CONTROL OF WHEEL/RAIL FRICTION

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SUMMARY

A joint, multi-project, track-related cooperative research program was initiated under funding by the Transit Cooperative Research Program (TCRP), Project D-7. The goal of the project was to adapt research already being performed by the Transportation Technology Center, Inc. (TTCI), for the Federal Railroad Administration (FRA) and the freight railroads for use by the transit industry, thus making best use of the TCRP investment.

A method for reducing friction and noise by applying a bonded film coating to the rail was shown effective, but only for a very short time. A demonstration was conducted in the field on the Portland (Tri-Met) yard lead in Gresham, Oregon. Data suggest that although the reduction in friction was minimal, noise generated from top-of-rail-to-wheel-tread contact was reduced significantly immediately after application. However, the coating used here did not provide a sufficiently robust modification of the surface to affect all trains for an extended period.

Noise data collected during periods before, immediately after, and 4 weeks after coating indicated a high variability of noise. During periods of extremely hot weather (98°F ambient), residual lubrication present on the gage face and wheel flanges appeared to migrate to the top of both rails, resulting in extremely quiet operations. During early morning operations, this condition could not be created or maintained.

Residual lubrication was carried to the curve from the wheel flanges of passing trains. Because the nearest wayside lubricator was some distance away on the mainline, this residual lubrication was not consistent from car to car, and single train results were highly variable as to noise reduction. The coating, applied only on the top of the rail, reduced top-of-rail friction from approximately 0.6μ to 0.5μ.

The results indicate that the coating alone was insufficient to reduce friction and noise for an extended period. The most significant noise reductions resulted from migrating lubrication, suggesting that a constant, reliable source of lubrication is needed. One or more properly located wayside lubricators or some type of onboard flange lubrication system could provide this.

CHAPTER 1

BACKGROUND AND OBJECTIVE

A joint, multiproject, track-related cooperative research program was initiated under funding by the Transit Cooperative Research Program (TCRP), Project D-7. The goal of the project was to adapt research already being performed by the Transportation Technology Center, Inc. (TTCI), for the Federal Railroad Administration (FRA) and the freight railroads for use by the transit industry, thus making best use of the TCRP investment.

Railroads use various lubrication methods and products to reduce rail and wheel wear, control truck steering forces, and reduce train energy. These methods incorporate a range of application systems that, when operated incorrectly, tend to distribute excess lubricant onto the ballast and underbody of passing cars. For these reasons, such “conventional” systems have not received favorable application in the transit industry. Additionally, the transit industry is especially sensitive to noise generated by passing trains; most lubrication systems primarily address other issues such as wear, forces, and energy. In the freight railroad environment, the ability of lubrication to control wear and energy is of the highest importance; noise mitigation capabilities are of secondary interest.

The application of a bonded film coating of the rail surface to control friction and noise has been proposed as an alternative to conventional rail lubrication. The advantages of rail coatings over conventional greases include improved cleanliness in the application and track areas, elimination of the film migration that accompanies most conventional lubricants, and the ability to apply material with specified friction values. Characteristics of the bonded material may also form a film that can trap existing lubrication, thus creating a sponge or reservoir at specific locations on the rail, thus maintaining desired friction levels.

Experience with coated rail is limited to evaluations conducted on a short (12-ft) section of rail installed on the High Tonnage Loop (HTL) at the Facility for Accelerated Service Testing (FAST) located at the FRA’s Transportation Technology Center (TTC), in Pueblo, Colorado. During this demonstration, the coating did reduce friction on the rail, but had a limited life under heavy-axle-load (i.e., 39 tons per axle) freight car loading. The purpose of this demonstration was to evaluate the effectiveness of bonded film coatings in the transit environment under lighter axle loads and determine the life of the film coatings.

It has been suggested that applying a coating engineered to withstand loads expected in the transit environment, combined with existing lubrication, should reduce noise and wear. This cooperative research program was intended to build on the knowledge derived from demonstrations addressing freight railroad performance and to modify the engineered coating for application in the transit environment. This project was also conducted to determine the life-cycle performance of a coated rail in order to assess the applicability of such a method for use in transit applications.

CHAPTER 2

PLAN OUTLINE

Using the past performance of coatings in the field and results from evaluations at FAST, Oregon Graduate Institute (OGI) engineering staff specified a formula for coating rail materials on site. Initial plans called for two different materials, one for the gage face and the other for the top of the rail. Site inspections of Tri-Met curves indicated that the wheels of passing trains and the rail gage face were already somewhat lubricated. This was because Tri-Met was already using a few wayside lubricators to control noise at some sensitive locations on the system. Because it was not feasible to stop lubricating for purposes of this demonstration, only the top of the rail was selected for application of the friction control film. The design of the bonded film was such that excess lubricant would be trapped on the surface where the bonding occurred and would provide extended protection.

A curve on the main departure lead of the Gresham Yard in Portland was selected by Tri-Met representatives for this demonstration project. This curve suffered from excessive noise and squeal, even though varying amounts of gage face lubrication were noted. The top of the rail was dry, thus much of the noise was thought to originate from the wheel tread-railhead creepage contact area.

Baseline measurements of friction and noise were recorded with the rails in the “as is” condition. After this condition was documented, the top of the low rail (followed by the top of the high rail) was coated for the entire length of the curve. Prior to coating of each rail, the full length of the test zone rail was cleaned using sandblasting techniques, after which a contractor placed a coating on the clean, top running surface. The coating was applied to the top of both rails for approximately 200 ft in two steps. First the top of the low (inside) rail was coated, then measurements of passing car noise were taken. The top of the high (outside) rail was then cleaned and coated, followed by repeating the performance monitoring measurements.

Measurements were made approximately 4 weeks later to assess the long-term durability of the coating and its effect on reducing noise.

CHAPTER 3

SITE DESCRIPTION

Portland Tri-Met personnel evaluated several curves for use in demonstrating the film-coating project. Although curves on the mainline track had been preferred, those with existing noise-related problems had already been fitted with wayside lubricators; ceasing this application for test purposes was not a viable option. For this reason, curves in heavily trafficked yard leads were evaluated. TTCI and Tri-Met personnel inspected several curves, after which curve C-538 was selected for the demonstration. Refer to Figure 1 for a map of the site, and Figure 2 for an overall view.

This curve is located on the main exit from the Gresham Yard, and virtually all trains stored and serviced in the yard depart using this curve every morning. Curve C-538 is 166 ft long, contains no spirals, has approximately 1 in. of superelevation, has a radius of 90 ft (approximately 64 deg.), and contains a restraining rail along the low/inside rail. The track consists of standard 115-RE section carbon rail, fastened on wood ties with cut spikes, and standard ballasted track construction. Rail was continuously welded within the test zone curve. The only mechanical joints encountered were at the extreme ends near turnouts and insulated joints.

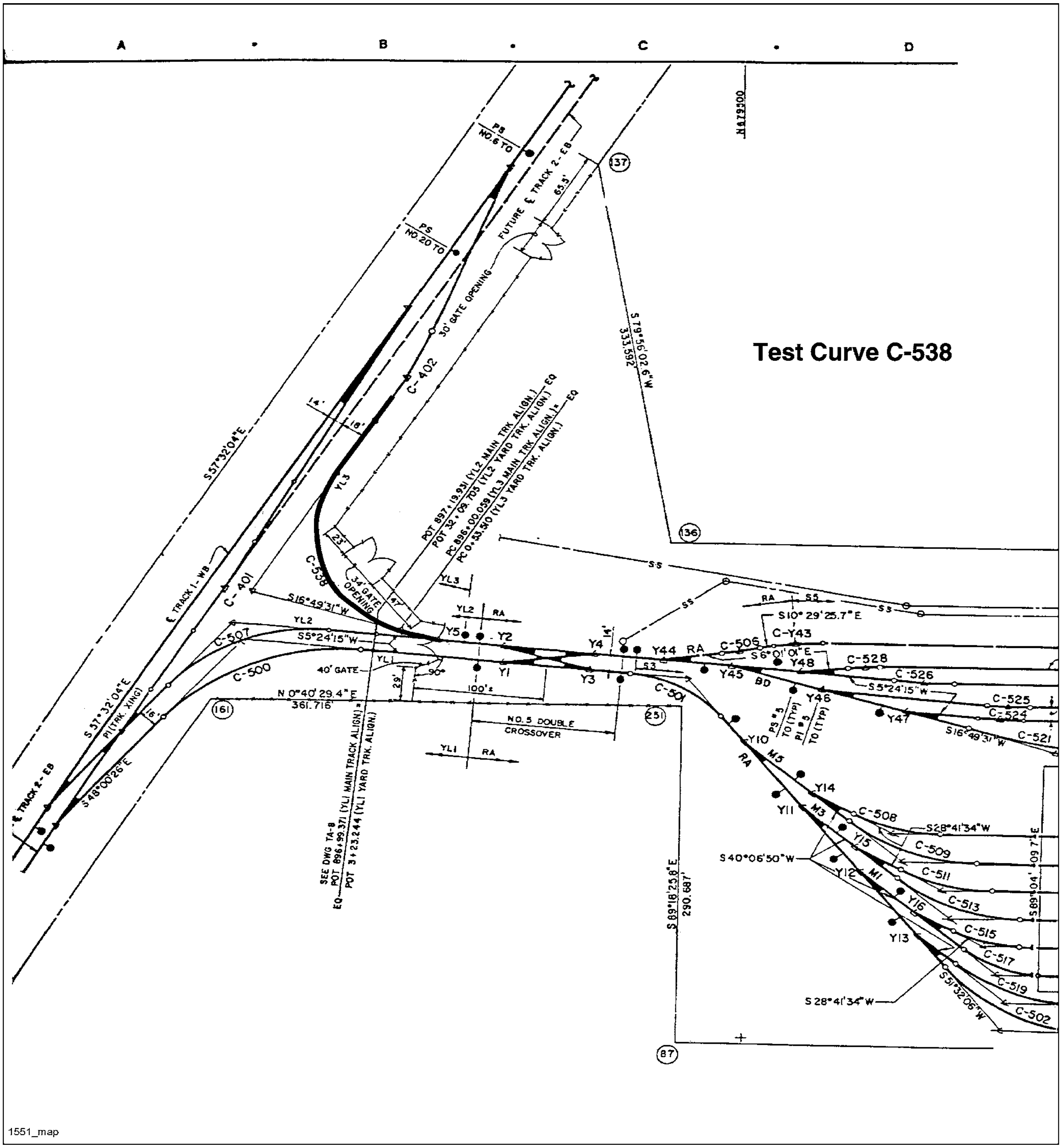


Figure 1. Map of yard lead showing Curve C-538.

Figure 2. *Test site and typical Portland Tri-Met car.*

CHAPTER 4

RAIL VEHICLES

Two types of rail vehicles are in use by Portland Tri-Met. These are designated as "Type 1" and "Type 2." The vehicle types are similar in appearance but have significantly different mechanical details. Both are three-unit articulated cars, with a powered two-axle truck at each end, and a non-powered two-axle truck in the center unit. These vehicles are operated intermingled with each other; however, because Type 2 rail vehicles are handicapped-accessible, single trains are generally Type 2 vehicles and most two-car trains have at least one Type 2 rail vehicle in their consist.

Type 1 vehicles have a high floor, and the center truck utilizes solid axles connecting the left and right wheels. Type 2 vehicles are of low-floor design, and the center truck is configured with independently rotating wheels on stub axles. The vehicle types have similar, but slightly different, key dimensions, as shown in Table 1.

TABLE 1 Key dimensions of vehicles by type

Dimension	Type 1	Type 2
Overall length	89.14 ft	92 ft
Powered wheel diameter (new)	28 in.	28 in.
Non-powered wheel diameter (new)	28 in.	26 in.
Center-to-center truck spacing	29.7 ft	34.5 ft
Truck wheel base	74.8 in.	70.8 in.

CHAPTER 5

DESCRIPTION OF DATA COLLECTED

Data collected during this test were intended to document the effectiveness of the film coating on the following performance parameters:

- Rail friction,
- Noise generated from passing trains, and
- Rail wear.

Where possible, data were collected before, during, and/or immediately after film deposition efforts, and after a 4-week period of daily operation.

5.1 RAIL FRICTION

Rail friction was measured using a hand-operated tribometer (Figure 3). The tribometer can be oriented to measure the rail friction of a single location on the rail, gage face to the top of the rail. The location and clearances of the low rail guard rail were such that no friction readings could be obtained on the rail in the curve. All low rail readings represent locations at the extreme ends of the curve. Typical well-lubricated gage faces in heavy-haul freight railroads would be indicated by friction readings of 0.2µ or less, while dry rail conditions are defined as any friction reading of 0.45µ or greater.

5.2 NOISE DATA COLLECTION HARDWARE AND SETUP

The Bruel & Kjaer (B&K) sound level meter, with a 4-Hz to 40-KHz frequency response microphone, was placed 8 ft from the rail gage and was used as the primary acoustic collection instrument (see Figure 4 for setup). In addition, two stereo microphones with 4-Hz to 20-KHz frequency response were placed within 4 ft of the passing transit car wheel-rail interface. All three test microphones were placed along a line perpendicular to the rails and at the top of the rail elevation. In this arrangement, the microphones maintained a direct line of sight to all noise-generating locations on the wheel-rail contact during every car pass.

Approximately 3 hours'worth of recorded acoustic information was collected during the test cycle. The acoustic signals from each microphone were simultaneously saved directly to magneto-optic digitizing media. Each acoustic-based file contains a time stamp that logs the date and time (within 1 min) of the recording of each collected test file. Some recorded audio tracks were also used to collect notes related to the physical setup and the recording procedures.

All recordings from the B&K sound level meter were made in the "linear" mode, so that the maximum bandwidth of the sound source is preserved. In this way, post filtering and/or plots from a limited set of frequency bands can be performed at any time in the future.

5.3 RAIL PROFILES AND RAIL WEAR

Tri-Met provided the use of a MiniProf™ rail profile measurement system during the test. The MiniProf™ uses a manually operated encoder mounted on a shaft with a linked arm. After inputting identification information into a laptop personal computer (PC), the operator traces the railhead using the linked arm, creating an $x:y$ profile matrix, which is then stored in the PC's memory. The use of software allows the user to obtain various overlay, wear, and profile characteristic statistics. Figure 5 shows a typical MiniProf™ profile from one of the test locations. The accuracy of the MiniProf™ is a function of the operator properly setting up the device at exactly the same location for each successive measurement and ensuring that the unit support arm is perpendicular to the rail. Repeatability audits have indicated that the MiniProf™ is accurate to approximately 0.002 in.; however, as coating thickness and wear experience during this test appeared to be less than this value, no significant information was obtained from the profile data.

Figure 3. Hand-operated tribometer.

Figure 4. Noise data microphones located on test curve.

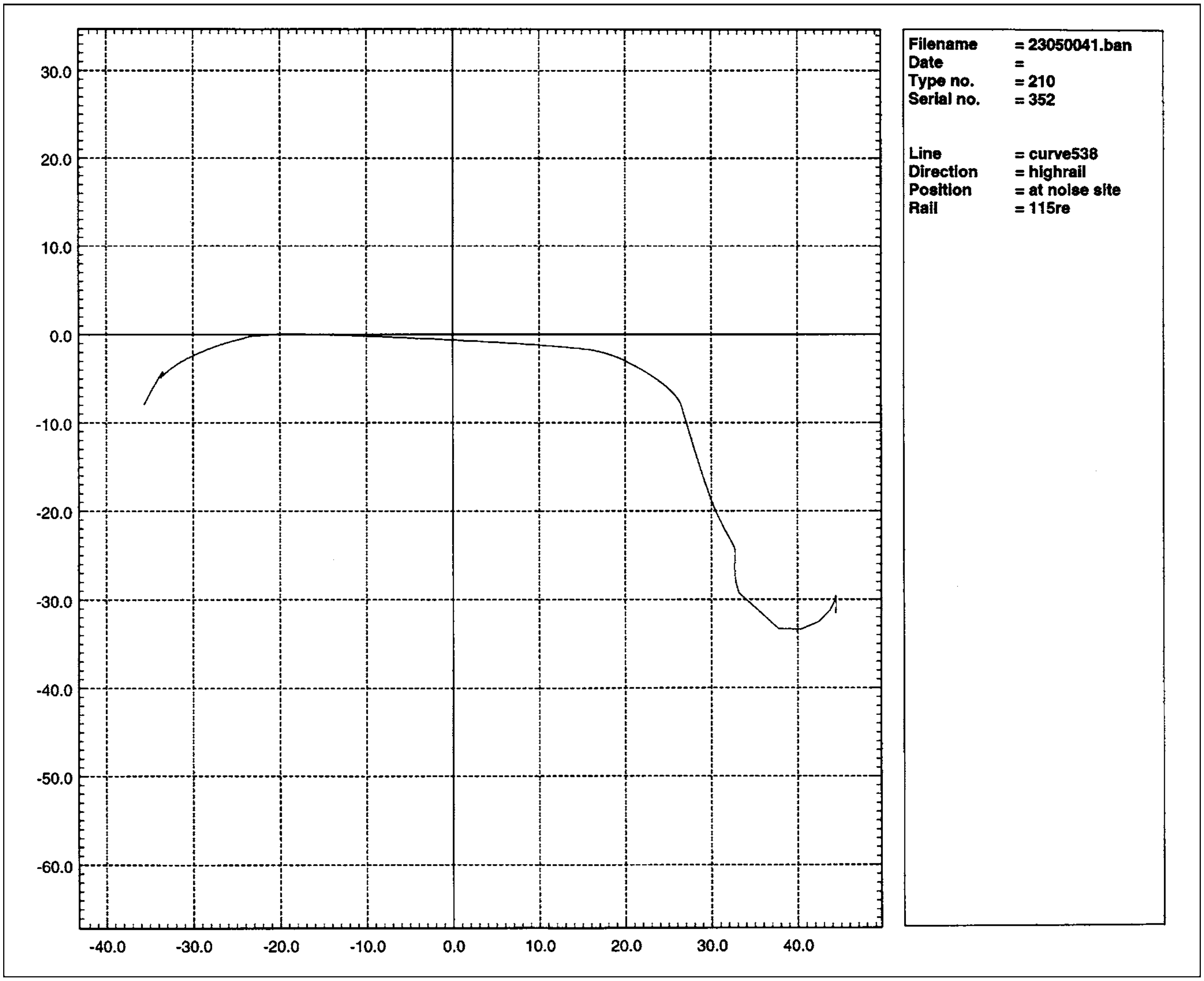


Figure 5. Typical MiniProf™ profile trace.

CHAPTER 6

FILM COATING

The material and the application process utilized for this demonstration were based on those used during earlier evaluations at TTC in Pueblo, Colorado, and modified to suit transit-specific needs. The process included the following major efforts:

1. Selection of optimum material for top-of-rail protection;
2. Site visit by engineering staff and application contractor representatives;
3. On the day of application, sandblasting of the rail running surface to remove all traces of oil, grease, and other contaminants; and
4. Spraying of coating material on the top of rail in the sequence as follows:
    a. Top of low rail and
    b. Top of high rail.

6.1 MATERIAL SELECTED

The material chosen, Fe-25Cr-5Al, has been used successfully in sliding contact applications and has proven durable and capable of consistently high-bond strengths. The high chromium content yields some measure of corrosion resistance and hardness, while the aluminum acts as both a hardening agent and a source of exothermic energy, which aids in increasing adhesive bond strength.

The coating was applied using a Thermion arc spray gun with Fe-25Cr-5Al wire. Excess grease was removed from the rail surface with a common degreasing agent. The rail was grit-blasted with garnet (abrasive) immediately prior to spraying. The rails were sprayed in sections 10 to 20 ft long. The applied coating was 0.003 to 0.005 in. thick. Only the running surface was coated. There was no post-treatment of the coating after deposition.

The results of the friction measurements after several weeks of traffic suggest that although some of the coating had been removed, enough surface modification remained to drop the friction level below that of the untreated rail. This behavior suggests that lubricant entrapment may be the primary mechanism of friction reduction over the untreated rail. Unfortunately, the only way to know for certain is to excise a section of rail. It may be possible to take advantage of how the coating behaves by designing a suitable solid lubricant system, which is easily applied and retained by the treated rail surface. Previous work on thermal spray coatings for freight railways used a nylon coating over a thin 1080 steel coating, with both coatings deposited by high-energy plasma spraying. There was a valid concern about the possibility of increasing the wheel-rail electrical contact resistance with this system, even with the nylon coating being only 0.005 in. thick. Any solid lubricant system for the transit system must consider this constraint.

6.2 THERMAL SPRAY COATING OF RAILROAD RAIL

Thermal spray coatings are formed by the aggregation of molten and semi-molten particles on a substrate, as Figure 6 illustrates. Figures 7 and 8 show the actual field process of sandblasting and film coating, respectively. Coatings can be formed from almost any material, ranging from polymers (such as nylon and Teflon) to metals (such as copper and lead) to ceramics (such as alumina and chromium oxide) to cermets (such as tungsten carbide-cobalt and chromium carbide-Nichrome). Almost any material that can be formed into a powder or a wire can be used.

Various processes are used to form these coatings. Common thermal spray processes are plasma spraying, high-velocity-oxygen-fuel (HVOF) spraying, flame spraying, detonation gun spraying, and twin-wire arc spraying. In the plasma spray process, a constrained arc is generated in a hollow anode. Gas flowing through the arc in the anode is heated and accelerated, producing a jet of hot (>15,000 kelvin) gas. The HVOF process uses the combustion of a fuel (e.g., propane, hydrogen, or kerosene) and oxygen at high pressure to form a high-velocity, hot exhaust jet. In detonation gun spraying, an explosive charge of oxygen and acetylene is ignited behind a cloud of powder, with the resulting shock wave both accelerating and heating the powder particles. The twin-wire arc process uses wire feedstock exclusively. In this process, an arc is formed between two wires and a gas jet accelerates the molten particles from the wire that are generated in the arc. All impart both kinetic and thermal energy to feedstock in the form of powders or wires.

Each process is tuned to impart enough thermal energy such that at least semi-molten particles are formed. The kinetic

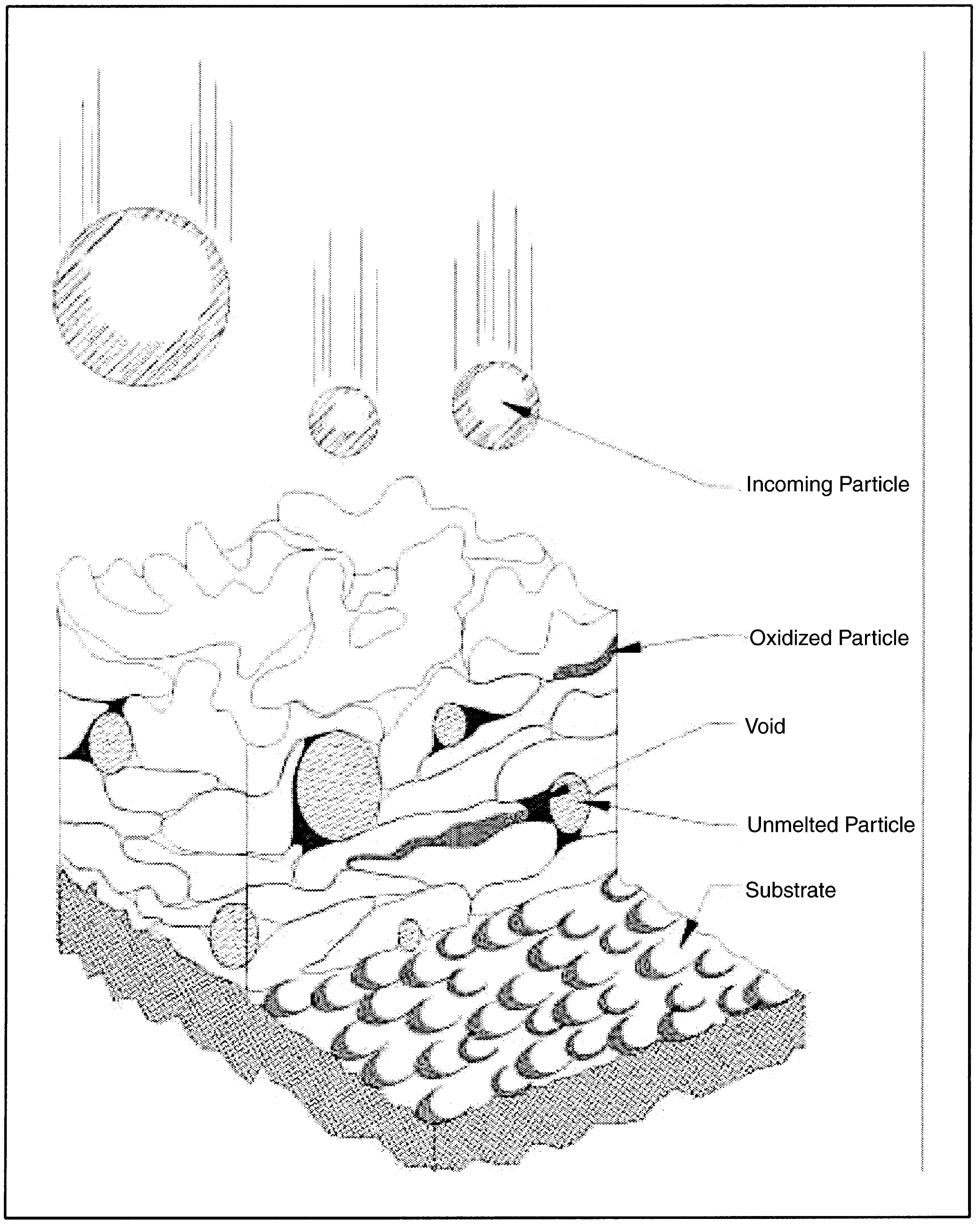


Figure 6. Schematic of a film coating.

energy inherent in the jet or plume of each process accelerates the particles to the substrate. The velocity attained ranges from sub-sonic (i.e., flame spraying) to near-sonic (i.e., plasma and twin-wire arc) to super-sonic (i.e., HVOF and detonation gun). In general, the higher the velocity attained by the particles, the greater the density (i.e., lower porosity) in the resulting coating.

In general, coating quality—as measured by adhesion/cohesion strength and amount of porosity—increases as the thermal and kinetic energy components of the process increase. However, an additional practical commercial consideration is the deposition rate. The throughput of many processes can be quite high, but actual deposition rate is quite low. Deposition efficiency is essentially the ratio of the deposition rate to the throughput. Processes such as plasma spraying and HVOF have deposition rate efficiencies on the order of 40 to 60 percent, while a process such as twin-wire arc spraying can be over 90 percent efficient and yield high-quality coatings. This was an important consideration in selection of a process to deposit a coating on the transit rails. In previous work for heavy-haul rails, plasma spraying was utilized, which, while producing a high-quality coating, had relatively low deposition rates. Deposition rates with twin-wire arc systems can easily exceed 50 lb/hr. With high deposition rates and coating quality approaching that of high-energy plasma and HVOF spraying, the twin-wire arc process was

Figure 7. Sandblasting of rail prior to film coating.

Figure 8. Application of coated film onto rail.

selected to deposit the friction modification coatings. An ancillary advantage to the twin-wire arc process is that power requirements are low (less than 40 kW), no gases other than compressed air from a standard air compressor are required, and the equipment is highly portable. One disadvantage to the twin-wire arc process is that it is limited to metallic feedstocks or those that can be produced in the form of a conductive wire.

The rail coating for noise reduction is essentially a friction modification coating. The aim for this project was to produce a coating that exhibited a low coefficient of friction as deposited. The original research in rail thermal spray coatings for heavy-haul systems examined two scenarios: one where the deposit provides inherently low friction in rolling contact with the wheel, and one where the as-deposited roughness captures conventional lubricants, such as greases, and acts as a reservoir or acts as a mechanical attachment mechanism for more non-conventional lubricants, such as polymers. The complexity of the latter scenario dictated that an inherently low friction deposit be used for the transit experiment.

Various wire feed stocks are available for use in the twin-wire arc process, ranging from pure metals (such as copper and nickel) to high-strength alloys (such as Inconel, Hastalloy, and 420 stainless steel), as well as alloy compositions with no relation to conventional wrought materials. Unfortunately, no data on any of these materials can be related directly to the friction behavior of the deposit under rolling contact, under either dry or lubricated conditions.

CHAPTER 7

TEST PLAN

A test sequence plan was formulated after site visits and discussions with Tri-Met engineering and operations personnel. Appendix A to this subreport details the schedule and sequence of events. No significant deviations from the test plan were required.

CHAPTER **8**

RESULTS

8.1 RAIL FRICTION

Rail friction was measured prior to, during, and at subsequent intervals after the coating process. The gage face remained relatively lubricated with heavy grease during most of the period, and no strong conclusions can be made for gage face performance. The gage face prior to coating efforts indicated friction levels of approximately 0.15μ to 0.18μ, which is considered generously or well lubricated. As the nearest wayside lubricators are located well away from the yard, gage face lubrication was being carried into the yard from the wheel flanges of passing trains.

Table 2 summarizes friction readings taken before, during, and after the coating process. On May 22, during the baseline testing period, the 1 PM and 3 PM friction readings indicated a significant change (reduction) in friction. During this time, it became noticeably warmer and some lubrication appeared to be carried from the gage face onto the top of the rail. Such low readings were never achieved during any subsequent measurement period.

A photograph of the rail surface, taken on June 29, shows the transition between the coated and uncoated section of the low rail (Figure 9). The darker area, to the right of the middle of the photograph, is of the coated rail while the shinier surface indicates where the rail was never coated. Friction measurements taken in this area indicate that at least a 0.1 higher friction value was obtained on the shiny, uncoated rail. This was consistent on both the high and low rails.

Friction data suggest that no significant reduction in friction was obtained as a result of the coating material, but that some lubricant was trapped in the coating surface, reducing friction by a factor of approximately 0.1 μ, when compared with the non-coated rail immediately adjacent to the coated rail.

8.2 NOISE

Noise data were collected from test cars operated especially for this program and from the fleet of cars departing under routine operations. The cars used for the special runs were selected from those in the yard being serviced or repaired. For the initial database, one car from each type (Type 1 and Type 2) was selected and held in the yard for a 2-day period. This allowed for multiple passes to be made with a single car of each type, as opposed to the routine departure fleet, which consisted entirely of two-car sets, usually with mixed types.

Initial baseline noise data were collected with single “test” car numbers 121 and 210. These runs included 10 to 12 passes (5 to 6 round trips) per car. The car was brought to the beginning of the test zone; the noise data collection equipment was then armed; and the car was given a signal to make a single pass and then stop. Car speed past the noise measurement data collection site was about 3 to 5 mph. Once stopped, the car was reversed and another pass was made. Car movements were not made when trains were approaching or passing on the adjacent mainline.

During early morning (4 to 6:50 AM), most of the car fleet in the yard departed using the test curve. Cars are operated in two-car train sets, passing the test site with the first car at about 4 to 5 mph and stopping at the departure signal. This brought the second car in each consist to a stop with the center truck near the measurement site. The trains would restart, generally within 15 to 40 sec, after which the last truck was measured. Because this was the general fleet departure and operations were “as is,” there was much more variability between trains and passes. A composite of all noise for each condition was made; data were presented from various scenarios, as Figure 10 shows.

Figure 10 demonstrates how the acoustic signature of a passing car varied with time. This figure shows the typical change in amplitude as a typical car travels by. The equipment was set up and, as a result, cars leaving the facility stopped at a point where the second measurement device was near the front end of the second car or near the middle of the second car’s body. The highest amplitudes in Figure 11 represent the times when the car’s wheels were nearest the reference B&K microphone. The high-pitched squeal and its variation in sound level, typically heard from the wheel-rail interface, is not fully demonstrated in this display. High-pass filtering of the above signal reveals a more rapidly changing amplitude over time. Figure 10 represents over 250,000 data points over the time span displayed. Unlike the time domain display of the noise shown in Figure 10, the remainder of the documented plots, relating to the acoustic recorded information will be presented in the spectral frequency domain.

Figure 11 shows the relative amplitude of noise over the frequency range of 100 to 5000 Hz for multiple passes of Car 121 at the following times:

TABLE 2 History of tribometer/rail friction measurements on test curve

DATE/ TIME	LOCATION OF MEASUREMENT/ TIME OR SEQUENCE	TOP OF INSIDE OR LOW RAIL	TOP OF OUTSIDE OR HIGH RAIL
5/22 1PM	Pre coating, existing rail	0.60	0.56
5/22 3PM	Pre coating, existing rail (warmer)	0.32	0.30
5/23 6AM	Pre coating, after morning fleet departure (light rain)	0.53	0.52
5/23 11AM	- No coating applied on high rail - After low rail only coated	>0.55 -	- 0.53
5/23 1PM	High rail no coating, Low rail coated Readings after 20 car passes Top rail lubrication migrated from gage face	0.55	0.30
5/23 4PM	Both rails coated, 15 additional car passes	0.43	0.46
5/23 4:30PM	Both rails coated, 12 additional car passes	0.48	0.50
5/23 5PM	Both rails coated End of day, approximately 50 car passes	0.58	0.40-0.48
5/24 6:30AM	During car fleet departure	0.60	0.60
5/26	**During normal operations***	**0.54**	**0.55**
5/31	**During normal operations***	**0.56**	**0.57**
6/2	**During normal operations***	**0.53**	**0.53**
6/8	**During normal operations***	**0.56**	**0.55**
6/13	**During normal operations***	**0.54**	**0.54**
6/28 12:30PM	4 weeks after coating. Coating measured in curve	0.49	0.45-0.49
6/28 12:30PM	Rail immediately next to end of coated section	0.62	0.58

*5/26 through 6/2 gage face, high rail, reading range from 0.40 to 0.47

- Before the rail was coated (dry top of rail, lubricated gage face), shown as Day 1 at 2 PM;
- After the top of the low rail was coated, high rail as before, shown as Day 2 at 1 PM;
- After the tops of both the high and low rails were coated, shown as Day 2 at 4:15 PM, and
- One day after the rail was coated, after the entire fleet had passed over the curve; shown as Day 3 at 7 AM.

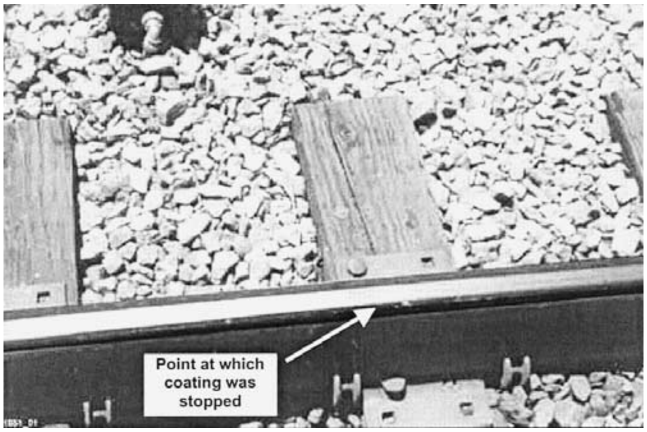


Figure 9. Arrow points to dark to shiny rail at end of coating.

The data show that, before coating, this car created very high relative amplitudes at 2200, 2600, 2800, and 3900 Hz; whereas, immediately after coating, all peaks were significantly reduced. In fact, all dominant peaks were about one-fourth the amplitude of that observed before rail coating. In the case of the highest peak, the reduction was more than a factor of six.

The next morning at 7 AM, a follow-up recording revealed that the noise reducing capability of the coating had diminished. The early morning post-test of Car 121 provided evidence that the 2200 and 2800 Hz peaks had returned and actually grown to extend above what they had been before the rails were coated. The other major acoustic peaks, however, had remained at their relatively low amplitude state. The same data, only displayed over a relative log amplitude sound-level scale, are shown in Figure 12.

The information in Figures 11 and 12 has several implications. That the acoustic signatures were reduced in amplitude immediately after the rails were coated implies that noise normally generated by the wheel-rail interface had changed

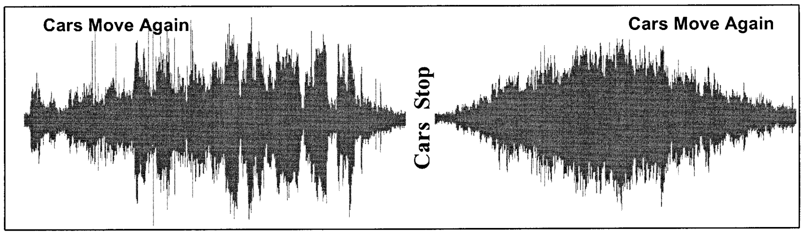


Figure 10. Acoustic changes over time as Car 121 passes the microphone recording site.

drastically at the loudest noise-generating frequencies. If this noise suppression capability could be sustained over a long period, it would be highly advantageous to the transit industry. Permanent suppression of the wheel-rail noise would allow the industry to selectively apply the rail coating wherever excessive car noise occurs. In addition, wear might also be reduced. Unfortunately, this particular coating—as applied in this test—did not appear to sustain its immediate noise suppression capacity over the long term.

Figures 11 through 20 represent all of the acoustic data gathered during the rail-coating evaluation study. Two types of graphics are presented: linear spectra and log base 10 spectra. For all the plots displayed, only two scales have been used throughout for the vertical axes of the plots. Graphs presented on a linear vertical scale have a uniform relative vertical scale. All plots presented in log form have another uniform vertical scale. This allows comparison of the various graphics presented. The various horizontal lines in the log plots represent relative decade changes in the recorded sound level.

While Figures 13 and 14 show that the coating provided some reduction in noise level immediately after application, they also show that the reduction was not effective over a 4-week period. Although Car 121 was not available for use in dedicated test train moves during the 4th week data collection period, Car 121 was in one of the outbound train consists. Given that each car was identified in the sound file logging procedures, the original acoustic signals from Car 121 could be directly compared with the signatures captured from it 4 weeks later.

Figure 13 shows that the peaks generated during uncoated rail operations were about the same for 2600 and 3900 Hz. Figure 14 shows these same data; however, amplitudes are on a log scale. After 4 weeks, the lower frequencies (less than approximately 2300 Hz) generated higher levels of noise than before the coating process. In particular, the peak at 1300 Hz is noticeably higher.

Even though these frequency noise data plots are very similar in character, many frequency bands are clearly related to the car wheel dynamics and rail surface stick-slip friction stability. Some low-frequency noise content (particularly that below 500 Hz) could, however, be the result of higher ambient background noise at the site from one day to another. It is also possible that some of the spikes in these curves are related to slight variations over time in the mechanical assemblies carried on the vehicle itself (e.g., brake rigging, air conditioning blowers, and hydraulics) and not derived solely from the wheel-rail interface.

As can be expected, each car (or two-car train) generated different levels of noise. During train passes, some cars were noticeably quieter than others, despite rail conditions that

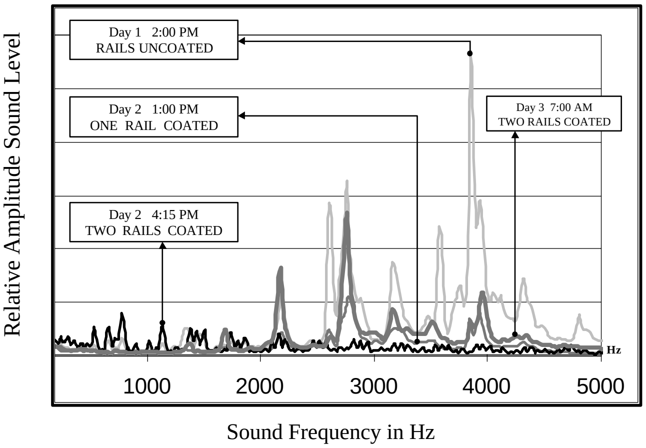


Figure 11. Acoustic changes before, during, and immediately after coating (relative amplitude sound level) Car 121 only.

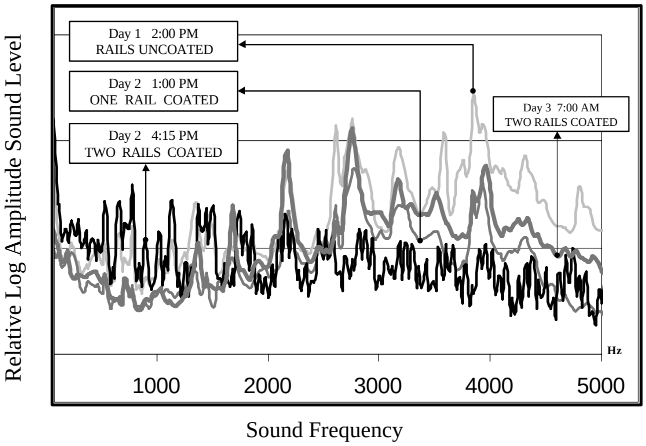
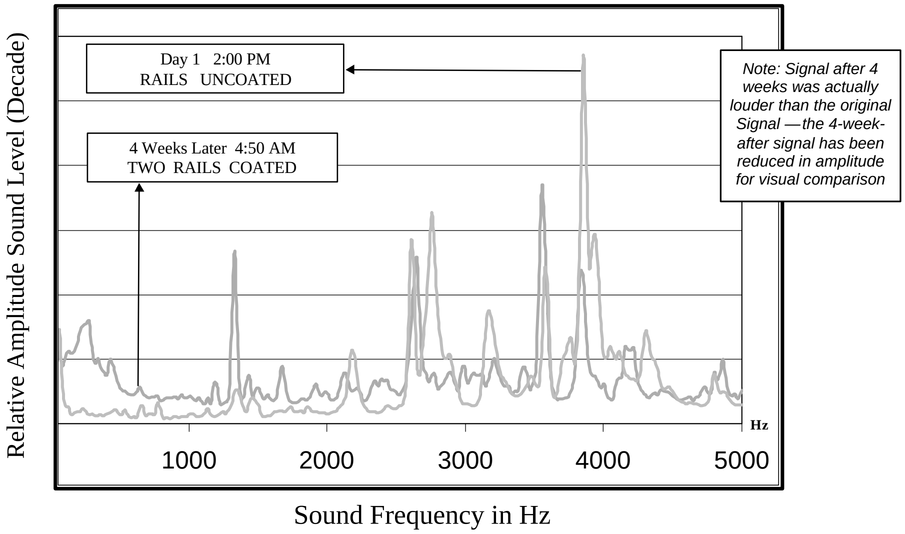


Figure 12. Acoustic changes before, during and immediately after coating.



Note: Signal after 4 weeks was actually louder than the original Signal — the 4-week-after signal has been reduced in amplitude for visual comparison

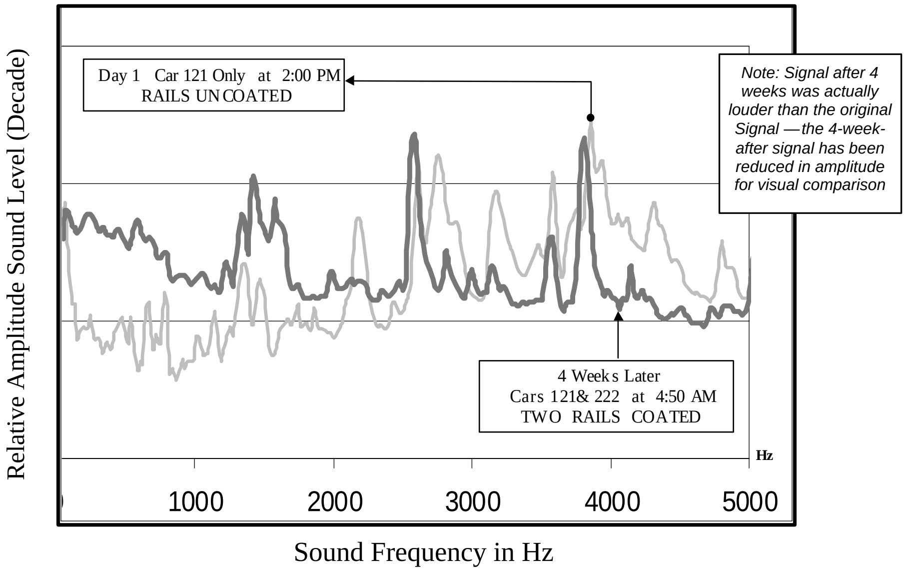
Figure 13. Noise changes, Car 121 only, uncoated compared to coated after 4 weeks of operation.

remained uniform. Thus one car may be very quiet, while the next one may produce a loud squeal.

The data in Figure 15 are identical to those presented in Figure 16. However, Figure 15 is in linear form and Figure 16 is in log form–which is equivalent to the sound decibel level of the noise. Displaying the acoustic data in both formats is for convenience and allows readers to use whichever format is most familiar.

The various amounts of squeal and their associated frequency bands are shown in Figures 15 and 16, which display the noise history of all 10 two-car train departures during the morning shift. Peak noise amplitude is the problem noticed by most people. This is not surprising given that specific frequency bands generate 10 to 30 times the nominal noise generated by most bands.

Figure 15 contains the acoustic signatures from every car that left the yard on the morning of June 29. There was a wide variation in emitted sound. Some cars emitted loud squeals and others generated little or no sound at all. The curves in Figure 15 provide a representative image of the sound spec-



Note: Signal after 4 weeks was actually louder than the original Signal — the 4-week-after signal has been reduced in amplitude for visual comparison

Figure 14. Noise after coating and after 4 weeks, Car 121 only, relative log amplitude sound level.

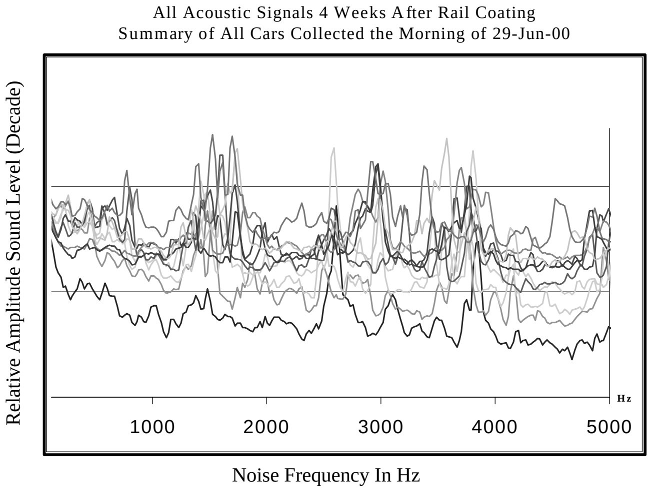


Figure 15. Noise data from 10, two-car trains departing yard noise frequency in Hz.

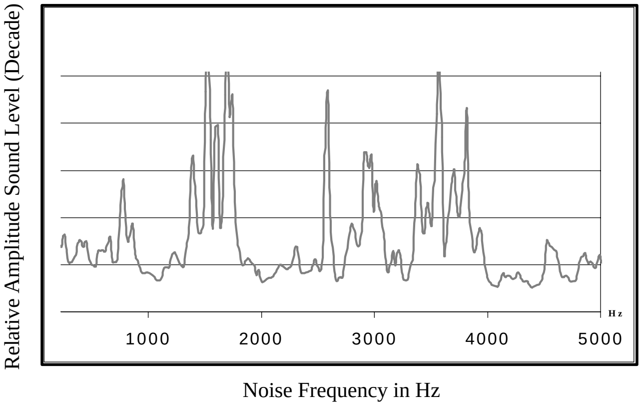


Figure 17. Maximum noise for all trains departing 4 weeks after coating relative log amplitude sound level.

tral variation seen throughout the morning of recording. The sound amplitude varied by as much as two orders of magnitude as the various cars passed the wayside monitoring site.

Figure 17 shows the maximum peak for all the car passes shown in Figure 15, while Figure 18 displays the same peak data in a relative log amplitude form that is shown in Figure 16.

The variations shown in Figures 15 and 16 are quite typical when stick-slip instability occurs at the wheel-rail interface. Stick-slip is a condition in which a mechanical system, such as the wheel rail, oscillates rapidly, resulting in noise such as squeal. This type of sound generation is similar to that of a snow shovel on pavement. With just the right pressure and movement, the tip of the snow shovel can oscillate rapidly, creating a very loud squeal.

By comparing the data from the entire departure fleet immediately after coating both rails and 4 weeks later, the effect of the coating over this period can be shown. This is shown in Figures 19 and 20, and as the single car (121) data show, the noise level after 4 weeks is considerably higher than immediately after coating.

One band of frequencies (1000 Hz) appears to be louder before coating than it was observed to be after 4 weeks. A specific audio review of that noise band revealed that a mainline train had passed on adjacent tracks during a portion of the time that one of the initial datasets was recorded. Careful review of that one passing train indicates that, because of its relative distance from the microphone, this particular band of frequencies is the only one affected.

The data collection times compared on Figures 19 and 20 were from May 24 and June 29, respectively. The car fleet making up the 10 trains on the 2 days was different. Of the 20 cars making up the noise databases, only 6 had been in both consists on both days.

Again this figure demonstrates that the wheel-rail interface sound observed immediately after rail coating was approxi-

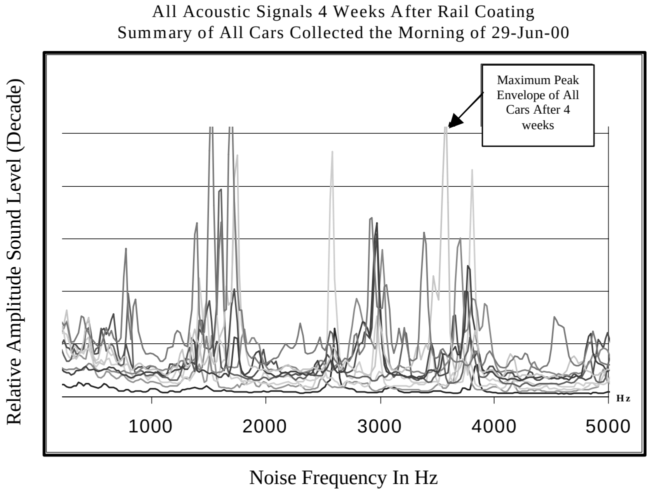


Figure 16. Noise data from 10, two-car trains departing yard relative log amplitude sound level.

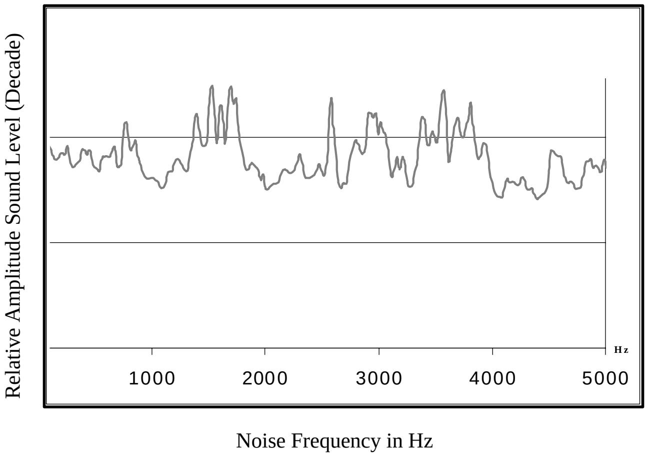


Figure 18. Maximum noise for all trains departing 4 weeks after coating relative log amplitude sound level.

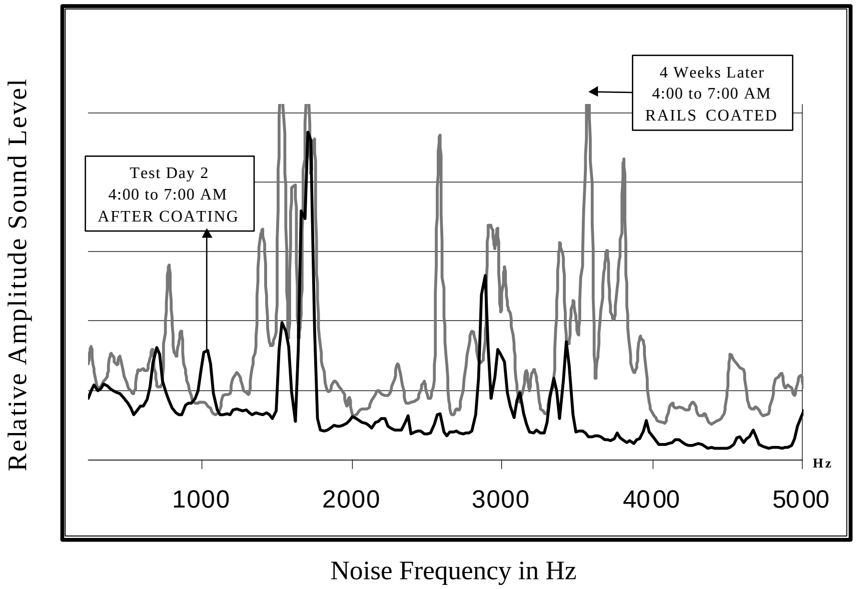


Figure 19. Maximum peak noise for morning train fleet, after coating and 4 weeks after coating, relative amplitude sound level.

mately 1 to 2 log scale decades below that observed after 4 weeks of train operation over the coated rail section.

8.3 PROFILE/SHAPE CHANGES

MiniProf™ data were collected to show profiles of the rails before coating, after coating, and after 4 weeks of operations. MiniProf™ allows multiple profiles to be overlaid and measurements of changes in rail height and width to be computed. Because overlaying a profile is difficult and because of the thickness of film coating, no significant differences between profiles measured before and after coating were noted.

Three locations on the body of the curve were selected—one at the noise collection site near mid curve, and the others near the curve ends. Profiles were collected at each site on the low and high rails and were repeated at least twice each time. Comparing the uncoated with immediately after coating data indicated changes in railhead height of 0.002 to 0.335 mm; but, most sites indicated changes of less than 0.2 mm. Comparison of rail profiles after coating with those profiles of 4 weeks later indicated no discernable changes, indicating the amount of rail wear (gage and top) during this period was insignificant and not measurable. Appendix B to this subreport shows examples of several profiles.

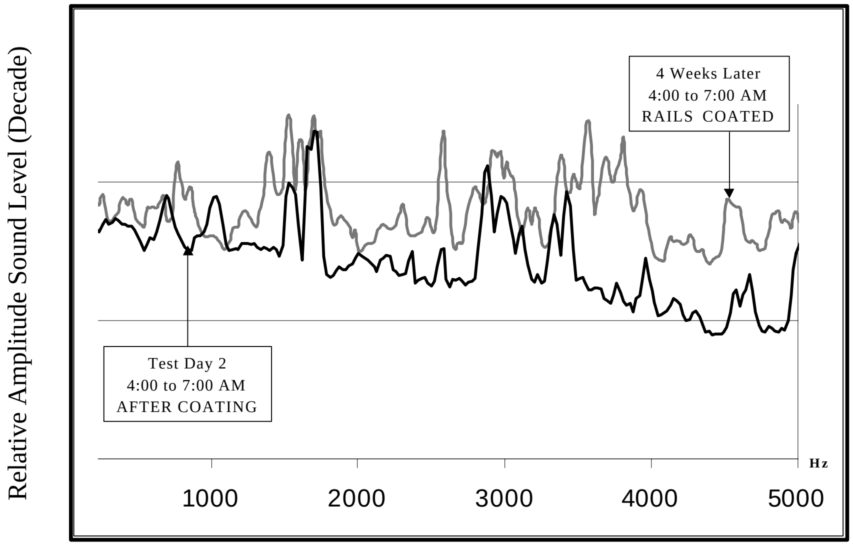


Figure 20. Maximum peak noise for morning train fleet, immediately after coating and 4 weeks after coating, relative log amplitude sound level.

8.4 FILM PERFORMANCE AND DURABILITY

The film was applied on the top surface of both the inside and outside rails. After several weeks of operation, observers noted small flakes appearing on the rail surface at or near the edge of the rail-wheel contact patch. During the 4-week measurement cycle, additional larger flakes were noted at isolated locations along the curve. Figures 21 and 22 show the appearance of the top of the rail at locations where thin metal flakes were being created on the rail surface.

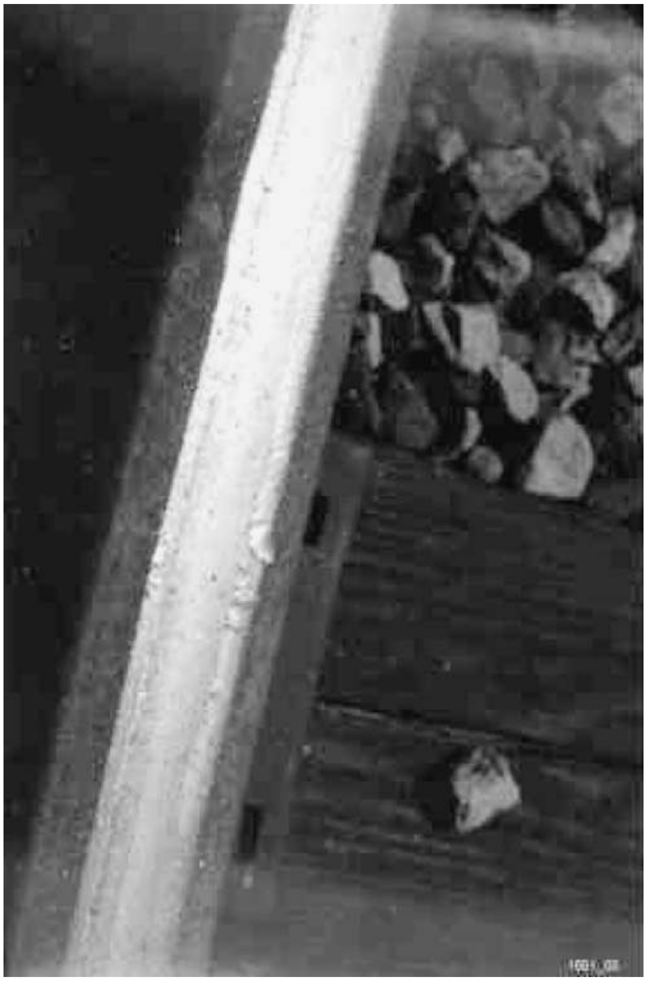


Figure 21. Top of rail flaking 4 weeks after treatment.

Figure 22. Top of rail 4 weeks after coating, showing film flaking off rail.

CHAPTER 9

CONCLUSIONS

- Although the use of a material bonded to the rail did reduce noise and friction, its effect was not sufficiently significant (friction reduction was approximately 0.1), and the material only withstood the rigors of daily operation for 4 or fewer weeks. Because of the cost and complexity of the application equipment, field application in the railroad environment appears to be limited.
- Cleaning requirements for the rail surfaces are stringent, and any residual dirt, oil, or grease will reduce the bond strength between rail and coating materials. This will result in premature flaking and loss of material.
- Future applications of this process may be feasible for in-the-shop application where surface preparation efforts are easier to control and material to be coated will be more uniform. Potential applications include moving parts, such as switch plates and gears, where a thicker coating that is more apt to hold excess lubricant can be applied.
- The use of a bonded film with lubrication could reduce the amount of lubricant that migrated to areas where it is not needed.
- During the various phases of data collection, noise reduction appeared to be affected most by the presence of excess lubricant on the gage face migrating to the top of the rail. This suggests that alternative and more reliable applications of oil and grease may produce more consistent reductions in noise with resulting increased rail life. Such lubrication can be obtained by optimizing the layout of wayside or vehicle-mounted lubricators.

APPENDIX A

TEST SCHEDULE FOR THE PLASMA SPRAY FILM COATING PROJECT

Portland Tri-Met—Gresham Yard, Curve C-538

Overview: Evaluate effectiveness and life of Plasma Spray Film Coated rail to reduce noise in track under revenue conditions. Noise, friction, and rail profile information will be collected before, during, and after the rail has been coated with a metallic-based film designed to reduce noise and friction. Application system requires that the rail be cleaned utilizing a grit blast method just prior to installation. All application devices and measurements during the evaluation utilize either off-track-based equipment or can be removed from the track upon 5 minutes notice to allow passage of non-test trains and equipment. Primary test installation date is the week of May 22, 2000.

Monday, May 15	TTCI to verify with Ken Kirse overall schedule. Tri-Met to ensure residual lubrication is minimized and no additional lubrication to be applied manually at or near test curve.
Sunday, May 21	TTCI, NSEW staff arrive Portland.
Monday, May 22	
9:00 AM	TTCI, NSEW and Ken Kirse meet at Gresham Yard. Inspect curve and ensure rail is “dry.” If not, make arrangements for additional cleaning. Set up noise data collection system. Requires 110 vac power extension cord to nearby commercial power. Mark and identify all microphone locations to facilitate replacement in exact same locations for future data collection efforts. Park van containing noise data collection equipment inside of “wye” area, run cables to and under rails near center of curve. Tri-Met/TTCI personnel to select and mark locations on the rail for MiniProf$^{\mathrm{TM}}$ profile data. Measure locations for initial profile shape database using Tri-Met MiniProf$^{\mathrm{TM}}$ profilometer.
1:00 PM	OGI/Flamespray Northwest personnel arrive at Gresham Yard with coating equipment. Tri-Met to provide 125 cfm air compressor, pushcart for use during coating procedures. 440 volt, 3-phase power supply to be provided by OGI/Flamespray NW. Set up hoses and application equipment off track, next to curve. Will require access to inside of wye and opening of gate.
1:30 PM or later (exact time TBD)	Identify and “hold” one each of single car Types 1 and 2. Cars identified should have “normal” wheel wear patterns (avoid cars with condemnable or recently turned or replaced wheels). These two cars will need to be kept out of regular service until approximately 10 PM the next day. Operate single car Type 1 back and forth along Curve C-538 under direction of noise data collection crew/Ken Kirse for approximately 40 minutes. This will serve as baseline data for car Type 1. Collect tribometer (rail friction) and noise data. Move car Type 1 to yard for storage, bring out a single car of Type 2. Repeat noise and tribometer tests, for up to 40 minutes. Move car Type 2 and store in yard. Note: Ensure that both cars are not utilized for revenue service until released from testing, approximately 10 PM next day.

Crews to remove noise collection equipment as needed to ensure security. Equipment to be stored in van that will remain parked and locked in wye location.

Similar security measures as needed by the film deposition crew.

Tuesday, May 22

4:00 AM TTCI, NSEW and Tri-Met personnel arrive at Gresham Yard.

Set up wayside noise-collection equipment (approximately 1 hr).

Collect data from all passing trains departing yard via test curve. Car configurations (Type 1 or 2) and car numbers to be collected by NSEW for log purposes. Obtain periodic tribometer readings to verify rail friction.

6:00 AM Revise time as needed. OGI and Flamespray Northwest crews arrive at Gresham Yard. Proceed to set up application equipment and prepare for coating.
Note: Limit extra noise and warm-up of compressor, generator to avoid impacting noise data.

7:30 AM (approximate) Morning departure fleet completed.
Commence application of film on top of inside rail only.
During coating operation, tribometer and MiniProf™ rail profile measurements will be made periodically on the inside rail.

From this point on, we will request full-time occupancy of the test curve. Other train moves can be made with a 5-minute advance notice to allow clearing of applicator equipment and personnel. At no time during the test will the track be impassable or out of service.

Current estimate allows for 6 hours to coat 200 ft of rail.
All subsequent schedules are based on a 6-hour time slot to coat 200 ft of the inside rail. This schedule will be revised if a new application estimate is received, thus all train crew time requirements are tentative.

1:30 PM Complete coating of rail.
Remove and relocate coating equipment in preparation to coat top of outside rail.

Locate stored car Type 1 from yard, operate for approximately 30 minutes to obtain noise data from cars passing over rail with low-rail-only friction control. Take selected tribometer measurements during the operation to determine if friction changes due to “wear in” of the coating.

Move car Type 1 back into yard, repeat with car Type 2.

Store car Types 1 and 2 for additional runs later this shift.

2:30 PM Complete car Types 1 and 2 noise testing with low rail only coated with film.

Repeat coating process on high rail, top of rail only for the same 200-ft length of track. Obtain periodic tribometer and MiniProf™ measurements during the coating process.

8:30 PM Complete coating process, store equipment.

Repeat single-pass noise data with car Types 1 and 2.
Bring cars from yard one at a time, collect noise and tribometer data for approximately 30 minutes each car.

9:30 PM Activities complete for this day.
Cars can be released to general service at this time.
Store/secure noise collection equipment as needed for final data collection next morning.

Wednesday, May 24

4:00 AM Tri-Met, TTCI, NSEW personnel meet at Gresham Yard.
Setup noise data collection equipment (approximately 1 h).

Collect data from all passing trains departing yard via test curve. Car configurations (Type 1 or 2) and car numbers to be collected by NSEW for log purposes. Obtain periodic tribometer readings

	to verify rail friction. This will repeat data collected previously on dry rails and allow noise generated by a train passing over track with both rails coated to be compared with other conditions.
7:30 AM (approximate)	Morning departure fleet completed. NSEW, OGI, and Flamespray Northwest pack all equipment used during test.
Thursday, Friday	Contingency days for delays caused by rain, equipment failures.

Note: Film friction to be monitored by Tri-Met personnel on a daily/weekly basis to be determined and agreed during installation sequence. When friction rises to a level indicating that effectiveness is wearing off, a 1-day measurement of typical train passes (as shown for Wednesday, 4:00 AM to 7:30 AM) will be scheduled. This will entail bringing in NSEW to collect additional noise data during the morning outbound rush. This last data collection is tentatively planned for approximately 8 weeks after initial installation.

Primary contacts:

Ken Kirse, Portland Tri-Met
Phone: 503-239-2141

Richard Reiff, TTCI
Phone: 719-584-0581

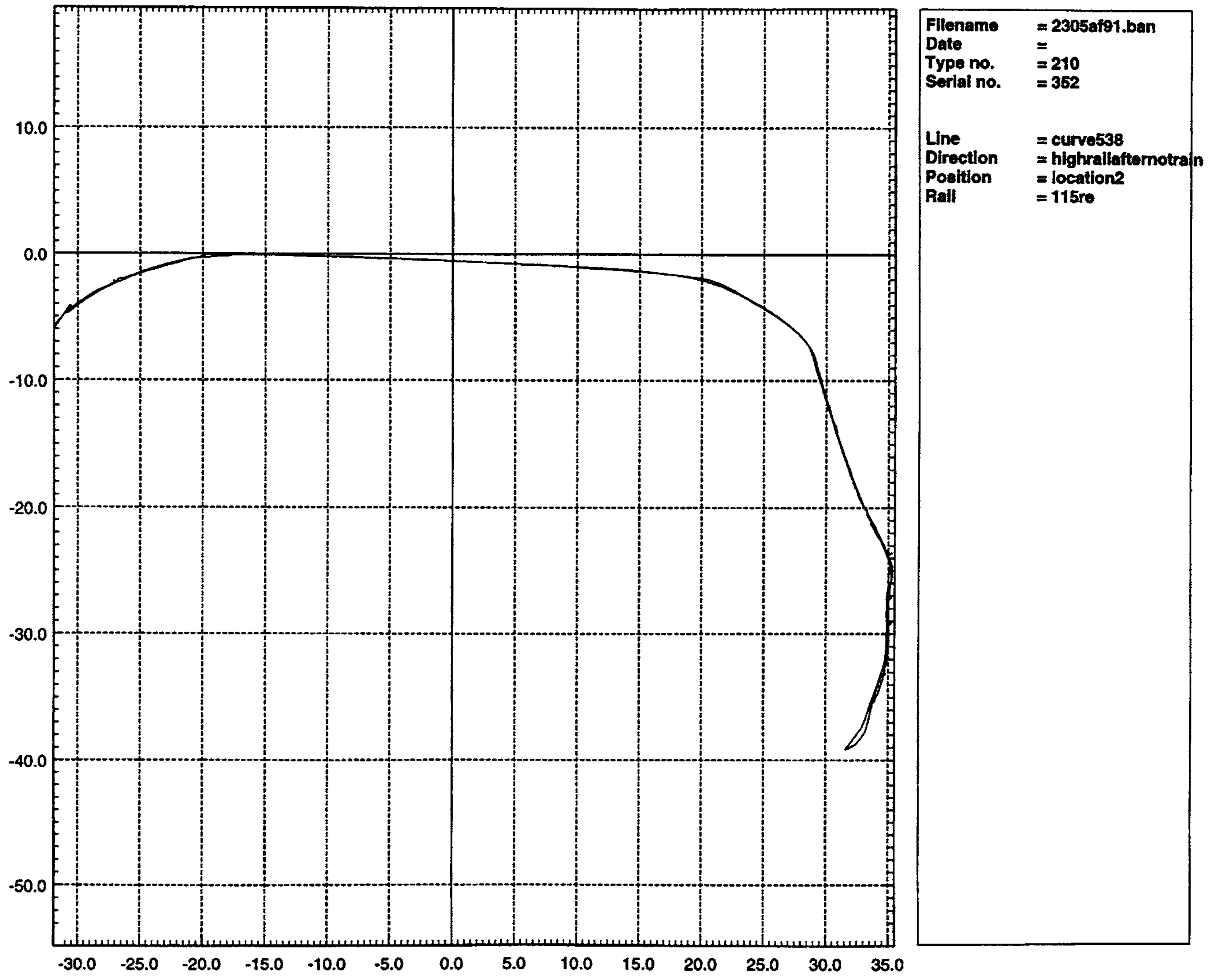
Richard Smith, NSEW
(noise data collection and analysis contract)
518-877-6085

Milt Scholl, OGI
503-690-1271

Joe Orint, Flamespray Northwest
(film coating equipment and installation)
206-762-8019

APPENDIX B

SAMPLE MINIPROF™ OVERLAY TRACES



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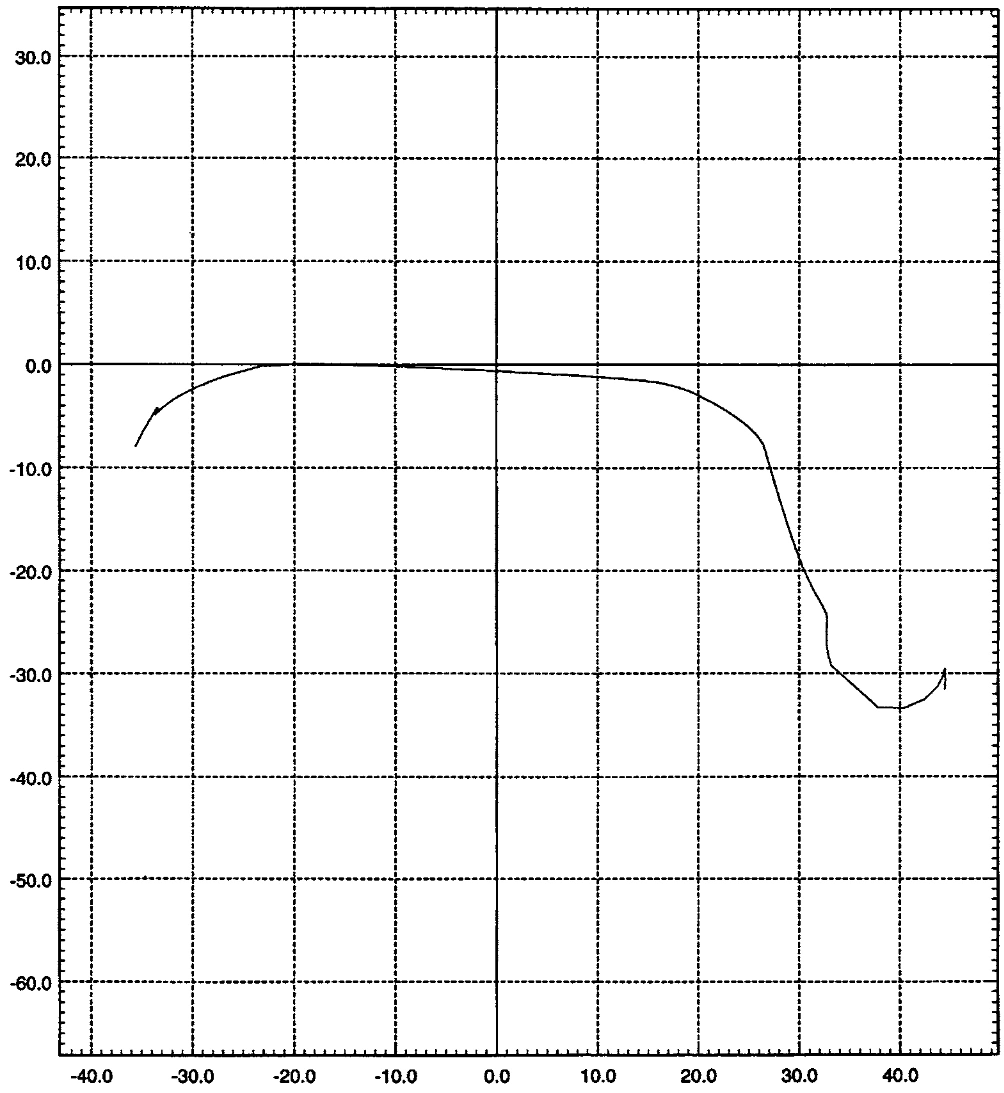

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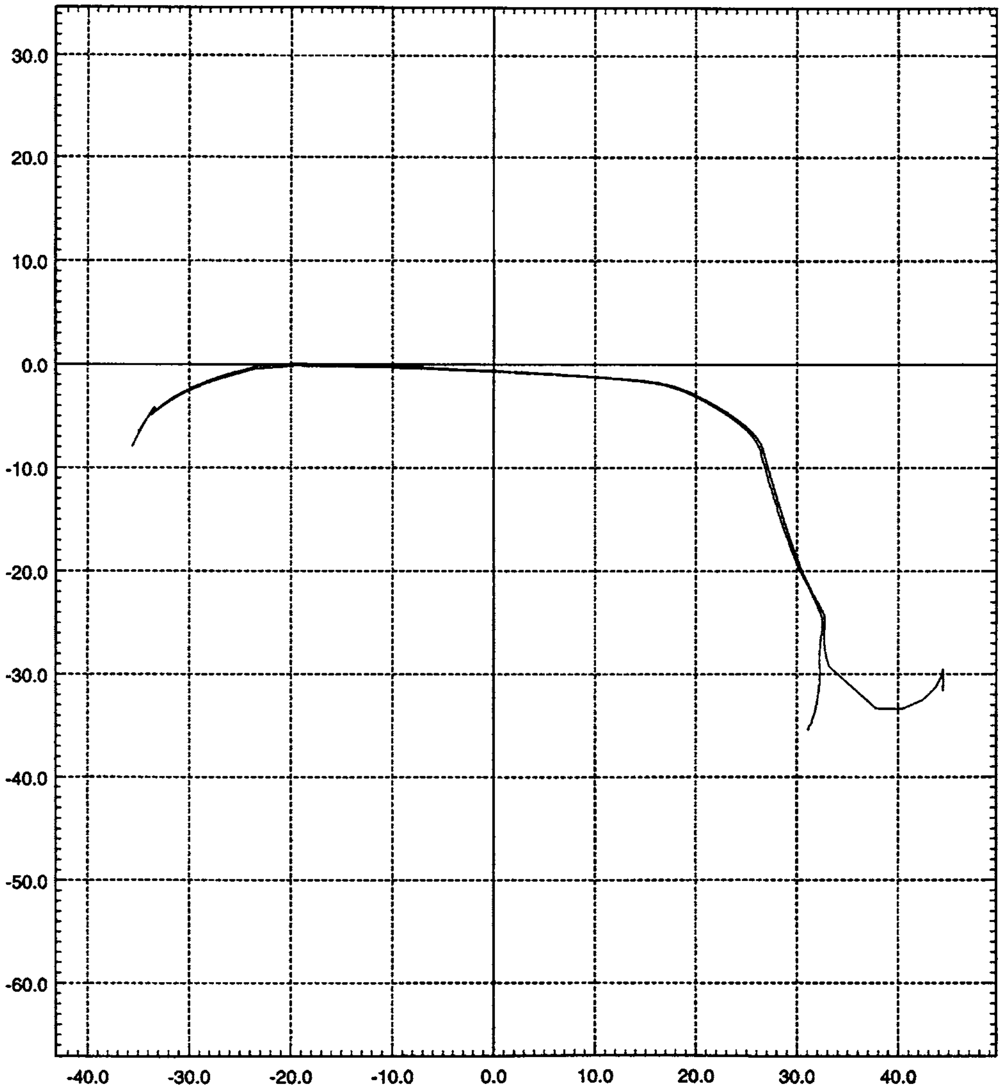

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