2/4/87 | 244 | 0 | 0 | 1(c) |
| 8R | 2/5/87 | 222 | 0 | 0 | 4(d) |
| 9R | 2/5/87 | 222 | 0 | 0 | 4(d) |
| 10R | 2/5/87 | 128 | 0 | 0 | 0 |
| 11R | 2/6/87 | 264 | 0 | 0 | 0 |
| 12R | 2/6/87 | 86 | 0 | 0 | 0 |
| 13R | 2/6/87 | 86 | 0 | 0 | 0 |
| 14R | 2/6/87 | 181 | 0 | 5(e) | 0 |
| 15R | 2/6/87 | 176 | 0 | 0 | 0 |
|  |  | 2958 | 2 | 6 | 9 |

a) vertical load dipped below 3 kip threshold

b) vertical load below threshold except at initial impact

c) faulty slack adjuster and worn brake shoes found when axle was inspected in Richmond. A 5-axle intentional brake application was also reported.

d) hand brake detected in both directions in yard move

e) train parked on sensor rail

the same train. It crossed over the stuck brake detector while making a yard move. Force levels over 1000 lb per axle were detected on all four axles of one interior car, clearly indicating an unreleased hand brake. The train backed over the stuck brake detector a few minutes later and the same force levels were measured at all four axles of the same car as shown in the detector output listing in table 7. The train was inspected before being allowed to leave the yard again, but the brakes had been released by this time.

The incident involving the train identified as run 7R in table 6 is noteworthy. The 750 lb alarm threshold was in use at this time. Five axles in a row were measured at high braking forces. The stuck brake detector reported an intentional brake application at those axles according to its programmed algorithm which assumes intentional braking if 5 of any group of 8 axles have brake forces over the threshold. Since the intentional braking reporting criterion was an untested judgement, the railroad was asked to investigate those axles when the train reached Richmond. The inspector in Richmond reported no evidence of unreleased hand brakes at those axles, validating the intentional brake application message. And, he also reported that another car on the same train had badly worn brake shoes on one truck due to a faulty slack adjuster but no sign of wheel overheating damage. When the stuck brake detector printout for the corresponding axles was examined it confirmed that one axle of that truck had been measured at 253 lb and the other axle at 386 lb. This car would have caused an alarm at the design threhsold of 375 lb. The alarm threshold is valid up to 60 mph and this car was operated in a zone of 55 mph track speed. The significance of this discovery is that an axle with continuous braking at nearly the exact proposed alarm threshold of braking power showed damage to the brake shoes but not to the treads of its 33 inch wheels. This observation strongly supports the alarm criterion as being conservative but not unreasonable.

SOUTHBOUND TRAIN (RUN 8R) CROSSING STUCK BRAKE DETECTOR

| | AXLE | FAULT | NET DRAG | AXLE LOAD | DRAG1 | DRAG2 | VERT1 | VERT2 | LAT1 | LAT2 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Locomotive Leading** | 001 | 81 | -07827 | 059130 | -04043 | -03816 | 029070 | 030060 | 02922 | -00936 |
| | 002 | 81 | -08015 | 066720 | -05329 | -03280 | 033330 | 033390 | 00197 | 02261 |
| | 003 | 81 | -07839 | 066090 | -04393 | -03483 | 034000 | 032090 | 01144 | -00128 |
| | 004 | 81 | -08015 | 063620 | -05933 | -02612 | 034620 | 029000 | -00656 | 03118 |
| | 005 | 81 | 00059 | 032950 | -00878 | 00918 | 017160 | 015790 | -00559 | 02355 |
| | 006 | 81 | 00040 | 031190 | 00253 | -00235 | 020090 | 011100 | 01022 | 01551 |
| | 007 | 81 | 00000 | 018470 | -01721 | 01710 | 010000 | 008480 | 00498 | 00456 |
| | 008 | 81 | -00001 | 018000 | 00075 | -00087 | 009180 | 008830 | 01000 | 00164 |
| | 009 | 81 | -00004 | 027940 | 01759 | -01781 | 017000 | 010950 | -00514 | 00978 |
| | 010 | 81 | 00067 | 028740 | -02826 | 02875 | 016530 | 012210 | 00662 | -00562 |
| | 011 | 81 | -00002 | 016470 | -01410 | 01399 | 008380 | 008090 | 00091 | 01309 |
| | 012 | 81 | 00008 | 016180 | -00927 | 00926 | 008400 | 007790 | 00528 | 00521 |
| | 013 | 81 | 00038 | 016100 | -00707 | 00736 | 008880 | 007220 | 00419 | -00127 |
| | 014 | 81 | 00016 | 016730 | -00279 | 00284 | 009340 | 007390 | 00910 | -00315 |
| | 015 | 81 | 00007 | 016240 | -01212 | 01211 | 008190 | 008050 | 00776 | -00327 |
| | 016 | 81 | 00036 | 015840 | -00536 | 00563 | 008390 | 007450 | 01026 | 00756 |
| | 017 | 81 | 00039 | 015140 | -00772 | 00801 | 008660 | 006480 | 00309 | 00131 |
| | 018 | 81 | 00031 | 015520 | -00962 | 00984 | 008880 | 006640 | 00819 | -00159 |
| | 019 | 81 | -00009 | 017270 | -01454 | 01436 | 009110 | 008160 | 00952 | 00157 |
| | 020 | 81 | 00050 | 017400 | -01025 | 01066 | 007900 | 009500 | 00906 | 00634 |
| | 021 | 81 | 00002 | 016330 | -00523 | 00514 | 010080 | 006250 | 00476 | -00067 |
| | 022 | 81 | 00023 | 017020 | -01028 | 01040 | 010530 | 006480 | 00833 | -00397 |
| | 023 | 81 | -00037 | 016550 | 00066 | 00113 | 008410 | 008150 | -00498 | 00710 |
| | 024 | 81 | 00069 | 017020 | -01276 | 01335 | 008800 | 008220 | 00888 | 00493 |
| | 025 | 81 | -00008 | 015510 | -00452 | 00434 | 008730 | 006790 | 00638 | -00216 |
| | 026 | 81 | 00033 | 016640 | -00967 | 00990 | 009280 | 007370 | 01153 | -00044 |
| **Stuck Brake Alarms** | 027 | 83 | 01195 | 018580 | -00132 | 01317 | 009310 | 009260 | -00351 | 00832 |
| | 028 | 83 | 01699 | 016650 | 00431 | 01258 | 008670 | 007980 | 00702 | 00414 |
| | 029 | 83 | 01560 | 017080 | 00526 | 01024 | 009230 | 007860 | -00487 | 00591 |
| | 030 | 83 | 01235 | 016330 | -00079 | 01304 | 009380 | 006960 | 00660 | -00170 |
| | 031 | 81 | -00043 | 016750 | -00917 | 00863 | 009970 | 006780 | 00086 | 00099 |
| | 032 | 81 | 00002 | 017050 | -01158 | 01151 | 008030 | 009020 | 00884 | 00385 |
| | 033 | 81 | -00011 | 016250 | -01246 | 01224 | 010160 | 006080 | 00779 | 00486 |
| | 034 | 81 | -00022 | 016660 | -00368 | 00335 | 010130 | 006530 | 01161 | 00182 |
| | | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| | | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| | | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| | 219 | 81 | 00011 | 014210 | -00243 | 00247 | 006430 | 007780 | -00021 | 00239 |
| | 220 | 81 | -00002 | 014010 | -00725 | 00717 | 006180 | 007830 | 00225 | -00121 |
| | 221 | 81 | -00027 | 014580 | -01067 | 01032 | 007310 | 007260 | 00058 | 00326 |
| | 222 | 81 | -00021 | 014360 | -00439 | 00409 | 008080 | 006270 | 00687 | -00208 |

SAME TRAIN BACKING NORTHBOUND (RUN 9R) OVER DETECTOR

| | Southbound Axle # | AXLE | FAULT | NET DRAG | AXLE LOAD | DRAG1 | DRAG2 | VERT1 | VERT2 | LAT1 | LAT2 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 222 | 001 | C1 | 00047 | 014550 | 00991 | -01046 | 008120 | 006430 | -00959 | 00819 |
| | ● | 002 | C1 | 00059 | 015260 | -00616 | 00548 | 007020 | 008250 | -00611 | 00221 |
| | ● | 003 | C1 | 00048 | 014370 | 00601 | -00657 | 006910 | 007460 | -00523 | 01008 |
| | ● | 004 | C1 | 00029 | 014880 | 00358 | -00394 | 006390 | 008480 | -00824 | 00294 |
| | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| | 34 | 189 | C1 | 00068 | 016620 | 00778 | -00856 | 009350 | 007270 | -00707 | 00832 |
| | ● | 190 | C1 | 00050 | 017230 | -00423 | 00364 | 008290 | 008930 | -00911 | 00977 |
| | ● | 191 | C1 | 00094 | 016760 | 00256 | -00360 | 009570 | 007190 | -00737 | 01241 |
| | ● | 192 | C1 | 00090 | 017230 | 01763 | -01862 | 008550 | 008680 | -00874 | 00249 |
| **Stuck Brake Alarms** | 30 | 193 | C3 | 01611 | 017840 | -00545 | -01077 | 010050 | 007790 | -00593 | 00850 |
| | ● | 194 | C3 | 01533 | 015590 | -00504 | -01037 | 007600 | 007990 | -01120 | 00283 |
| | ● | 195 | C3 | 01838 | 017090 | 00009 | -01856 | 008700 | 008380 | -00056 | 01060 |
| | 27 | 196 | C3 | 01285 | 017230 | -01273 | -00021 | 008120 | 009110 | -00529 | -00007 |
| | ● | 197 | C1 | 00091 | 016140 | 01517 | -01618 | 008510 | 007630 | -00935 | 00260 |
| | ● | 198 | C1 | 00100 | 016640 | -00958 | 00850 | 007820 | 008820 | -01135 | 00307 |
| | ● | 199 | C1 | 00103 | 017290 | 00764 | -00878 | 009850 | 007450 | 00461 | 01391 |
| | ● | 200 | C1 | 00091 | 016720 | 00713 | -00813 | 007850 | 008870 | -00135 | 00818 |
| | ● | 201 | C1 | 00131 | 016940 | 00658 | -00800 | 009900 | 007040 | -01325 | 00259 |
| | ● | 202 | C1 | 00073 | 017110 | -00613 | 00531 | 008550 | 008560 | -01596 | -00041 |
| | ● | 203 | C1 | 00108 | 016340 | 01277 | -01393 | 007930 | 008410 | -00817 | 00826 |
| | ● | 204 | C1 | 00152 | 017120 | 01337 | -01498 | 007770 | 009350 | -00528 | 00670 |
| | ● | 205 | C1 | 00131 | 014510 | 00688 | -00828 | 008240 | 006270 | -00713 | 00691 |
| | ● | 206 | C1 | 00048 | 015050 | -00131 | 00074 | 007520 | 007530 | -01331 | 00476 |
| | ● | 207 | C1 | 00129 | 014240 | 01052 | -01189 | 007190 | 007050 | -00528 | 01142 |
| | ● | 208 | C1 | 00085 | 015130 | 00324 | -00417 | 007040 | 008090 | -00602 | 00511 |
| | ● | 209 | C1 | 00068 | 016300 | 00457 | -00535 | 008790 | 007520 | -00653 | 00842 |
| | ● | 210 | C1 | 00095 | 016030 | -00290 | 00186 | 007990 | 008030 | -01124 | 00666 |
| | ● | 211 | C1 | 00076 | 015720 | 00534 | -00618 | 008130 | 007600 | -00806 | 01278 |
| | ● | 212 | C1 | 00093 | 015710 | 01397 | -01498 | 007320 | 008400 | -00537 | 00842 |
| | ● | 213 | C1 | 00065 | 028490 | -01487 | 01404 | 016350 | 012140 | -01781 | 00895 |
| | ● | 214 | C1 | 00113 | 028470 | 01548 | -01679 | 016890 | 011580 | -01479 | 01355 |
| | ● | 215 | C1 | 00080 | 017190 | 00994 | -01083 | 007870 | 009330 | -01566 | 00827 |
| | ● | 216 | C1 | 00141 | 017110 | 01288 | -01438 | 008730 | 008390 | -00655 | 00877 |
| | ● | 217 | C1 | 00072 | 030340 | -00332 | 00244 | 014970 | 015360 | -03272 | 02930 |
| | ● | 218 | C1 | 00135 | 030150 | 02351 | -02503 | 014810 | 015330 | -01492 | 02200 |
| **Locomotive Backing** | ● | 219 | C1 | -04769 | 053070 | 04749 | -00012 | 030400 | 022660 | -01521 | 02320 |
| | ● | 220 | C1 | -04408 | 074960 | 02349 | 02017 | 038580 | 036380 | -04020 | 04154 |
| | ● | 221 | C1 | -04501 | 052330 | 03248 | 01224 | 026920 | 025410 | -02442 | 02950 |
| | 1 | 222 | C1 | -04104 | 070990 | 03151 | 00918 | 031620 | 039380 | -04297 | 03713 |

Table 7. Exerpt of Real-Time Detector Reports Showing a Car Suspected of Having An Unreleased Handbrake Being Detected in Both Directions of a Yard Move

## 10) CONCLUSIONS AND RECOMMENDATIONS

The stuck brake detector showed in the test that it can detect stuck brakes early. In the short field trial unreleased hand brakes and other detectable brake malfunctions (including inoperative brakes) were observed to escape conscientious visual inspection. With specific improvements for long term unattended use discussed below, the stuck brake detector can provide railroads with a safer operation, reduced equipment loses and lower operating costs.

The only reason the prototype could not perform stuck brake inspection in long term field service was the lack of durability of the rail sensors and installation components. These problems were not evident during the proof of concept test because the traffic volume of revenue service could not be simulated. The necessary durability can be achieved without modification of the concept.

The adhesive bonds at the heavily stressed strain gages of the drag force bridge were the most susceptible to fatigue. About half of the stress was due to the vertical load rather than the longitudinal force. Bending of the railhead portion of the sensor with a wheel mid-span between the vertical posts within the sensor rail imposes an angular deflection on these strain gaged posts. The very large strains in the longitudinal bridge caused by vertical loads are cancelled by the bridge design and do not produce its signal. Making the sensor rail deeper with a stiffer railhead and longer posts will reduce the unproductive strains and improve crosstalk cancellation without reducing the strain sensitivity of the longitudinal bridge. Additional reduction in strain can be made by stiffening the posts and accepting a reduction in sensitivity. Since the sensitivity is extremely high in the present sensor, a reduction would not sacrifice accuracy. The stress can be halved by reducing the stress due to vertical load by the above means coupled with a stiffening of the posts by about 25%. If more space for gage installation is allowed for clamping devices, heat curing epoxy adhesives with superior fatigue properties can also be used.

The installation of the sensor rails with long double joint bars was simple, but it was inadequate for long term use. Figure 12 shows an installation method which reduces the joint bar stress by about a factor of 10 and stiffens the platform to reduce dynamic load fluctuation for reliable wheel presence sensing of unloaded cars. Another advantage of the stiff track is that the effect of very heavy axles approaching the sensor is reduced so that the wheel presence load threshold may also be reduced. About 20 feet of 140 lb rail is used on both sides of the sensors. Heavy spacer plates are welded to the base of the 140 lb rail sections and bolted to an I beam sized for stiffness similar to the rail.

The sensor rail also mounts to the I beam, and the end gaps are fixed by the I beam. The I beam rather than the simple flat joint bars hold the track together. All of the thermal changes are taken at the remote compromise joints (not shown). The I beams for each rail are fastened together by cross beams so that the sensor rail stagger is also constrained to the optimum dimension. The I beams are attached to either conventional cross ties or concrete ties which are buried deeper than the other ties.

This installation can be prefabricated so that only the excavation of about 10 ft of road bed and the establishment of compromise joints is required on site. The substitution of a dummy rail for sensor rail maintenance is very quick because thermal movements, which make fitting bolts to close holes difficult, are eliminated by the I beams. Tamping the hidden ties would be the most unconventional maintenance requirement of the improved installation.

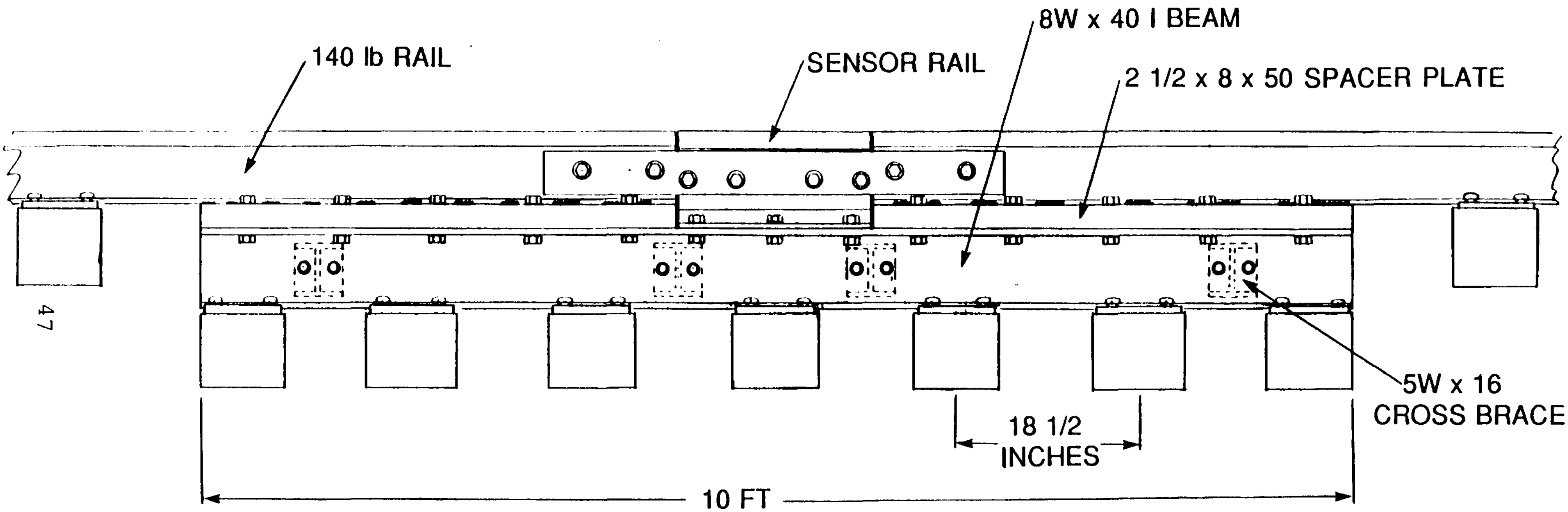


FIGURE 12 -- RECOMMENDED IMPROVED INSTALLATION OF SENSOR RAILS

## 11) POTENTIAL EXTENSIONS OF THE STUCK BRAKE DETECTOR

The same hardware and basic software used for stuck brake detection can perform other useful wayside inspection tasks. Any vehicle condition which can be related to wheel forces can be detected. The stuck brake detection function, in fact, requires much greater measurement precision than most other functions because the accurate determination of the small difference of two larger forces is necessary.

### Brake Force Applications

The reverse of stuck brake detection is inoperative brake detection. The test data in Table 3 for axles 19 and 20, runs 11 through 19, illustrate the detection of this condition by the present system.

### Driving Force Applications

Locomotive driving forces are measured by the stuck brake detector. The axle drive forces were observed to be consistent between axles and proportional to throttle positions and locomotive horsepower. Quality control checking of locomotive maintenance and systematic performance monitoring are possible because deviations from established norms can be spotted by wheel force measurement. The simple sensor rails can make spot measurements usually obtainable only by massive dynamometers.

### Vertical Load Applications

With a suitable foundation 1% accuracy of car weights should be possible up to 25 mph. Single axle weighing is not likely to satisfy the 0.1% accuracy requirement for rate setting measurements, but it can perform safety and maintenance measurement functions. The checking of safe load distributions (side to side and forward and aft), center of gravity height determination by weighing on tangent track with crosslevel, and axle overload detection are likely applications.

## Faulty Truck Detection

The measurement of lateral forces and vertical forces can be used to spot trucks with a variety of faults. Mismatched wheels, dry center pins, and skewed trucks would be expected to produce distinctive patterns of lateral wheel and axle forces. Broken springs would be expected to create detectable patterns of vertical wheel force.

# APPENDIX A

## PERFORMANCE SPECIFICATION FOR STUCK BRAKE DETECTION

### 1.0 GOAL

The goal of a stuck brake detector is to correctly identify the location of axles of a moving train having axle braking drags greater than 375 lb. Its false alarm rate must be less than one false alarm per 10,000 axles, and it must distinguish between probable intentional brake application and random cars with stuck brakes. It must report the information to the locomotive engineer and/or tower dispatcher and it must produce a permanent record. It must be capable of safe unattended operation with zero and gain adjustment intervals of at least three months. The following system and component performance specifications are intended to guide the development of devices to meet the goal. These performance requirements are the result of actual field experience of the detector presented in this report. They are not intended to advocate a single hardware approach within the operating principal of stuck brake detection by direct force measurement.

### 2.0 SYSTEM SPECIFICATION

### 2.1 AXLE DRAG FORCE MEASUREMENT

|  |  |  |
|---|---|---|
| 1. | Range: | ± 8,000 lb |
| 2. | Accuracy: | ± 90 lb for free rolling axle<br>± 100 lb up to 600 lb<br>± 200 lb up to 1,500 lb |
| 3. | Repeatability: | standard deviation of 75 lb or less based on a sample of at least 2,000 measurements in the range of vertical loads and speeds typical of the particular installation. |

## 2.2 VERTICAL FORCE MEASUREMENT (Minimum Characteristics to Permit Correction of Crosstalk Influence on Drag Force Measurement)

| | | |
|---|---|---|
| 1. | Range: | 0 to 50,000 lb wheel force |
| 2. | Accuracy: | within 10% for mean of ten repeated measurements of the same car |
| 3. | Repeatability: | within 10%, maximum range between ten repeated measurements of the same car |

## 2.3 LATERAL FORCE MEASUREMENT

Not required if the cross talk influence of lateral force on longitudinal force measurements is less than 1% of the applied lateral force.

## 2.4 TRAIN SPEED RANGE FOR STUCK BRAKE DETECTION

2-25 mph

## 2.5 MINIMUM REPORT BY RADIO LINK

- Location of stuck brake detector.
- Direction of travel of train tested.
- Total number of axles.
- Locations of axles with stuck brakes.
- Range of axle numbers with probable intentional brake application
- Acknowledgement of no alarms occuring.
- Acknowledgement of invalid test.

## 2.6 MINIMUM HARD COPY STUCK BRAKE REPORT

A listing of each axle separated by train showing:

- Date and Time of Test

- Announced Direction
- Announced Alarm Status
- Net Axle Drag or Traction Force
- Individual Wheel Drag Force
- Individual Vertical Wheel Loads
- Date and Time of Test

## 2.7 TEMPERATURE AND DRIFT COMPENSATION

| | | |
|---|---|---|
| 1. | Maximum uncompensated drift in:<br>in three months | 50 lb drag<br>1000 lb vertical |
| 2. | Maximum reduction in range due:<br>due to compensation | 10% of full scale |

## 2.8 SAFETY AND DURABILITY

1. Infinite fatigue life for sensor rail and support assembly for 50 kip wheel loads (vertical), calculated with sensor rail assembly and load centered over ties 40 inches apart. (This conservitively assumes three ties without significant support from the center tie).

2. Fail safe retention of sensor rail head in the event of fracture of the instrumented web structure.

## 3.0 <u>COMPONENT SPECIFICATIONS</u>

### 3.1 INSTALLATION OF SENSOR RAILS

1. Tangent track for at least 100' on either side.

2. Less than 1/4" crosslevel.

3. Track grade level to within .05° for ten feet with the sensor rails centered.

4. 1-1/2" ± 1/4" stagger between sensor rails to assure direction determination at 25 mph.

5. Ballast tamped to prevent vertical track movement greater than 3/8" with approximately 35,000 lb wheel load.

6. The support structure must be stiff enough that a 50,000 lb wheel load applied 3" ahead of the sensor rail causes a vertical force output of less than 1,000 lb.

### 3.2 SENSOR RAIL

#### 3.2.1 <u>CONSTRUCTION CHARACTERISTICS</u>

1.1 Infinite fatigue life of sensor rail body and instrumentation (including strain gage adhesive) for a combined 50 kip vertical load and 5 kip reversing longitudinal load.

1.2 Water proofing against emersion (with cable connected)

1.3 Active length of at least 18".

1.4 Attachment bolts accessible from top and sides.

#### 3.2.2 <u>CALIBRATION CHARACTERISTICS</u>

The force measurement of a moving wheel will be processed during stuck brake detection as a series of samples taken with the wheel contact point moving longitudinally from one end of the sensor rail to the other with a constant flange clearance. The force samples along the sensor rail are averaged as the first processing step. Consequently the calibration loadings are made at one inch intervals on the rail along various paths representing different flange clearances. Unless stated otherwise a calibration characteristic refers to the average of measurements along a particular path. The basic calibration paths are along the center of the rail and paths displaced one inch laterally to either side of the center path.

### 3.2.2.1 Longitudinal Force

| | | |
|---|---|---|
| a. | Overall Sensitivity: | 1.25 volt/kip or greater amplified with a gain less than 1250 (this would be the equivalent of about 200 $\mu\varepsilon$/kip bridge strain) |
| b. | Repeatability: | within 1% for ten 5000 lb loads |
| c. | Linearity: | within 50 lb to 5000 lb, 80 lb to 8000 lb |
| d. | Lateral Load Point Sensitivity: | less than 1%/per inch from center point at 5000 lb |
| e. | Hysteris: | less than 25 lb following combined load of 25,000 lb vertical and 5000 lb longitudinal |

Note: Limiting the crosstalk influence of the very large vertical loads on the measurement of the much smaller longitudinal loads is the most crucial element of the design of sensor rail. In order for the crosstalk correction data processing to sufficiently eliminate crosstalk, the raw crosstalk must be very small and uniform over the range of wheel/rail contact points. A vertical load of at least 25,000 lb should be used to evaluate vertical crosstalk.

| | | |
|---|---|---|
| f. | Vertical Force Crosstalk: | less than 1% of vertical load before correction; less than .1% after correction. |
| g. | Repeatability of Vertical Crosstalk: | within 0.1% of vertical load. |
| h. | Lateral Load Point Sensitivity of Vertical Crosstalk: | less than 0.1% from center. |

| | | |
|---|---|---|
| i. | Variability of Individual Vertical Crosstalk Measurements Along a Longitudinal Path: | less than 1% of vertical load. |
| j. | Lateral Force Crosstalk | less than 1% of lateral force or 25 lb. |

### 3.2.2.2 Vertical Force

| | | |
|---|---|---|
| a. | Overall Sensitivity: | 0.2 volt/kip or greater amplified with a gain less than 3000 (equivalent to about 15 $\mu\varepsilon$/kip bridge strain). |
| b. | Repeatability: | within 1% for ten 25,000 lb load. |
| c. | Linearity: | within 1% of full scale. |
| d. | Lateral Load Point Sensitivity: | less than 1%/in from center path |
| e. | Crosstalk: | Uncorrected crosstalks up to 10% of applied longitudinal force and 10% of applied lateral force are tolerable because the vertical load is so much larger than the lateral and longitudinal. |

### 3.2.2.3 Lateral Force

If calibration loads indicate that lateral force crosstalk influences are less than 10% on vertical force measurement and less than 1% on longitidinal force measurement, the sensor rail does not require a lateral force channel.

## 3.3 ANALOG SIGNAL CONDITIONING

1. Excitation Voltage

| | | |
|---|---|---|
| 1.1 | amplitude: | 10v to 15v dc |
| 1.2 | output current: | 100 ma max |
| 1.3 | regulation: | 0.05%/V |
| 1.4 | output voltage to supply: | 0.05%/V |
| 1.5 | load regulation (1 ma to 50 ma): | 0.1% |
| 1.6 | temperature stability: | .015%/C$^{o}$ max |
| 1.7 | output noise: | 1 mV rms |

2.2 gain nonlinearity: .01% max

2.3 gain temperature stability: .0025%/C$^{o}$ max

3. Anti-aliasing Filtering

3.1 type: 3 pole bessel

3.2 corner frequency: 75 Hz

4. Thermal Rail Force Compensation

4.1 Theory: The 75 Hz amplified force signal (vertical or lateral depending on channel assignment of circuit card) is input to three circuit paths. The first path creates a steady reference signal by low pass filtering at a very low frequency. The second path creates a trigger signal by high pass filtering at a low frequency. The third path freezes the reference signal upon a trigger signal exceeding a threshold and subtracts the reference signal from the 75 Hz force signal. If the trigger signal has not been refreshed by a wheel pulse during a set delay time, the reference signal is allowed to follow the force signal again.

4.2 reference signal filter: 0.05 Hz low pass 2 pole

4.3 trigger signal filter: 0.65 Hz high pass 1 pole

4.4 wheel pulse refresh delay: 11 sec

4.5 trigger signal threshold: 300 lb lateral
2000 lb vertical

## 3.4 DIGITAL SIGNAL PROCESSING

1. A/D Converter

1.1 Resolution: 10 bits minimum

1.2 Sample Rate: 500 samples/sec per channel

2. Computer Hardware

2.1 Type: single board STD bus 8088 16 bit microprocessor

2.2 Memory: 8K RAM minimum
5K ROM minimum for program storage

| | |
|---|---|
| 2.2 Memory: | 8K RAM minimum<br>5K ROM minimum for program storage |
| 2.3 Coprocessor: | 8087 floating point numerical coprocessor |
| 2.4 Output: | parallel port configured to drive printer<br>memory mapped 8 bit relay card to drive talker |

3. Computer Software

| | |
|---|---|
| 3.1 General Features: | reset on power up to recover from power interruptions |
| 3.2 Language: | 8086 Assembly language for speed of execution |
| 3.3 Optimization Strategy: | Processor continually samples tests for presence of a wheel. It stores all rail force channel samples only when wheels are on sensor rails. It computes and stores all average wheel/rail force channels in less than 100 ms to free up memory to collect the samples of the next axle. As soon as the train passes it examines the pattern of drag forces to determine intentional brake application, and reports by means of a 'talker' and a printer. |
| 3.4 Flowchart: | Figure A-1 summaries the processing logic. |

### 3.5 OUTPUT DEVICES

| | |
|---|---|
| 1. Voice Synthesized Talker: | hot box detector talker such as units manufactured by SAB HARMON INDUSTRIES or SERVO CORP programmed for messages listed in Table 8. |
| 2. Printer: | standard parallel printer for PC compatible computers. |

# STUCK BRAKE DETECTOR PROGRAM

## FLOW CHART

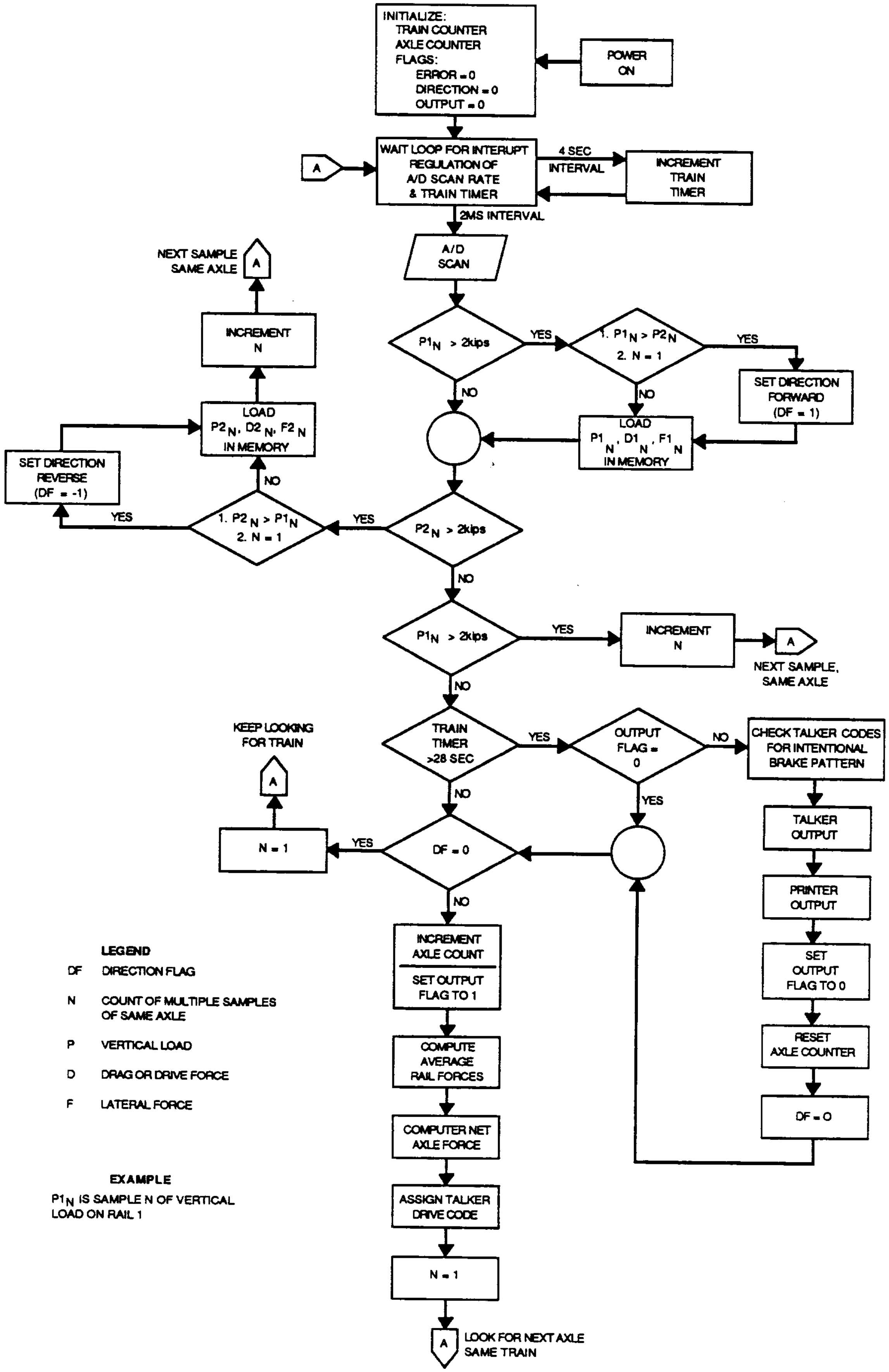


Figure A-1

## TABLE A-1
## TALKER VOCAUBLARY AND FORMAT

### ---*** END OF TRAIN ***---

| CONDITION | (MESSAGE SPOKEN) |
|---|---|
| (A) SITE IDENTIFICATION | "xxxxx RAILROAD, LOCATION xx"<br>"STUCK BRAKE DETECTOR"<br>"TRACK 1(2)" (switch selectable)<br>MILEPOST zxxx POINT z"<br>where z is switch selectable to 1,2,3 or nothing at all (0).<br>"dd TRAIN WITH xx AXLES"<br>where dd is "NORTHBOUND", "SOUTHBOUND", "EASTBOUND", OR "WESTBOUND". |
| (B) NO DEFECTS WITH GOOD INTEGRITY | SITE I.D.<br>"NO STUCK BRAKES DETECTED"<br>"DATE mm dd yy"<br>"TIME hh mm AM(PM)" |
| (C) WITH DEFECTS AND GOOD INTEGRITY - NO INVALID TEST ALARM | SITE I.D.<br>"FIRST (second,third..) STUCK BRAKE, AXLE xxx"<br>"BRAKES APPLIED AT AXLE xxx"<br>"BRAKES RELEASED AT AXLE xxx"<br>"FIRST (second,third..) OVERLOAD, AXLE xxx"<br><br>Message will be announched to the maximum set by switch S3 on the speech board. If there are more messages than the maximum allowed, "MORE FAULT MESSAGES" will be annunciated. |
| (D) WITH DEFECTS AND GOOD INTEGRITY - INVALID TEST ALARM | SITE I.D.<br>"INVALID TEST"<br>"DATE mm dd yy"<br>"TIME hh mm AM(PM)" |
| (E) NO DEFECTS WITH BAD INTEGRITY | SITE I.D.<br>"INTEGRITY FAILURE"<br>"DATE mm dd yy"<br>"TIME hh mm AM(PM)" |
| (F) WITH DEFECTS AND BAD INTEGRITY | Same as (D) |