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of Transportation

**Federal Railroad
Administration**

INFLUENCE OF CONTACT PATCH RESISTANCE ON LOSS OF SHUNT AT HIGHWAY-RAILROAD GRADE CROSSING

**Office of Research and
Development
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Final Report

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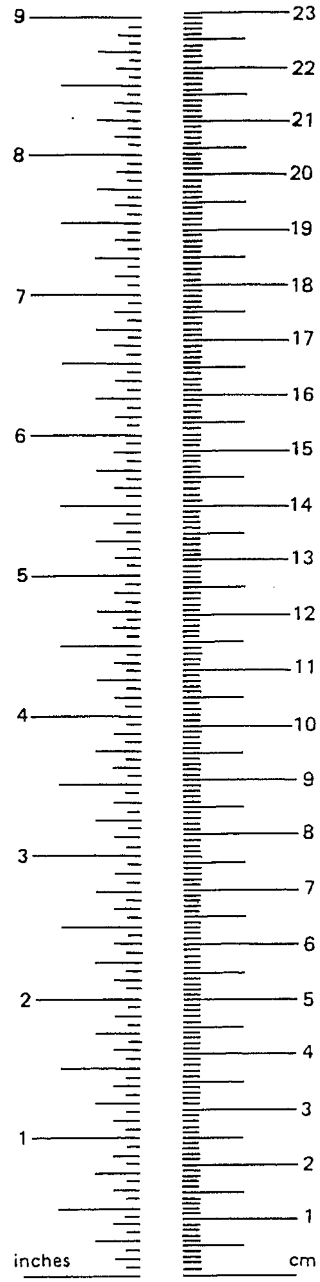
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

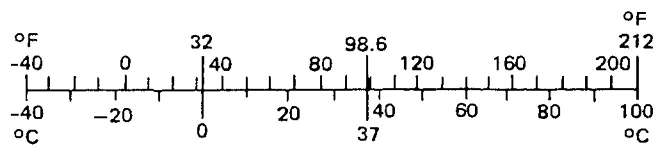
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.50	centimeters	cm
ft	feet	30.00	centimeters	cm
yd	yards	0.90	meters	m
mi	miles	1.60	kilometers	km
		AREA		
in^2	square inches	6.50	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.80	square meters	m^2
mi^2	square miles	2.60	square kilometers	km^2
	acres	0.40	hectares	ha
		MASS (weight)		
oz	ounces	28.00	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.90	tonnes	t
		VOLUME		
tsp	teaspoons	5.00	milliliters	ml
Tbsp	tablespoons	15.00	milliliters	ml
fl oz	fluid ounces	30.00	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.80	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* 1 in. = 2.54 cm (exactly)



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.40	inches	in
m	meters	3.30	feet	ft
m	meters	1.10	yards	yd
km	kilometers	0.60	miles	mi
		AREA		
cm^2	square centim.	0.16	square inches	in^2
m^2	square meters	1.20	square yards	yd^2
km^2	square kilom.	0.40	square miles	mi^2
ha	hectares (10,000 m^2)	2.50	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.10	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36.00	cubic feet	ft^3
m^3	cubic meters	1.30	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius° temperature	9/5 (then add 32	Fahrenheit temperature	°F



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16. Abstract

Results of testing completed to date have revealed no promising mitigation techniques to reduce or eliminate loss of shunt on highway/rail grade crossing island circuits. During the course of this test program, results have shown that resistive films that develop on the running surfaces of wheels and rails are a major contributor to loss of shunt. Some untested mitigation techniques, however, have been developed recently and may offer an effective long-term solution for removing these resistive films.

This phase of testing was based on results of the field monitoring effort performed at eight field locations throughout North America by the Association of American Railroads, Transportation Technology Center, Pueblo, Colorado, to document statistical occurrences of loss of shunt (interim report titled "Influence of Contact Patch Resistance on Loss of Shunt,"August, 1993).

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EXECUTIVE SUMMARY

Results of testing completed to date by the Association of American Railroads (AAR), at the Transportation Technology Center, Pueblo, Colorado, have revealed no promising mitigation techniques that can be recommended to reduce or eliminate loss of shunt on highway/rail grade crossing island circuits. Loss of shunt is a temporary lack of electrical continuity between train wheels and rails, evidenced by a brief deactivation of flashers or gate arms, while passing trains are still occupying highway grade crossings. During the course of this test program, results have shown that resistive films that develop on the running surfaces of wheels and rails are a major contributor to loss of shunt. Some untested mitigation techniques, however, have been developed recently and may offer an effective long-term solution for removing these resistive films.

Chemical analysis of resistive films taken from revenue service shows that both rail and wheel film samples exhibit similar trends in chemical makeup. The two major components of the films are silicon in oxide (Si) and iron as oxide (Fe). Rail samples show a higher iron as oxide content and a lower silicon in oxide content than the wheel samples. This is most likely due to the differences in environmental exposure — rails being stationary and wheels rolling.

Dynamic contact patch resistance testing, performed on the AAR's railroad wheel dynamometer, shows that sporadic loss of shunt occurrences can be created in a laboratory environment. However, these occurrences were difficult to control, sustain, or repeat. Film samples taken from the laboratory test were different than those collected from numerous field site locations, both physically and in degree of chemical composition. The highest level and most frequent shunt loss occurred with a non-conformal brake shoe (where the brake shoe wear surface did not fully conform to the wheel tread profile

surface). Although films that are representative of what exists in revenue service were not able to be developed during the initial testing, it is felt that with extended running, films more like those seen in the field could be developed.

In limited testing, a whetting current reduced the number of loss of shunt occurrences. However, limited data and a short test duration prevents strong conclusions being drawn as to the overall effectiveness of a whetting current being a long term solution.

Data results from the wheel/axle/wheel resistance study indicates that resistance through a solid axle is not a significant contributor to loss of shunt. As a result of this study, the AAR C&S Division has proposed a recommendation for maximum allowable wheel to wheel resistance that applies to solid and split axle railroad cars.

For determining the pressure/resistance relationship, attempts were made at developing a small portable device for measuring resistive films on rail and wheels in the field. The attemps were unsuccessful in that field measurements obtained using this device were unstable and inconsistent. However, a full scale device set up in a laboratory showed a distinct relationship between pressure and resistance. The higher the pressure, the lower the resistance. In support of these findings, it was shown during field site monitoring that heavier railroad cars tend to provide a better shunt.

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1.0 INTRODUCTION

Both the railroad signal community and the grade crossing equipment suppliers have reported an increase in the occurrence of loss of shunt (LOS) on railroad grade crossing island circuits. Loss of shunt is a temporary lack of electrical continuity between train wheels and rails, evidenced by a brief deactivation of flashers or gate arms, while passing trains are still occupying highway grade crossings. A preliminary evaluation and monitoring at eight field locations throughout North America was conducted by the Association of American Railroads (AAR), Transportation Technology Center (TTC), Pueblo, Colorado, to document statistical occurrences of LOS. This was reported in the interim report titled "Influence of Contact Patch Resistance on Loss of Shunt," as part of FRA Task Order 106, issued in August, 1993.

Data from the field monitoring phase of this program indicated that occurrences of LOS severe enough to cause release of the island relay were very rare. Monitoring over six months at the eight field locations resulted in 46 trains out of over 10,000 exhibiting a LOS leading to island relay release. Release of the island relay could, in certain cases, result in gate bob or intermittent operation of warning devices, even if the train is still occupying the crossing. A number of field conditions were also monitored during this period, such as evaluations of films, rail condition, and other environmental concerns.

Technical direction for this task order was provided by the AAR Cmmunications and Signal Section (C&S), Committee D, Highway Grade Crossing Warning Systems, Track Circuit Parameters Task Force. Based on results of the field monitoring data, a number of follow-on evaluations and tests were recommended by the Task Force. These evaluations were intended to provide better understanding of conditions leading up to or increasing the tendency for rail equipment to lose shunt within island limits.

2.0 OBJECTIVES

The objectives of this phase of the task order were based on results of the field monitoring effort. The objectives were focused on obtaining a better understanding of causes of LOS and to investigating possible solutions.

The objectives were as follows:

- Evaluate effectiveness of a "whetting current" in reducing or eliminating LOS.
- Determine if portable measurement systems could be designed to allow field evaluation of wheel and rail conditions leading up to LOS.
- Perform full scale laboratory wheel/rail dynamic contact patch simulations to determine contribution of brake shoes, brake application cycles, and various contaminants that might contribute to conditions leading up to LOS.
- Evaluate films created in various laboratory simulations of the wheel/rail contact system, and compare these films to those collected at field sites.

3.0 PROCEDURES

This final report addresses follow-on action items suggested in the conclusions and recommendations stated in the interim report, which reported on field monitoring efforts. Loss of shunt data from field monitoring was used to specify the following:

- Locations where films were to be collected
- Location where the whetting current should be evaluated
- Determine contaminants to be used in the laboratory test

Each of the objectives was monitored and conducted separately; however, in some cases two or three objectives were addressed concurrently. For example, field sites were evaluated for film resistance at the same time film samples were taken for laboratory tests.

A major delay occurred in the brake shoe testing due to unavailability of the test fixture. For this reason, the next phase of this task order, which was to evaluate alternative detection technologies, has already been started. Although the follow-on efforts are funded under the same task order and there is an overlap in scheduling, the alternative detection system program is under technical direction of a different industry task force and has different objectives. Therefore, this report will not include results of the alternative detection technology test phase.

4.0 EVALUATION OF WHETTING CURRENT

Results of the extended field monitoring period performed in the initial field site investigation (documented in an interim report) indicated that the Sterling, Nebraska, sites had a relatively high incidence of LOS. At the recommendation of the Task Force, this site was selected for long-term monitoring to determine the effectiveness of a whetting current.

A whetting current is a circuit that overlays the existing island circuit and is designed to enhance shunting performance of wheels entering the island. The whetting current was activated only after the island relay became deactivated. It was not designed to increase shunting performance of the wheels prior to entering the island limit. Once activated, however, the whetting current performance was intended to prevent shunt loss of the island control current by providing a path through contamination or other surface films. Its intent is to reduce or eliminate electrical obstructions in the island control current flow path.

Restart of monitoring efforts at Sterling was delayed due to flooding which occurred earlier in the year. As films leading to LOS might have had seasonal variations, the intent was to monitor the site for an extended period of time, periodically activating and then deactivating the whetting current operation.

Analysis included statistical comparisons of LOS history between periods when the whetting current was active or not, as well as comparisons of a nearby (1 mile) site on the same track that was not equipped with any enhancements.

4.1 STERLING SITE LAYOUT

The Sterling sites remained the same as that reported in the interim report, a single track railroad, with bi-directional traffic. Coal loads travel eastbound, while occasional unit grain trains travel westbound. Some mixed freight traffic is also present.

Two actual road crossings were selected for monitoring:

- Site H (east end of Sterling)
- Site G (west end of Sterling)

In addition, an auxiliary island circuit, site R, was installed adjacent to site H, just east of the island limits. Site R was selected during the extended monitoring phase to determine if LOS performance was different adjacent to the crossing (where no road traffic was present) than at the crossing itself. Note that rail shape and profile was also different between site R and sites G and H. Standard production grinding machines usually cannot grind though road crossings. Rail through road crossings is thus often not ground unless the use of a spot (switch) grinder is made. The Task Force requested that rail through the crossing not be ground for the duration of this test to allow for evaluation of varying profile.

4.2 RESULTS

Table 1 and Figure 1 summarize results of the limited monitoring period. The test was suspended due to the limited budget for this task and because the site was selected for future evaluation of alterative detection systems, which would also include a whetting current technology.

Table 1. Summary of LOS Occurrences at Sterling, Nebraska

	Before			During			After		
	Total	Occur.	Percent	Total	Occur.	Percent	Total	Occur.	Percent
Site G	454	28	6.2%	389	31	8.0%	302	16	5.3%
Site H	449	22	4.9%	389	0	0.0%	302	1	0.3%
Site R	N/A	N/A	N/A	389	23	5.9%	302	25	8.3%

The whetting current test was performed between July 20 and September 24. During the period when the whetting current was activated, no occurrences of LOS were recorded. During the period immediately after the whetting current was deactivated, the same island (site H) reported only one occurrence of LOS. This should be compared to over 20 occurrences of LOS for a similar number of trains during the period just before the whetting current was activated. The site located 1 mile away (site G), where no whetting current was ever installed, performed about the same during all three periods. Note that site R indicates N/A for first monitoring period, due to an equipment malfunction.

Field data did not contain indications explaining why the primary monitoring site (site H) behaved so differently immediately after deactivation of the whetting current. There did not appear to be any significant "micro seasonal" effects during the period; that is, LOS occurrences at the other sites (G and R) were relatively evenly spaced throughout the test period.

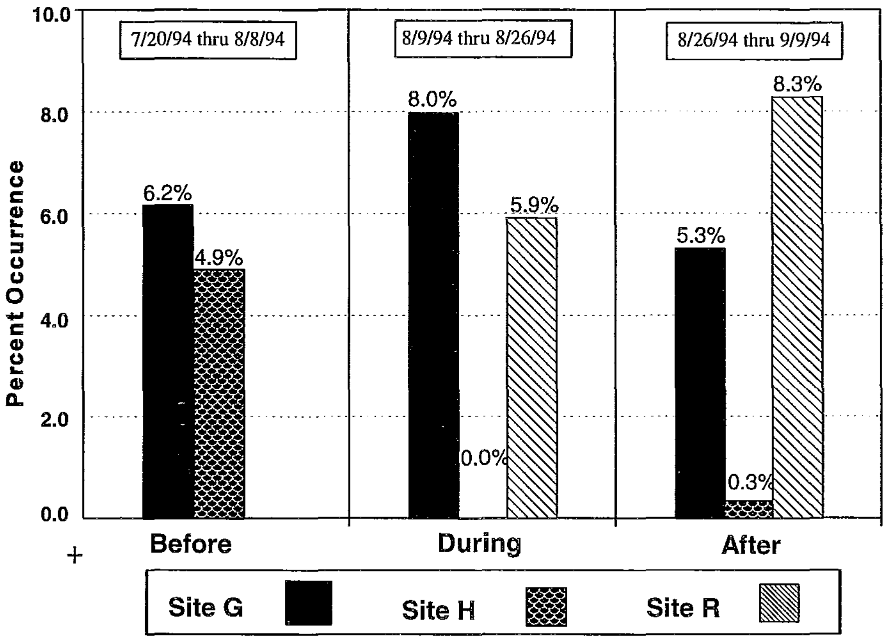

Figure 1. Percentage of LOS Occurrences

4.3 OBSERVATIONS

Based on the limited test period, the following observations are drawn from the test data:

- No LOS occurrences were recorded while the whetting current was active.
- Limited data and test duration prevents strong conclusions.
- Extended monitoring to eliminate seasonal changes and short term influences is suggested.
- Lack of site H returning to anywhere near its pre-whetting current performance makes results of this limited test questionable; although , it may be that application of the whetting current modified the oxide layer to form a better conductor

5.0 ELECTRICAL SHUNT PATH ENVIRONMENT

In order to better understand the total shunt environment, as well as determine if specific locations along the shunt path contributed significantly to LOS, a series of measurements were made to determine:

- Wheel-to-wheel resistance through the axle
- Electrical resistance of the film at various locations across the top running surface of the rail
- Durability of the film/change in electrical resistance under various contact pressures

5.1 WHEEL/AXLE/WHEEL RESISTANCE

The Task Force requested wheel/axle/wheel resistance information to determine typical ranges of resistances from one wheel, through the axle, to the other wheel. As wheel mounting procedures have changed with time (for example, the use of lead as a lubricant to assist in the wheel pressing process has been eliminated), there was a concern that some wheel sets might have higher than desirable resistances.

Also, such data could be used to provide "target" wheel-to-wheel resistances for new equipment being considered. For example, some equipment with independently rotating wheels is being evaluated for introduction into revenue service; because that equipment does not use a solid axle, wheel-to-wheel resistance might be significantly higher with no direct electrical path being provided. This data could also be used for proposed track circuit models that might simulate various components within the shunting path. A total of 140 wheel sets were measured for this task.

5.1.1 Measurement Apparatus

The TTC Instrumentation Calibration Laboratory provided a precision Kelvin bridge resistance meter that is suitable for making low-value resistance measurements. The Kelvin bridge device uses four input terminals which nullifies wire lead and contact resistances. The particular device used in this study was the Biddle model 72-439 portable Kelvin bridge with a measurement range of 0.01 micro-ohm to 1111.1 ohms in seven ranges. The error limits, as specified by the manufacturer, are +/-0.03 percent of reading +0.03 micro-ohm.

Two special C-clamps were fabricated so that they would attach between the back rim and field face of each wheel. Each clamp was electrically isolated in halves so that each area of contact was separate. The isolation was provided by a nylon bushing between the threaded drive and the pressure plate (see Figure 2).

The Kelvin bridge device was calibrated with the fabricated cables and modified clamps to assure accurate measurements.

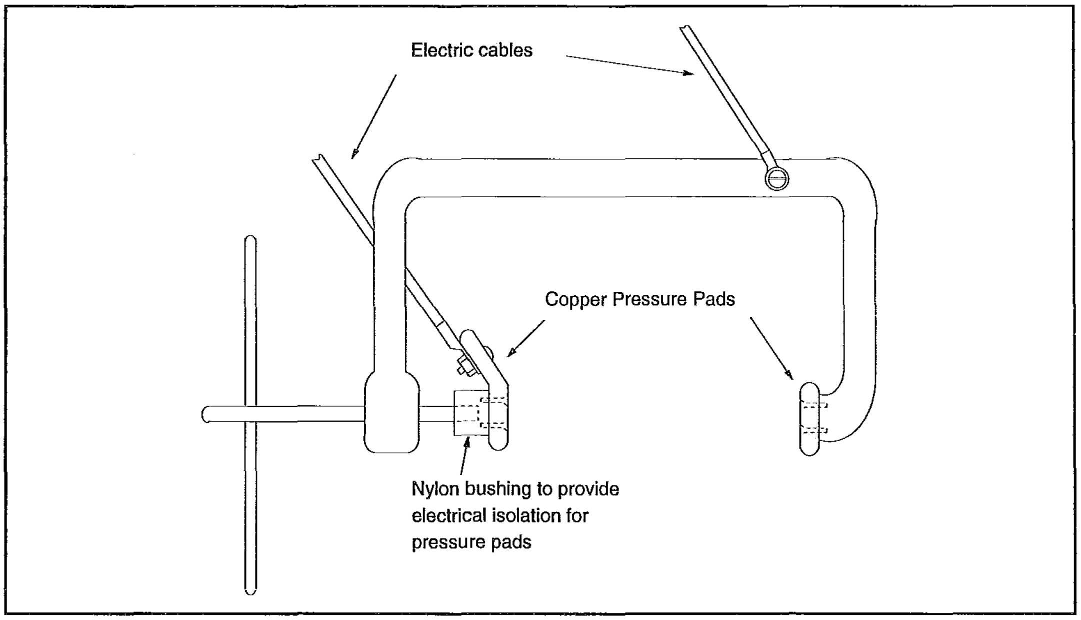

Figure 2. Modified C-clamp

5.1.2 <u>Data Acquisition</u>

During the latter part of May, 1993, measurements were taken of 126 varying wheel sets captive at TTC. It is important to note that these wheel sets *may* or *may not* have run in revenue service. All wheel sets measured were removed from trucks and isolated from any external shunting effects. This was achieved by resting both wheels on insulating rubber pads. Each wheel set was prepared for measurement by grinding the area of surface contact with an electric grinder on both sides of each wheel. This was necessary to warrant against surface contaminants, namely rust (Figure 3).

The Biddle meter has the capability of reversing polarity when obtaining measurements. Data was taken of both positive and negative applied voltage stimulus of each wheel set measured.

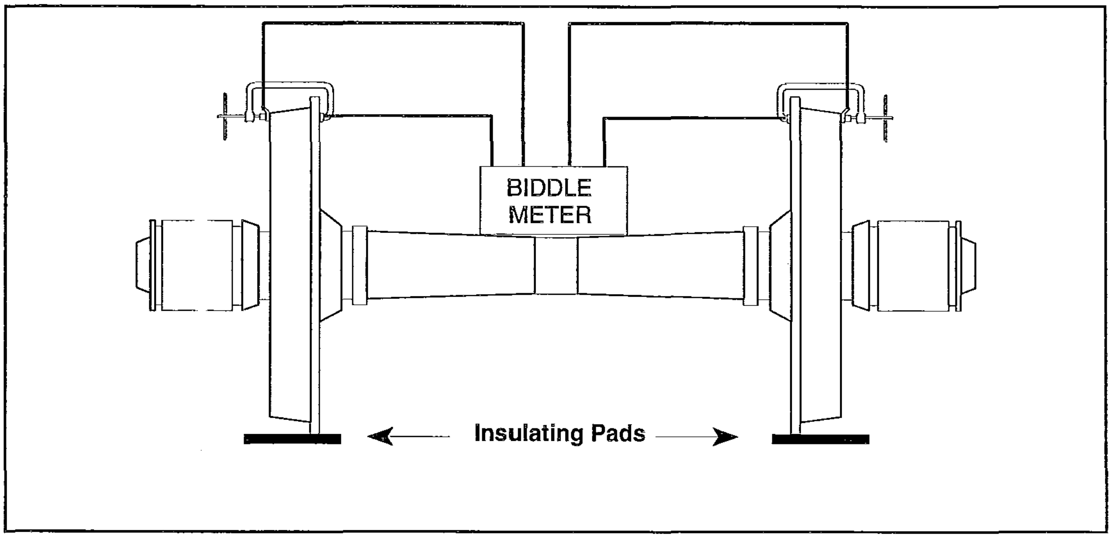

Figure 3. Wheel/Axle/Wheel Measurement

The remaining 14 wheel set measurements were obtained from revenue service. The same procedures of isolating the wheel sets and surface grinding were followed as those mentioned above.

5.1.3 Results

Data results of this study indicate that the resistance of a typical wheel set, as measured from wheel through axle to wheel falls in the micro-ohm range (Figure 4).

The frequency distribution of the data shows that all measured wheel sets fell within the 14 to 20 micro-ohm range, with the exception of one wheel set which measured in the 8 micro-ohm range.

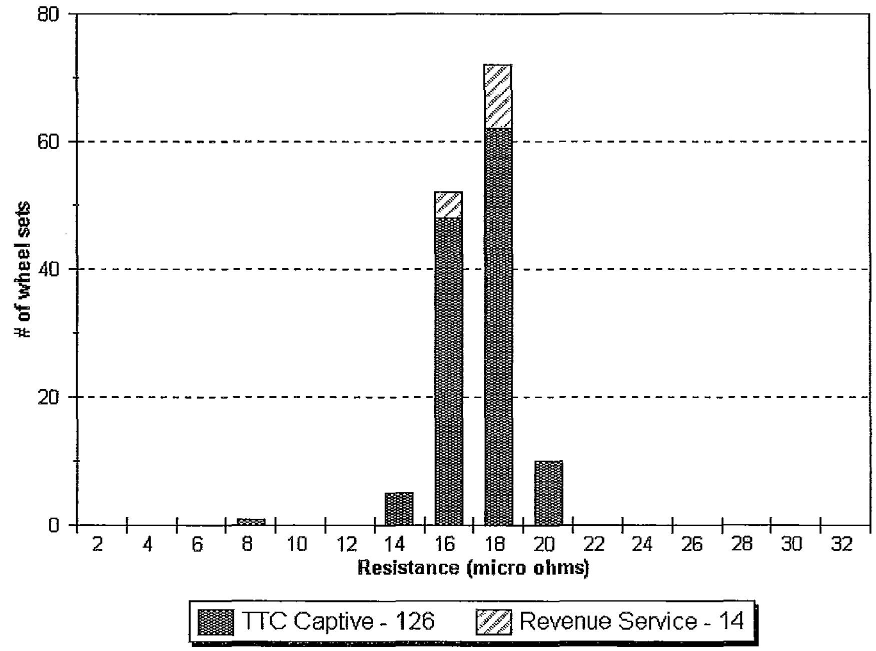

Figure 4. Wheel/Axle/Wheel Resistance Measurements

5.1.4 Conclusions

Data results from this study indicate that the resistance of wheel sets, as measured from wheel through axle to wheel, does not appear to contribute to LOS. This is based on solid axle wheel sets measured from typical freight railroad service and does not include independent rolling wheel configurations.

The measured resistances measured are well below values needed to cause intermittent shunt loss on AC track circuits.

As a result of this study, the AAR C&S Division has proposed a recommendation for maximum allowable wheel to wheel resistance (refer to Appendix A).

5.2 FILM RESISTANCE

During the extended field monitoring period, occurrences of LOS appeared to be significantly higher when light or empty car trains were passing. This was especially noted at the Sterling and Gothenburg, Nebraska, sites, where empty coal trains could be occasionally identified by special car tracking efforts. Car weights for unit train service have been reduced (by use of aluminum bodies, for example) during the past few years. A means of determining at what contact pressure rail films on the top running surface would breakdown their electrical resistance was desired.

The location on the rail of the highest resistance was desirable. Although some films were visible as a dark black or grey band, some were virtually transparent. A means of mapping where the film was most resistive would help determine what wheel/rail profile combination might lead to LOS. This could provide information as to remedial rail grinding shapes that would inhibit LOS.

Two measurement devices were designed and fabricated, one for measuring resistance under varying contact pressure, the other for determining resistance across the top running surface of the rail. These devices were evaluated at the TTC, and limited field data was subsequently collected; however, results were insufficiently repeatable to allow use in subsequent tests.

5.2.1 Rail Film Electrical Resistance Meter

To determine the location on the railhead of highest resistance, a rail film electrical resistance meter (RFERM) was designed and fabricated by Safetran, a member of the Task Force. The RFERM allows measurements of resistance, calculated from voltage and current measurements, to be made with a multiple pin fixture. Pins applying a light pressure are arranged across the top of rail, spaced at approximately 0.25-inch intervals (Figure 5).

Resistance is measured between each pin and the rail material. Each pin is measured separately, with an automatic control system designed by Safetran engineering staff to sequence across the railhead.

5.2.1.1 Results

Multiple readings at the same point (without moving the clamp) were very repeatable; however, multiple readings in the same vicinity on the top of rail using the RFERM were not repeatable. A wide range of resistances was recorded during repeated readings along a short distance of the rail. The RFERM appears to be adequate for indicating whether a resistive film is present, but the value may not represent true resistance.

The RFERM provided insufficient resolution between different locations to allow data to be useful. One problem may have been that the pins disturbed the film (by micro scratching), thus altering the data. Ensuring that all pins were clean for each measurement was also difficult.

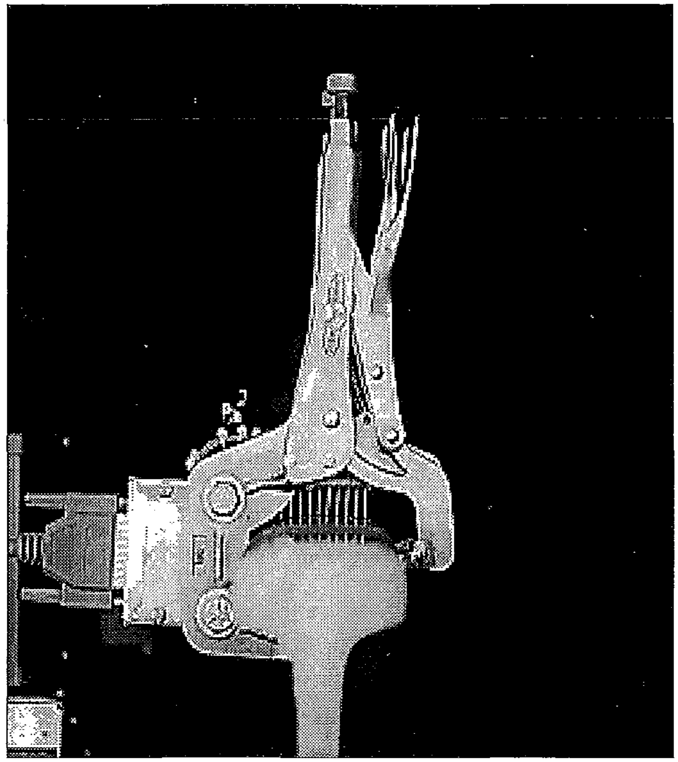

Figure 5. RFERM

5.2.2 Variable Pressure Electrical Resistance Meter

TTC designed and developed a variable pressure electrical resistance meter (VPERM) to permit measurements of rail film resistance as a function of varying pressure (see Figure 6). The VPERM clamps on the head of the rail and allows the test head to be lowered on the top of the rail. The test head is made from cut sections of cylindrical shaped steel bars. Three test heads were fabricated, each with a different radius (½", ¾", 1"), such that they could be interchanged easily.

The concept of the VPERM was to have the test head serve as a positive lead or probe which contacts the film while the negative lead is attached to the rail by a magnet on a surface that had been cleaned using an electric grinder to assure a good grounding surface contact. Measurements were taken using a Philips RCL meter. This particular meter is a four wire device that can measure both resistance

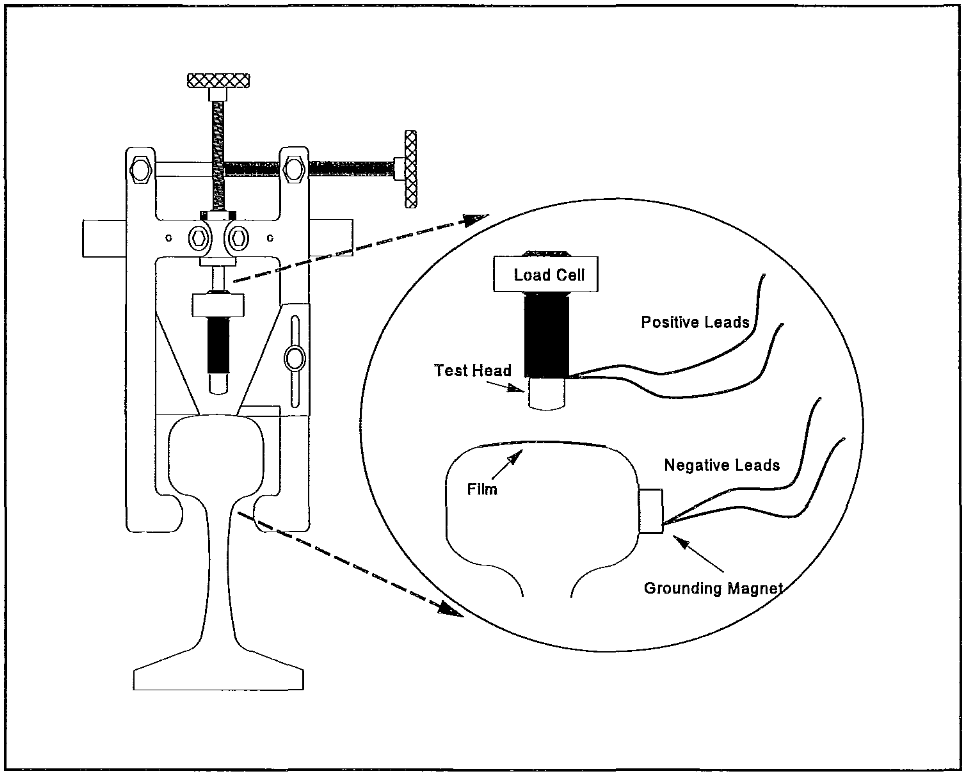

Figure 6. Portable VPERM Fixture

and reactance in DC and AC modes respectively. Resistance measurements for this test were taken using the DC mode. The Philips RCL meter also has a trim feature which allows for open and short circuit testing for the purpose of nullifying lead resistances.

Initial results indicated some variability of resistances. Concern was raised about the VPERM being able to accurately replicate the wheel/rail contact patch conditions. An audit with a previously utilized test fixture designed by Canadian National Railway was proposed.

5.2.2.1 Canadian National Audit

On July 5, 1994, Transportation Technology Center (TTC) personnel traveled to Montreal, Quebec, in an effort to audit the ability of VPERM to measure rail film resistance. This audit was based on the comparison of the VPERM against the results of a full-scale apparatus designed by Canadian National Railroad

(CN), which also measures the resistance of the film between the wheel and rail.

The results of this comparison showed that the VPERM device, in its current configuration, does not provide accurate nor consistent results in measuring film resistance due to the size of the test head probe. The CN device does, however, give consistent results and indicates a linear relationship between pressure and film resistance. CN conducted its own test, allowing observation by TTC personnel. CN provided TTC with its test data for the purpose of establishing a relationship with the VPERM results. Figure 7 shows the test circuit of the CN full scale setup.

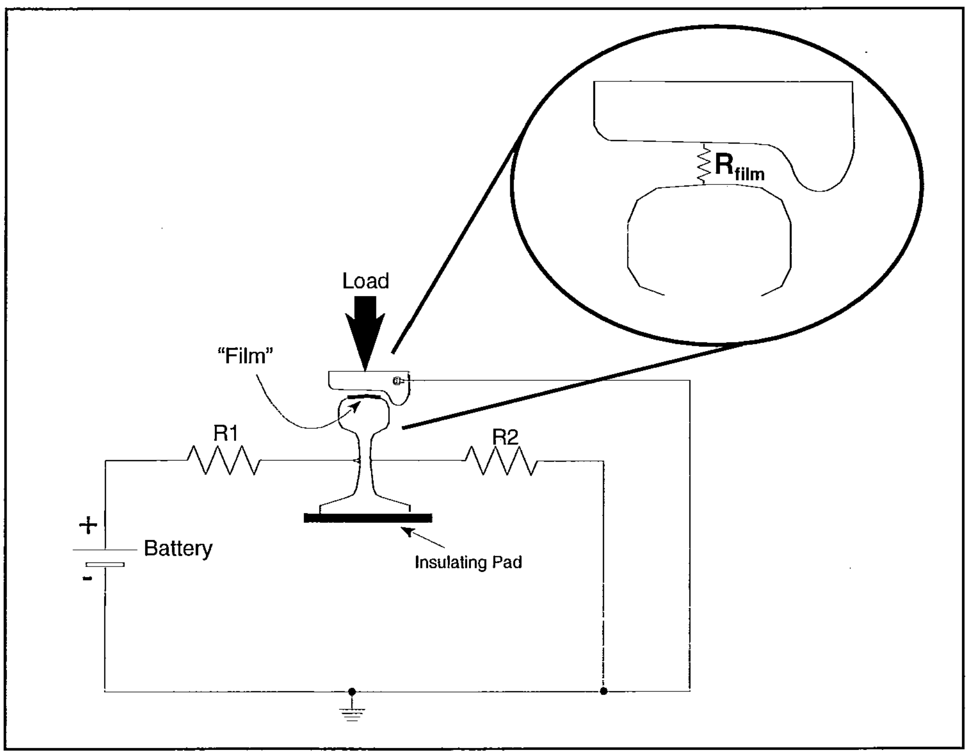

Figure 7. CN Full Scale VPERM Setup

Measurements were taken of voltage across resistors R1 and R2 (Figure 7). From basic electronic principles, current, voltage and resistance of the film were calculated. The test was conducted using a single cell and a double cell Ni-Cad battery. Three different rail samples were examined (1) an extremely rusty rail, which had been exposed to weather for about 2 years, (2) a 6-month rusty rail, and (3) a new rail. Three readings were taken from each rail at different locations to ensure there had not been any perforation of the film of the previous reading. Each rail was tested for loads of 2,000, 5,000, 10,000, and 20,000 pounds.

5.2.2.2 Results

Measurements obtained using the portable VPERM fixture were unstable and inconsistent. Numerous attempts were made to establish consistent readings at different locations of each rail; however, these attempts were unsuccessful (see Table 2). This may be due to the size of the test head. The actual contact area between the VPERM test head and the rail is so small (.0031 square inches - calculated at approx. 1/80 of 33" wheel) that surface roughness of the rail is causing inconsistent and unreliable readings.

In the case of the heavy rust film in Table 2, substantial fluctuations are seen throughout the load spectrum as well as between measurements 1 and 2. The attempted results to measure the 6-month rusty rail show the inability to maintain consistent readings. Numerous attempts were made to establish a consistent load/resistance relationship; however, the above data indicates the typical performance of the VPERM. Figures 8 and 9 show a strong inverse relationship between pressure and resistance using the CN device. In all cases, as pressure was increased, the resistance of the rust film decreased.

Table 2. Summary of VPERM Audit Data

Applied Load (lbs)	Heavy rust film		6 month rust film (Ω)
	*Measurement 1 (Ω)	*Measurement 2 (Ω)	
25	40500	233000	0.27
50	1400	82000	0.44
75	710	56000	0.33
100	750	3.2	0.72
130	1150	400	----
150	2700	438	----
170	3300	345	----

* Measurements 1 & 2 were taken on the same rail at the same location.

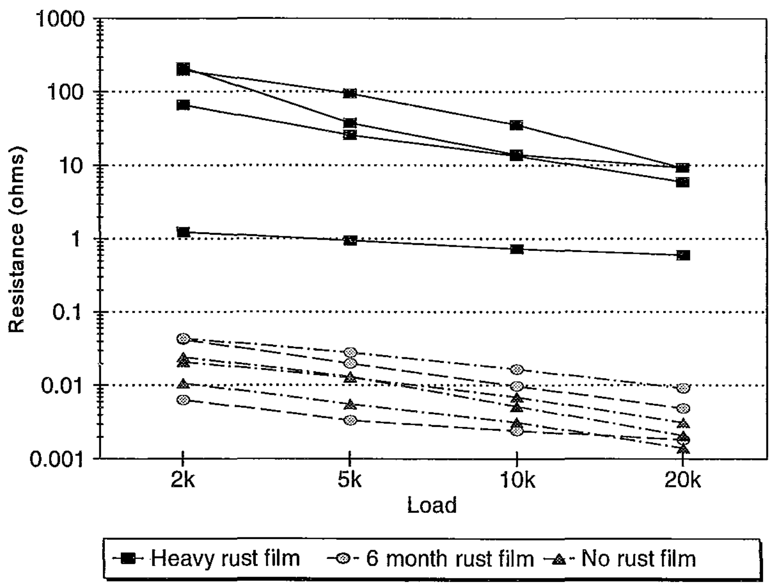

Figure 8. Film Resistance of Double Cell Test

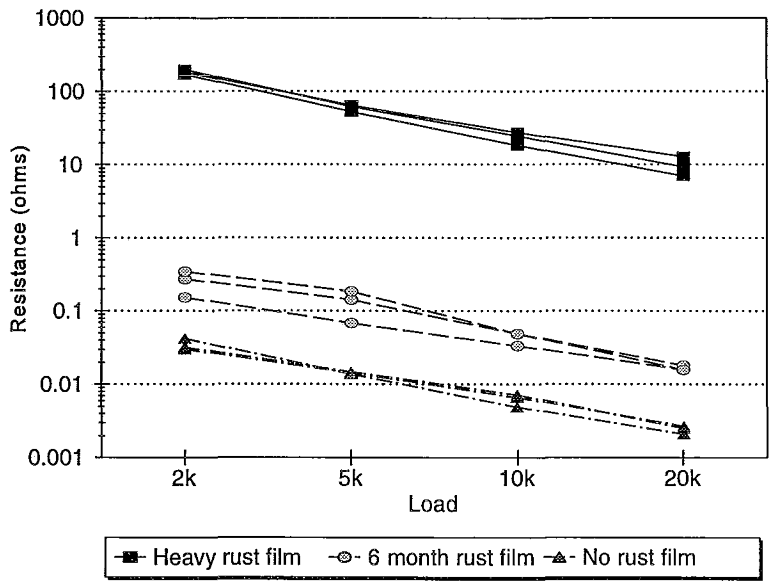

Figure 9. Film Resistance of Single Cell Test

5.2.2.3 Conclusions

Although no correlation could be established, the difference between the two devices indicate that not only pressure, but also contact area may have a significant effect on film resistance. There is no concrete evidence linking contact area and film resistance, but the results of the CN test could indicate a need for further investigation.

5.3 CHEMICAL FILM ANALYSIS

Chemical content and makeup of films were determined from samples collected at various field locations to address where and how mitigation techniques might be applied for reducing or eliminating LOS. Also, laboratory tests, conducted using the full scale wheel rail dynamometer, attempted to replicate these films to create LOS conditions by applying various amounts of contaminants. The resulting films were analyzed and compared to films collected in the field.

Samples from rails were collected from virtually all field sites where LOS long-term monitoring had been conducted. Specific details of these sites may be found in the interim report and will not be repeated here. In addition, samples collected during the training phase (on how to collect films samples) conducted by Oregon Graduate Institute (OGI) near Portland, Oregon, are also included in the database. In all but one case, rail samples were collected along the center top running surface at or near the location where the majority of the wheels appeared to be operating.

A field location at Washougal, Washington, was near a wayside lubricator. Samples were taken from the top running surface (Washougal 2) and from the field edge of the top of rail (Washougal 1). The material collected from Washougal 1 was not heavily worked and required considerably less effort to remove compared with other sites.

Film samples were collected from wheels located in three car shops. One was the Burlington Northern (BN) one-spot repair shop at Vancouver, Washington, (near Portland, OR), the others were in the Union Pacific car shops in North Platte, Nebraska, and the BN car shops in Lincoln, Nebraska. Wheels that had been removed recently were selected to avoid biasing the data with films containing large amounts of rust from time in storage.

5.3.1 Collection Method

Scrapings of films from top of rail (primarily the running surface) and from wheel tread surfaces were collected and sent to the OGI for analysis. Samples were collected by using a clean, sharp single-edge razor blade, scraping the rail or wheel surface at a very low angle 6 to 24 inches. When a sufficient amount of material was collected, it and the razor blade were carefully placed in clean plastic vials, sealed and labeled.

In many cases the film was very hard and strongly bonded to the rail. Significant force was required during the scraping process to remove an adequate amount of the film for laboratory analysis. The sample collection procedure was developed by OGI. Their representatives trained TTC engineering staff. Virtually all samples were collected by the same TTC engineering group to ensure that a uniform process was followed.

5.3.2 Analysis

Samples sent to OGI were analyzed using a number of laboratory techniques. These included scanning electron microscope/energy dispersive x-ray analysis. This permitted qualitative as well as quantitative microanalysis of the small sample available from each site.

OGI provided a data analysis of each site sampled, indicating the amount of carbon, iron oxide, silicon in oxide, aluminum in oxide, calcium in oxide, and oxygen present. This is shown as a percentage of the entire sample. A more detailed description of the analyses is shown in Appendix B.

5.3.3 Results

Figures 10 through 12 summarize results of film samples collected from the rails and wheels. Figure 10 shows percentage of major film components from all wheel samples collected. Figure 11 shows film sample results from all field sites except Washougal 1. Figure 12 shows only the results from the Washougal 1 site, which is the area sampled outside of the running surface.

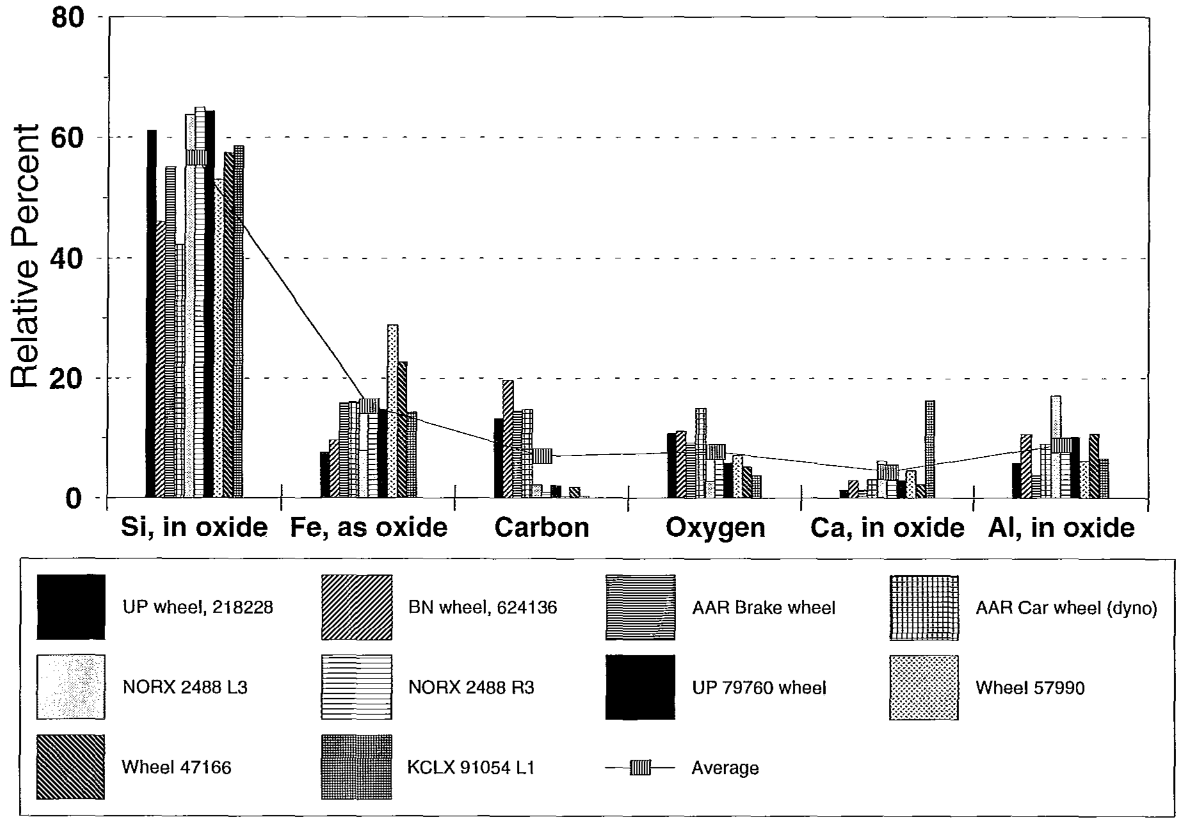

Figure 10. Film Samples Taken from Wheels in Revenue Service

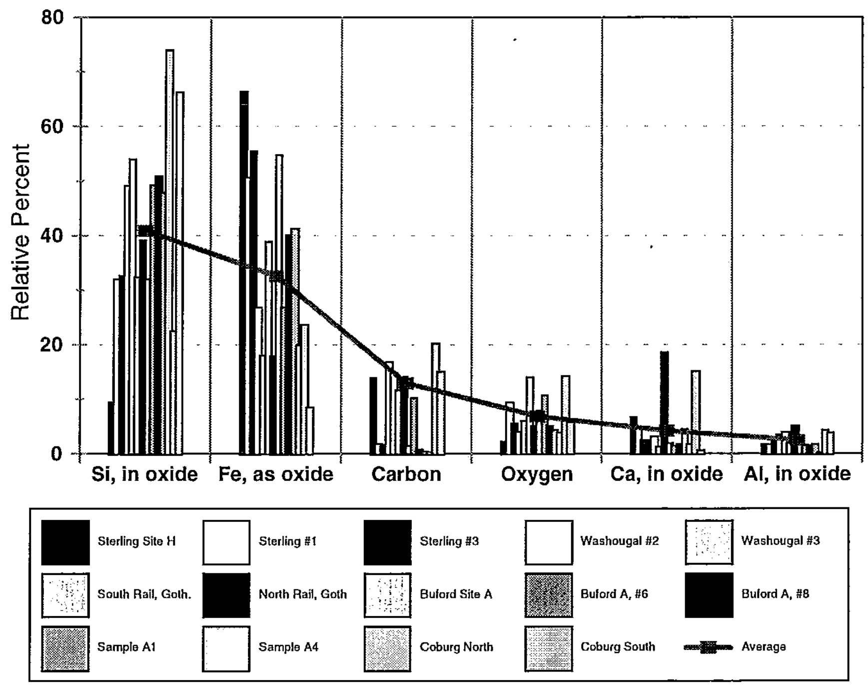

Figure 11. Film Samples taken from Rails in Revenue Service

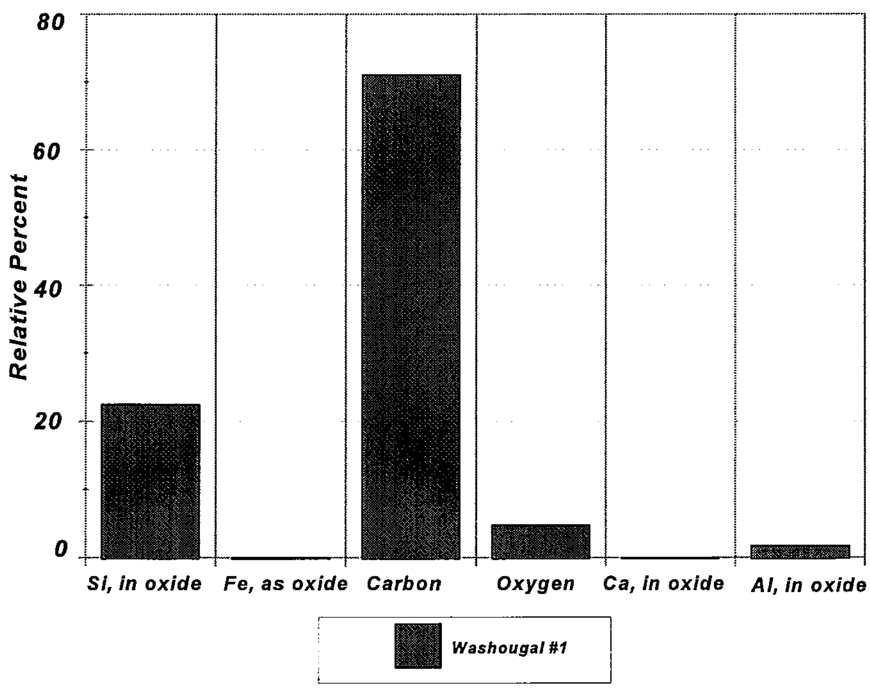

Figure 12. Film Sample Taken from Washougal 1 Site

As can be seen, the rails show a higher variability between sites than the wheels. Between different field sites, the highest variability is between content of carbon, silicon in oxide, and iron as oxide. Data showed a higher percentage of silicon in oxide from the wheel samples than from the rail sites; the rail data showed a higher percentage of iron as oxide than the wheels. The other components of film from both rails and wheels (carbon, oxygen, calcium in oxide, and aluminum in oxide) were similar in both locations (Figure 13).

Figure 14 shows the average of all rail sites compared to the one site that was heavily lubricated (Washougal 1). There are notable differences of silica in oxide, carbon, and iron as oxide. The high carbon content of the Washougal 1 site is likely due from track grease, while the low (almost 0%) iron as oxide may be due to lack of rust forming as a result of the protective layer of grease.

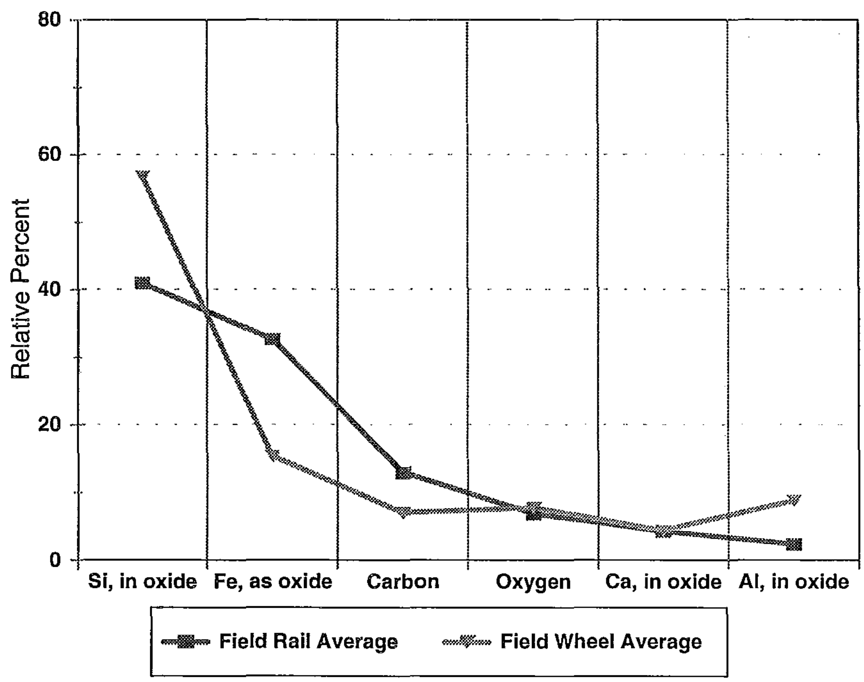

Figure 13. Average Wheel and Rail Film Composition

Additional analysis and observations of film results will be discussed in Section 6, after dynamic contact patch testing procedures have been described.

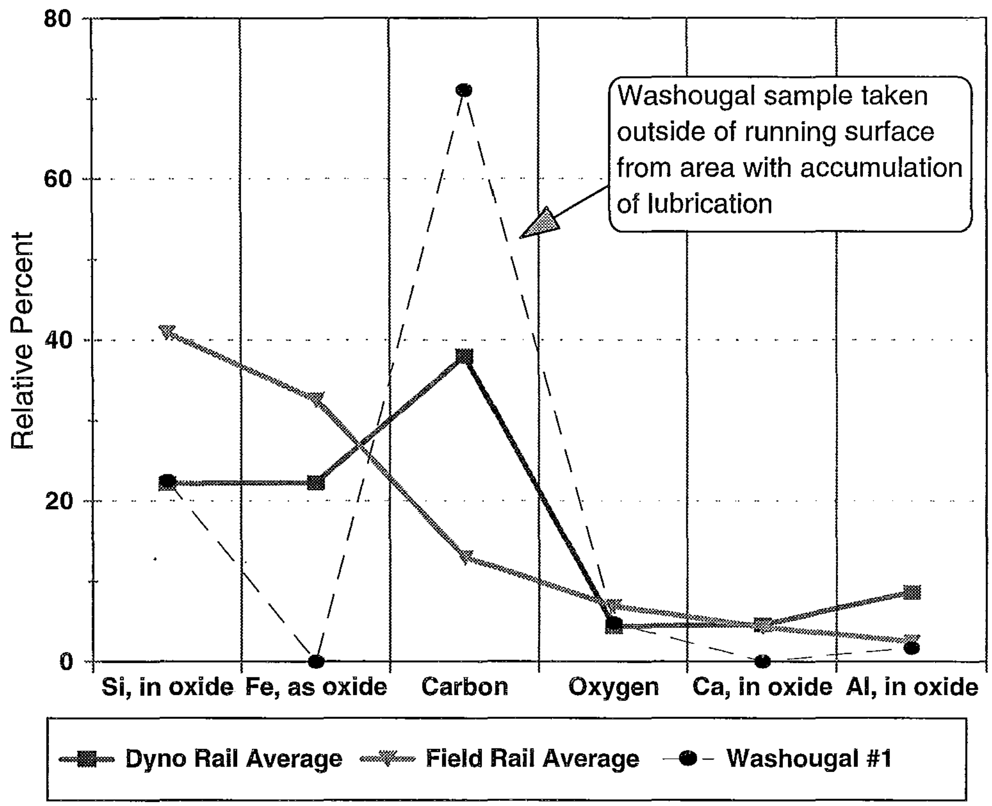

Figure 14. Field Rail Averages Compared to Washougal 1

5.3.4 Conclusions

Both rail and wheel film samples exhibited similar trends in chemical makeup, with silicon in oxide and iron as oxide being the two major components of the film composition. Rail samples had a higher iron as oxide content and a lower silicon in oxide content than the wheel samples. This is most likely due to the differences in the types of environmental exposure — rails being stationary and wheels rolling.

There were significant differences in carbon and iron as oxide in rail samples collected at a heavily lubricated area located well away from the running surface (Washougal 1). Rail samples did exhibit higher variations in individual material makeup than the wheel samples but remain relatively consistent in their makeup.

6.0 DYNAMIC CONTACT PATCH RESISTANCE

The source of the materials that makeup the composition of films was investigated to determine if mitigation techniques to reduce or eliminate LOS were feasible. By identifying a portion of the railroad operating procedures that is controllable and is also contributing to the LOS film, a mitigation technique or procedure could then be proposed.

These operating procedures can include brake shoe materials, braking procedures, rail lubrication, use of locomotive sand, leaking car lading or other controllable conditions. Environmental factors such as blowing dust and dirt, leaves, moisture, and oxidation were also considered; however, it would not be feasible to try and control all these factors.

Efforts were made to replicate films, as identified by field testing, in a controlled laboratory environment by independently varying parameters such as contact pressure (force), brake shoe type, braking activity (cycle, force), speed, lubrication (conventional calcium based 11% graphite track grease), and contaminants commonly found in the field. Film samples were taken after selected runs to compare with samples previously obtained in the field to determine if the same type of films were being developed.

The test was conducted at the former Chicago Technical Center (CTC) on the Railroad Wheel Dynamometer. The testing was performed during three separate visits immediately following AAR certification testing of three different manufactured brake shoe products from May, 1995 through June, 1995. For the purpose of this test, brake shoe manufacturers and materials are proprietary and are therefore not identified. Two to three days were allowed for each test.

6.1 INSTRUMENTATION

a special insulating sleeve was fabricated for the dynamometers car wheel axle for the purpose of electrically isolating the signal between the car wheel and rail wheel. The material was 0.030-inch Teflon sheeting (Figure 15). The sheeting was ordered with one side acid-etched so that it could be bonded to the axle using a high strength adhesive. The car wheel was also "sandwiched" between two BAKELITE rings to insulate the car wheel at the hub.

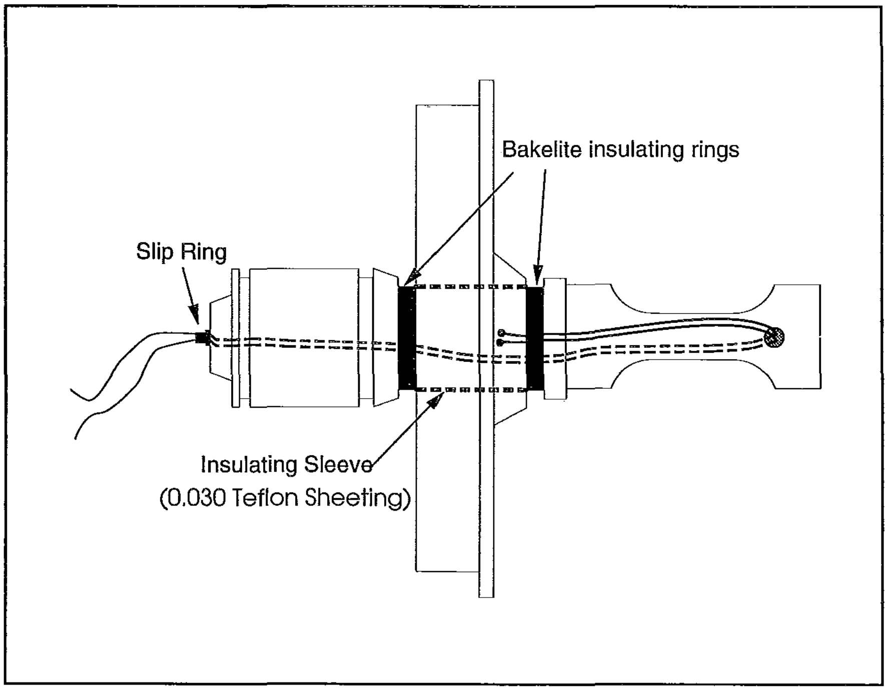

Figure 15. Car Wheel Setup

A locking key was also fabricated from BAKELITE material. This key (not shown in the figure) was positioned within the axle and locks through the wheel to keep the wheel from slipping as it rotates. Two wire leads were attached to the hub of the wheel and routed through the inside of the axle to the multi-channel slip ring. a Kelvin bridge four-wire measurement method was used (Figure 16). This measurement method is designed to negate lead resistance in order to accurately measure the expected low resistance of the contact patch.

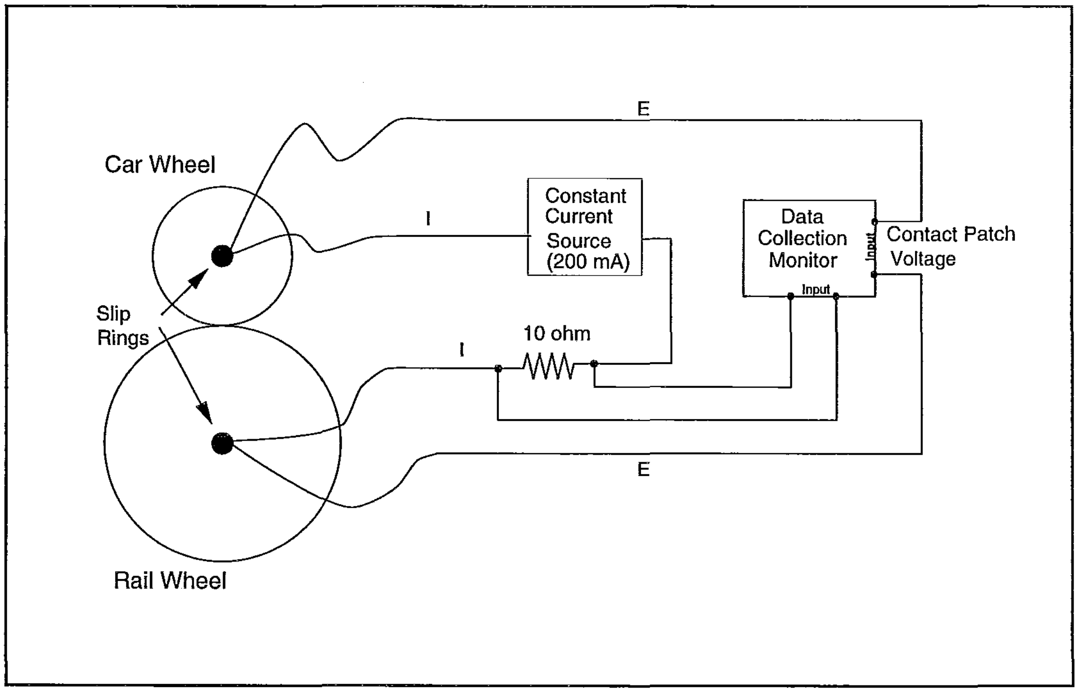

Figure 16. Kelvin Bridge/Data Collection System

Figure 17 shows both the car wheel and track wheel. Bond wires were welded at various locations from the rail to the rim, and from the rim to the stub axle to assure a good electrical conductivity path. Two wire leads were also connected from the slip ring mounted on the track wheel to complete the other half of the Kelvin bridge used for obtaining low potential resistance measurements. The desired measurement of the test was the contact patch resistance between the two surfaces of the car wheel and the rail of the track wheel. The current (I) and contact patch voltage drop (V) was measured. The contact patch resistance (R) was calculated as R = V/I .

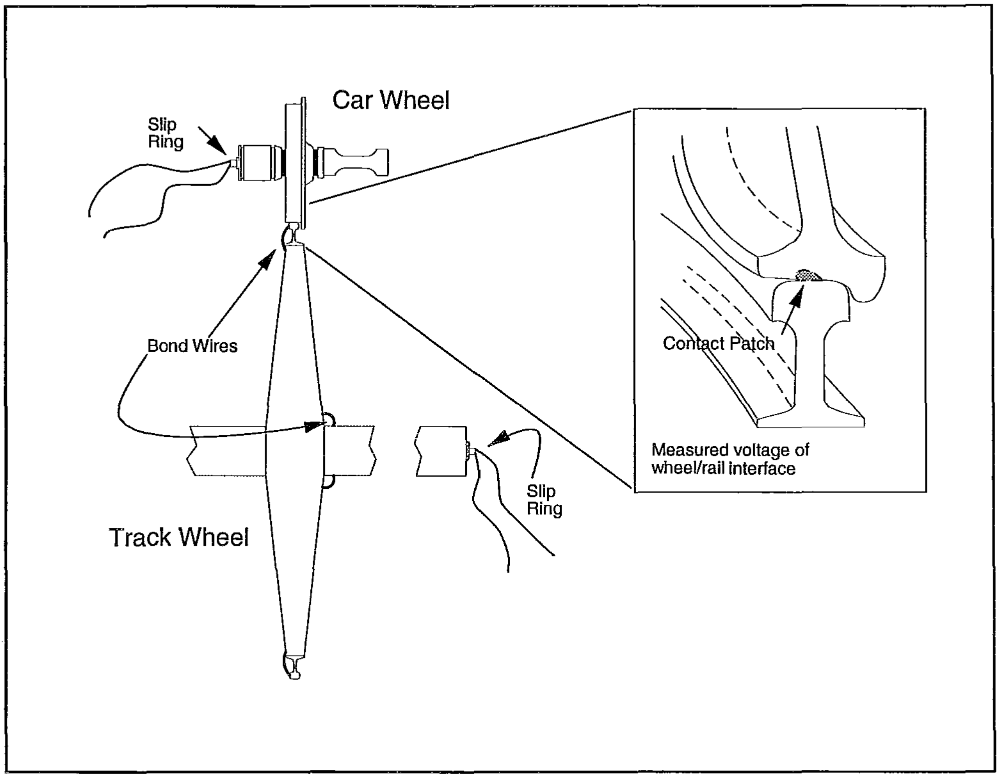

Figure 17. Railroad Wheel Dynamometer Test Setup

6.2 DATA ACQUISITION

The data collection system was set up to allow for real time viewing of the data, both measured voltage drop across the contact patch and calculated contact patch resistance (refer to Figure 16). This allowed the personnel conducting the test to make timely decisions as to when a resistive film was being developed, when film samples should be taken, and when test sequences should be discontinued. Along with voltage and current, other measurements monitored were brake force, wheel tread temperature, speed, and wheel load. Data was collected on a Toshiba 5300/386 laptop computer using Snap-Master Version 3.0 1991-1994 HEM Data Corporation acquisition software. The data was collected at 10 samples per second (10 Hz).

6.3 TEST CONDUCT

Because of the unknowns involved in this type of testing, namely, the method of developing and replicating resistive films, many of the decisions about the timing, degree and frequency of measurements, and amount of contaminants were made during each run. A full matrix of test runs was performed only for the first brake shoe test (Test A). Observations made during the first test sequence helped dictate the test procedures followed in the subsequent test series (Test B and Test C).

It is also important to note that only two of the brake shoe types were available for "full conformal contact" testing, due to a scheduled move of the dynamometer to TTC. The shoe used in the first test (Test A) was new and had not yet been worn to the point of full conformal contact. Figure 18 is an exaggerated illustration of the difference between conformal versus non-conformal contact of the brake shoe on the running surface of the car wheel.

6.3.1 Test A / Brake Shoe No. 1

Test A was performed from May 1 through May 4, 1995. Immediately following the data collection and instrumentation setup, the first test run was performed before cleaning the track or car wheels. The surface of the rail was extremely contaminated as a result of approximately 1½ years of inactivity (of the track wheel ONLY). It had been approximately that long since the track wheel had been engaged with the car wheel. During brake shoe certification tests, the track wheel is not engaged. Consequently, a fair amount of debris from the previous 1½ years of dynamometer operation had deposited on the track wheel from above. In addition to the accumulation of debris, rust had developed on the track wheel as a result of water which is used to help cool the car wheel during certain test operations.

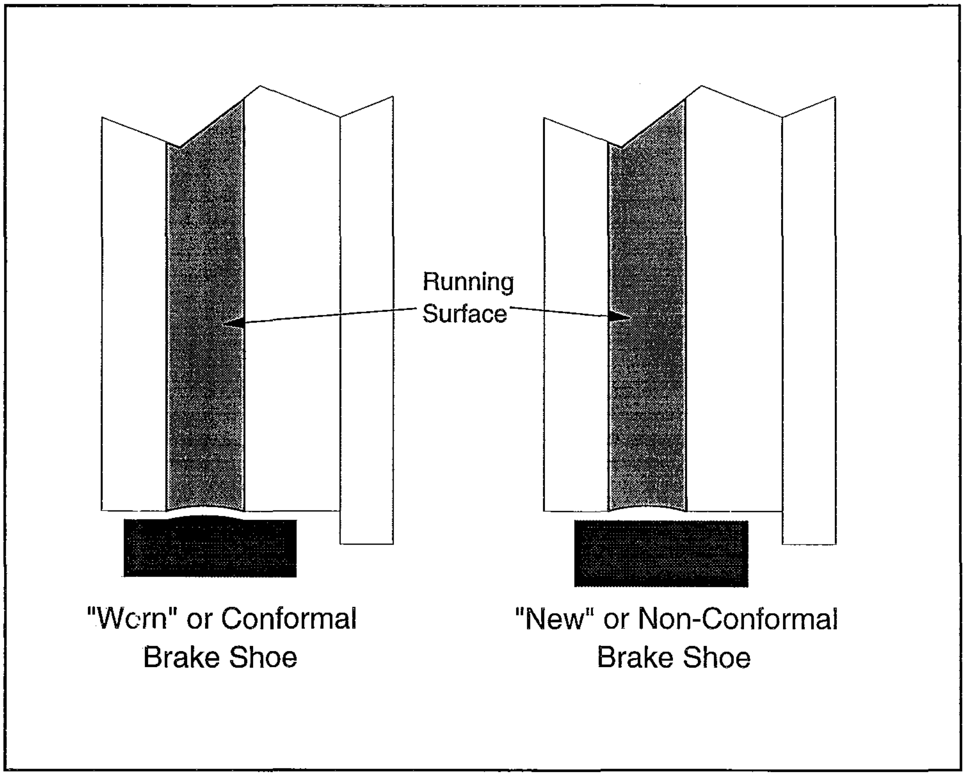

Figure 18. Conformal vs. Non-Conformal

Mechanical cleaning of the track wheel was performed using a hand held grinder with a heavy wire brush. This was necessary to remove the heavy build-up of rust and debris previously described. Both wheels were then cleaned with an acetone cleaning solvent. Initial test runs were made of clean/dry car and track wheel of various speeds and wheel loads.

Following the "clean" runs, each of the parameters and contaminants was added individually to examine each effect independently. The following is a list of the parameters and contaminants evaluated:

Wheel Load (6,300 lbs. - 32,000 lbs.)

- Speed
- Braking Pressure/Cycle
- Lubrication
- Locomotive Sand
- Other Contaminants (soil, leaves, water, etc.)

Lubrication was added to the track wheel with a paint brush directly to the top of rail as the track wheel was being operated at slow speeds. A couple of applications were also performed at higher speeds. The method of adding locomotive sand, and other contaminants, was done by using a make-shift funnel with a hose positioned as close to the wheel/rail interface as possible. Film samples were taken following select runs. A detailed log of all runs and description of conditions is included in Appendix C. Certain run sequences are missing. These numbers were skipped when computer failure and other anomalies required a test run to be aborted. They are not part of the database.

Again, it should be noted that the brake shoe used for this first test series was a new shoe and had not yet worn conformally to the profile of the car wheel. Figure 19 shows visible evidence of the non-conformal band. This photograph was taken following Run 25 as described in the appendix.

6.3.2 Test B / Brake Shoe No. 2

Test B was performed on May 26, 1995. This test was conducted following AAR certification test of brake shoe No. 2. Preliminary test condition decisions were made based upon observations derived from Test A of runs where there was a measurable resistance. The conditions where there was notable resistance measured were used as guidelines in an attempt to re-create similar results in subsequent tests. However, these observations and decisions were based strictly on observations of the real time data of the first test, as results of the film analysis had not yet been provided.

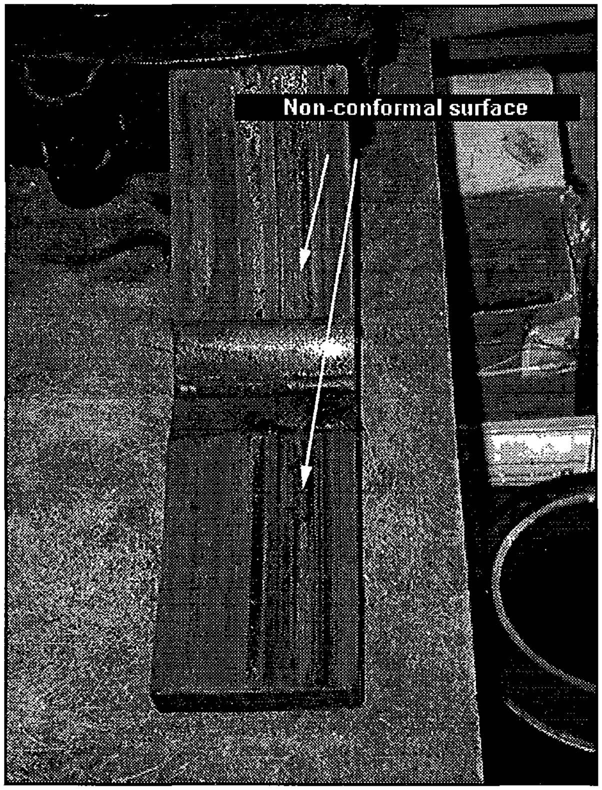

Figure 19. Brake Shoe No. 1

Results of Test A were not able to be repeated during this second test series. Contrary to the first test, brake shoe No. 2 was a worn (conformal) brake shoe (refer to Figure 18) and had previously completed AAR certification testing and was worn to the profile of the car wheel. An effort was made to duplicate a non-conformal contact of the brake shoe during latter runs with the car wheel running surface. This was physically done by grinding a groove on the brake shoe in alignment where the running surface of the car wheel was positioned.

The contaminants were added in a different manner in tests series B and C. Sand, dirt, leaves and other debris were mixed with lubrication. The lubrication served as a binder to assure that the contaminants were being worked into the interface of the wheel and rail. The mixture was then applied to the track wheel rail surface using a paint brush.

6.3.3 Test C / Brake Shoe No. 3

The procedures and test sequences run of Test C were similar to those performed during Test B. Again, a groove was ground into the brake shoe to simulate a non-conformal contact. And again, results of Test A could not be repeated during the third test series.

6.4 ANALYSIS

a method of evaluating and interpreting the data was established based on criteria set by the Ad-Hoc Track Circuit Parameter Task Force Committee. In order for a resistance measurement to be considered as LOS, one or both of the following conditions must have existed (Note: Data was collected at 10 samples per second):

- Continuous resistance greater than 0.06 ohms for 10 or more consecutive samples.
- Any time 0.06 ohms is exceeded for five samples within 1 second for each second during a moving 2-second window. The 2-second window is evaluated every 0.1 seconds, then incremented for 0.1 seconds, then re-evaluated. This process is repeated for the entire run.

Data plots of each run from all three tests is included in Appendix D. Each run includes data plots of the calculated resistance measured between the wheel and rail. A 0.06 ohm threshold line is drawn. The second plot is the criteria signal showing a LOS (signal level 1) or no LOS (signal level 0), based on the committee guidelines stated above. The final two plots are of the measured wheel/rail velocity and braking activity. The evaluation routine does not care what the level of resistance is, only if it exceeds the 0.06 ohm threshold of the conditions previously stated. Figures 20 and 21 are a sample of Runs 19A and 23A, respectively (the subscript A denotes results from Test A).

Figure 20 shows an example of a run with no LOS as established by the previously stated criteria. Although there is intermittent values of resistance that exceed the 0.06 ohm threshold, based on the evaluating criteria, the criteria signal stays "low" for the duration of the run. The conditions of this particular run were added lubrication, no braking activity, accelerate to 40 mph and coast with a wheel load of 24,000 pounds.

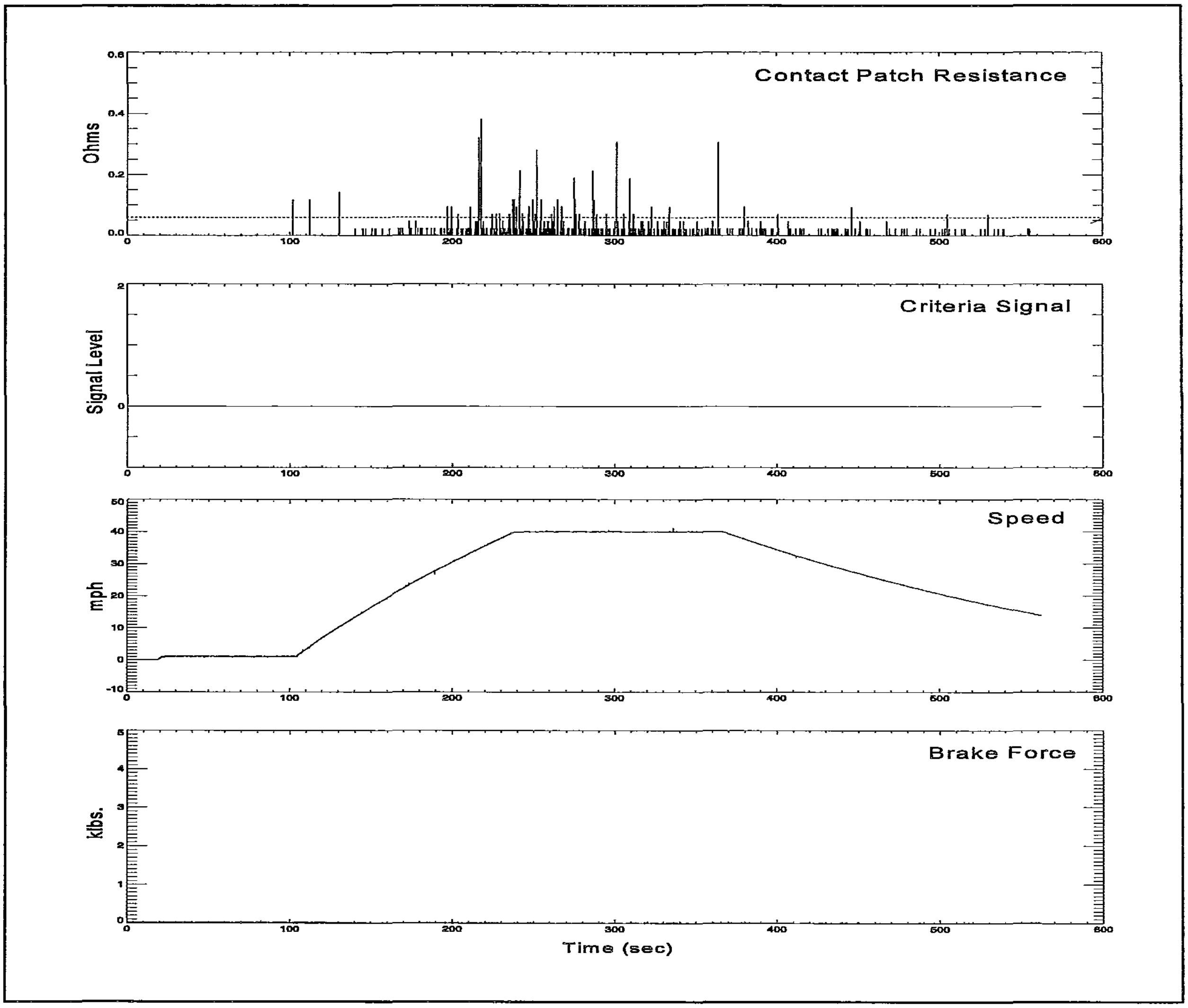

Figure 20. Run 19A / Example of No Loss of Shunt

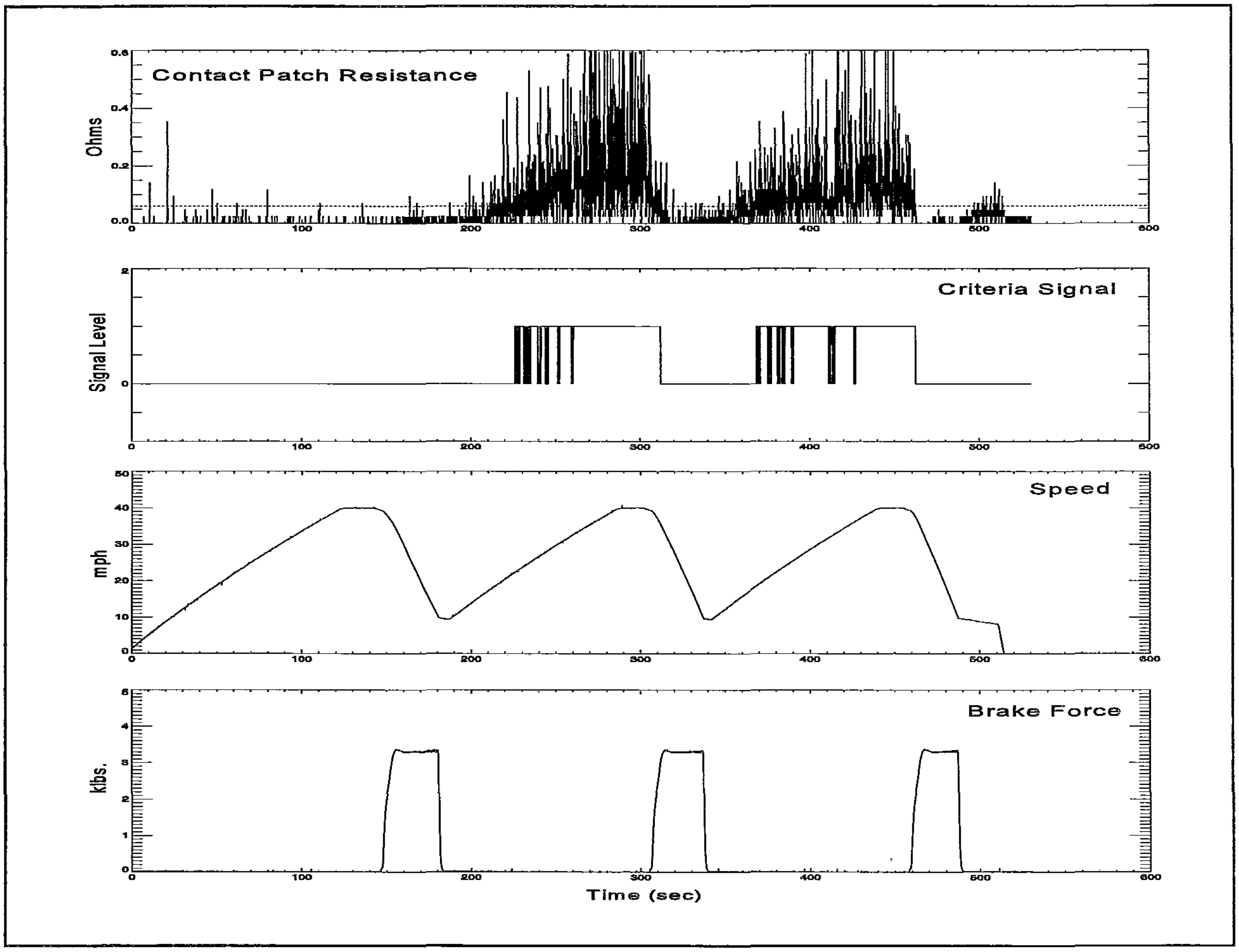

Figure 21. Run 23A / Example of Loss of Shunt

Figure 21 shows an example of LOS, both intermittent and sustained. The track wheel had a presence of lubrication from previous runs. Excess lubrication of the track wheel was hand wiped with a clean cloth. The run was then conducted by cycling from 5 mph to 40 mph using a 3,300-pound brake application. The criteria signal goes "high" during the second and third acceleration cycles, which is where the threshold of 0.6 ohms is exceeded.

6.5 RESULTS/CONCLUSIONS

Select runs of the wheel dynamometer test exhibited LOS patterns resembling island voltage time history plots that were previously seen in the revenue service environment. These occurrences of LOS were difficult to control, sustain, or repeat. Film samples taken from the laboratory test were different than those collected from numerous field site locations, both physically and in degree of chemical composition. The highest level and most frequent shunt loss occurred during the first test series utilizing a non-conformal brake shoe (Test A). Efforts to duplicate these same LOS occurrences in the subsequent test series of B and C were unsuccessful.

The runs in test series A where LOS was observed were repeated in test series B and C. Although there were similar LOS patterns during test series B and C, the test conditions were different. The only variables that changed between the running of test series A, B, and C were:

- Test series A was run with a non-conformal brake shoe where test series A and B were run with conformal brake shoe.
- The method of adding contaminants from series A to series B and C.

Test series A was performed with a new brake shoe prior to the AAR Brake Certification tests and therefore had not been fully "broken in" and was non-conformal to the car wheel. Test series B and C were performed with worn brake shoes after brake shoe certification and were fully conformal with the track wheel when shunting tests were performed.

Contaminants were applied to the track wheel by an unconventional method. In test series A, lubrication was applied to the track wheel with a paint brush while the other contaminants were introduced near the car wheel/track wheel interface. This method made it difficult to control the amount of contaminants being introduced. During test series B and C, the contaminants were mixed in with the lubrication and applied directly to the track wheel with a paint brush.

Analysis and comparison of film samples taken in the field and during the dynamometer testing suggests that films developed in the lab are both physically and chemically different than those obtained in the field. The results of the film samples collected during the dynamometer test show no instances where all components can be correlated with any given field samples, with the exception of lower percentages of oxygen, calcium in oxide, and aluminum in oxide. There was a large variability of the major components of silicon in oxide, iron as oxide, and carbon (Figures 22 and 23).

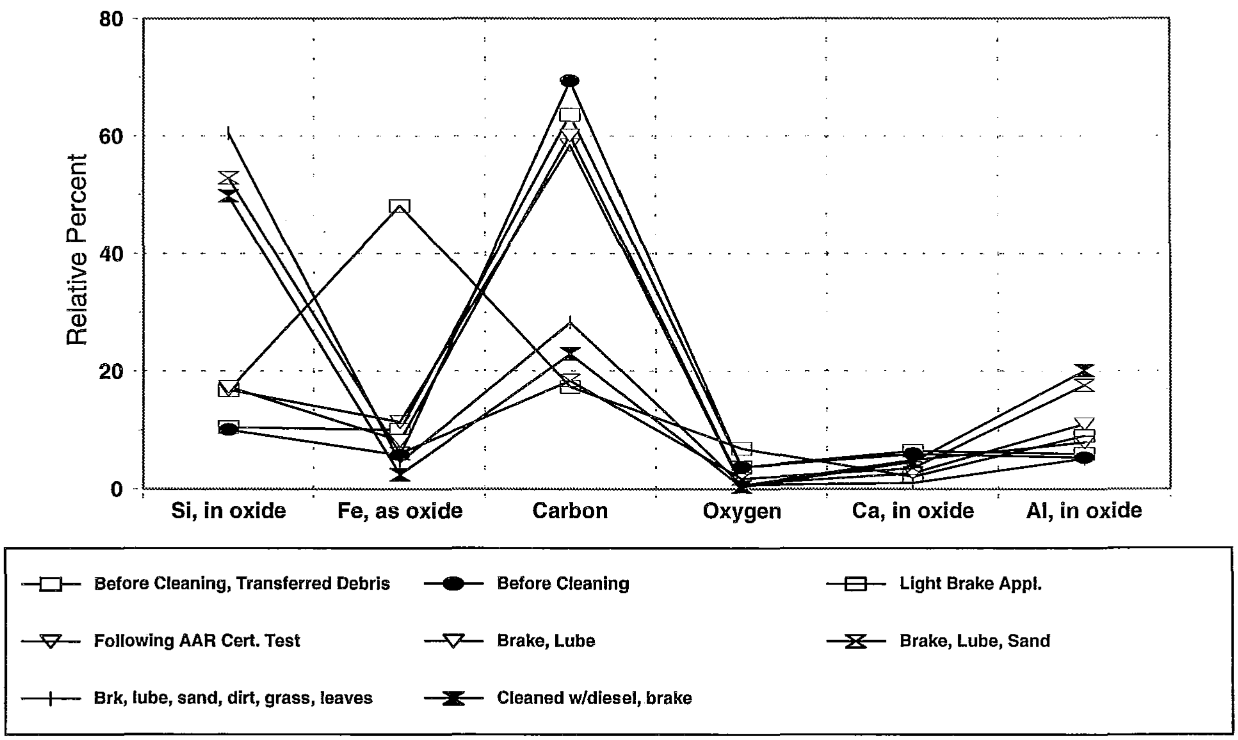

Figure 22. Dynamometer Car Wheel Film Sample Results

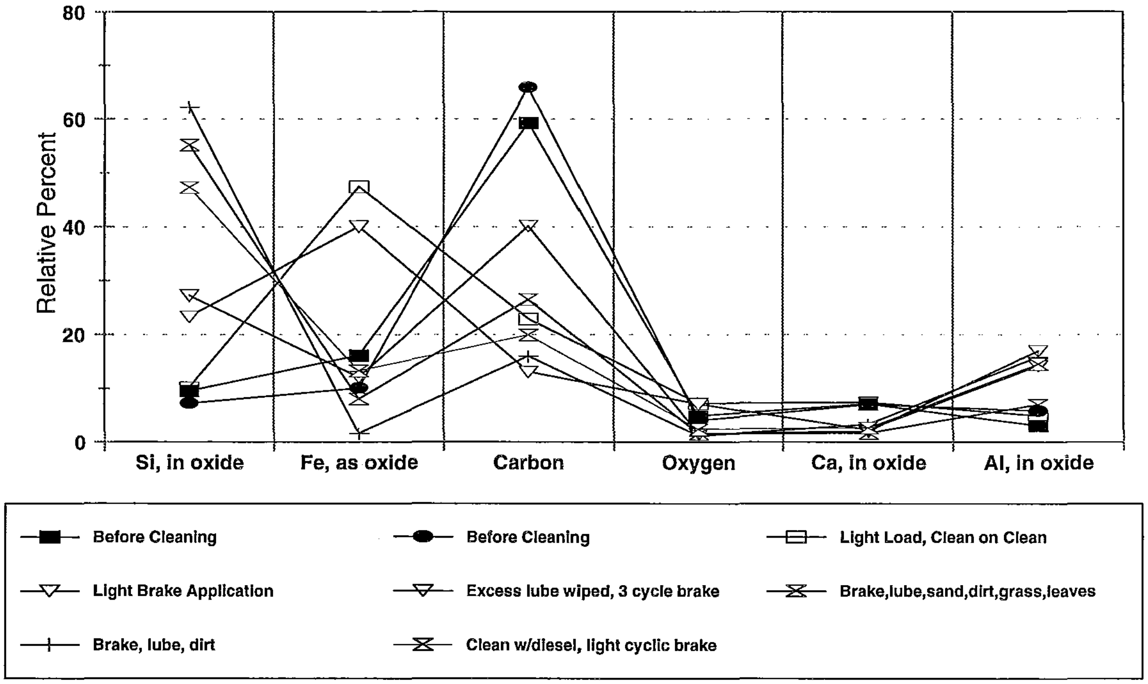

Figure 23. Dynamometer Track Wheel Film Sample Results

In addition, the physical characteristics of films, as noted by engineering personnel gathering the samples, were significantly different between field and laboratory. This was noted by a contrast of effort required to "scrape" the samples from the surface. The samples collected in the field required more effort and were, at times, extremely difficult to remove from the rail surface than those collected in the lab. The field samples collected were dry powdery substance whereas the lab samples were more tacky, likely due to the amounts of lubrication applied, difference in operating environment, and dwell-time between train passes.

It is important to note that an excessive amount of any of the applied contaminants, either separate or in combination, can cause immediate or temporary LOS.

The differences may be due to the effects of extended operational (lubrication practice, locomotive sanding, braking, and time between trains) and environmental exposure (wind blown contaminants, sun, cold, and oxidization) on the development of these films. In the field, contamination of the wheel and rail occur in random amounts and at random intervals and were difficult to simulate, particularly environmental, in a laboratory environment given the time and budget constraints on this test.

Although conditions were created in a laboratory environment that reduced shunting performance, the LOS mechanism in the laboratory could be different from that in the field. And while LOS conditions did occur as a result various combinations of speed, braking, wheel/rail pressure and added contamination, the physical and chemical differences of the films do not allow recommendations for effective mitigation techniques to be offered at this time based on the results of this test.

7.0 RECOMMENDATIONS

7.1 CONTACT PRESSURE/RESISTANCE RELATIONSHIP

There is an inverse relationship between film resistance and contact pressure (refer to Section 5.2.2.1). The AAR recommends further research in this area to gain a better understanding of this relationship in a laboratory environment. If this relationship is determined to be significant, a different device for measuring film resistance in the field would need to be developed to determine the effectiveness of mitigation techniques resulting from the research.

7.2 DYNAMOMETER TESTING

Although films that are representative of what exists in revenue service were not able to be developed during the initial testing on the dynamometer, it is felt that with extended running, films more like those seen in the field could be developed. Additional testing to determine relationships between contaminants and resulting LOS, films, and subsequent mitigation techniques is recommended.

Comments from individual task force members of the wheel dynamometer test are included in a Appendix E.

ACKNOWLEDGMENTS

Technical direction and review of results for this program were performed by the Track Circuit Parameters Task Force. This group is comprised of railroad, supplier, FRA and AAR personnel. The Task Force was chaired by Mr. Jim Murphy of the Union Pacific Railroad. Task force members provided significant assistance during all phases of testing, including coordination of field support, data analysis, and review of final results.

Task Force Members

Jim Murphy	UP	Bill Bryce	Conrail
Manuel Galdo	FRA	Tom Rose	Amtrak
Jim LeVere	BNSF	Chuck Johnson	NS
Max French	BNSF	Jim Moe	Safetran
Terry Therion	CN	Forrest Ballinger	Harmon
Mel McNichols	CSXT	Wayne Etter	AAR
Phil Miller	NS		

Field support at each monitoring site was an important requirement during this test. Each railroad designated personnel to coordinate installation, calibration, and follow-up inspections. Special thanks go to the following people:

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Dean Cook	BNSF	Mike House	Safetran
Jack Witcher	NS		
Mike Manella	CN		

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