APPLICATION OF NEW LUBRICANT and FRICTION MODIFIER FORMULATIONS FOR THE REDUCTION OF WHEEL SQUEL NOISE UNDER FREIGHT and PASSENGER SERVICE

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ABSTRACT

Wheel sequel noise on curved track is a serious problem in residential areas where the tracks are near or adjacent to homes and residences. This was the case in a Southern California community that was adjacent to a Southern Pacific Railroad mainline that carried both freight and passenger traffic. The specific wheel squeal problem was associated with the negotiation of the moderate curved track by the mix of traffic at a range of speeds and operating conditions.

While significant noise levels were recorded by all of the traffic, to include commuter and inter-urban passenger traffic, the highest levels of noise were recorded by intermodal freight equipment, both trailer and container carrying. These n0ise levels were of significant magnitude and resulted in numerous complaints as well a'$ follow up lawsuits from the residents.

In order to address this noise problem, the dynamics of the wheel/rail interaction mechanism was examined and a two part solution applied. The solution consisted of using a low coefficient of friction modifiers on the gage face of the high rail of the curve(s) in conjunction with a high positive coefficient of friction modifiers on the top of the rail head on both the high and low rails. In this configuration, lateral slip of the wheel tread across the rail head was significantly reduced, together with the more traditional flanging effects 011 the gage face of the high rail. The result was a significant reduction in the level of noise generated by all of the traffic types.

In order to achieve this dual application at specific locations on the rail head, a high rail vehicle mounted application system was developed and utilized. The hi-rail based system allowed for a uniform and accurate application of the friction modifiers onto the rail. However, the friction modifiers deteriorated with time and traffic (as a function of the number of axle passes), and as such had to be reapplied on a regular and ongoing basis.

This paper describes the development and application of this combination of friction modifiers to the high noise curve(s) as well as the determination of the rate of degradation of the friction modifiers under traffic. The testing of the Friction Modifiers (Lubricants) performance led to the development of a well defined friction modifier effectiveness degradation curve which served as the basis for an ongoing program of friction modifiers aimed at keeping the level of noise below a defined threshold. In addition, the need for a "reasonably long" interval between friction modifier applications led to the development of an extended life version of the friction modifiers that made them appropriate for use in an ongoing maintenance application.

INTRODUCTION

Wheel squeal noise is one of the most noticeable types of wheel/rail noise produced in the railway environment. It can be extremely discomforting to both riders (in the case of passenger operations) and to people within or adjacent to the right of way (in the case of both freight and passenger operations).

Wheel squeal is associated with curved track, and can be found on both passenger and freight operations. While most commonly associated with the very sharp curves found on transit systems, it is also present on moderate curves under a range of traffics. Wheel squeal is often intermittent in nature, thus varying with time of day, weather conditions, etc., usually due to changes in humidity or moisture conditions. [1].

Three different mechanisms have been postulated for wheel squeal [1]

- Longitudinal stick-slip
- Wheel flange contact with rail gage face
- Stick-slip due to lateral creep across the railhead

Of these three mechanisms, latera1 slip of the wheel tread across the rail head has been postulated as being the most probable cause of wheel squeal [1,2]. (Though there is still evidence to suggest that wheel flange contact also plays a role [l]).

Analysis of the lateral slip mechanism, indicates that the shape of the friction- creep curve is very influential in defining the stick-slip behavior of the wheel/rail set. If the slope of the friction-creep curve (see Figure 1 [1.]) is negative, amplification of the vibration at a modal frequency is possible, resulting in wheel squeal. This, in turn suggests, modification of the friction-creep curve characteristics to control noise. Such an approach, using friction modifiers (both positive and negative) have been used to control this class of wheel/rail noise

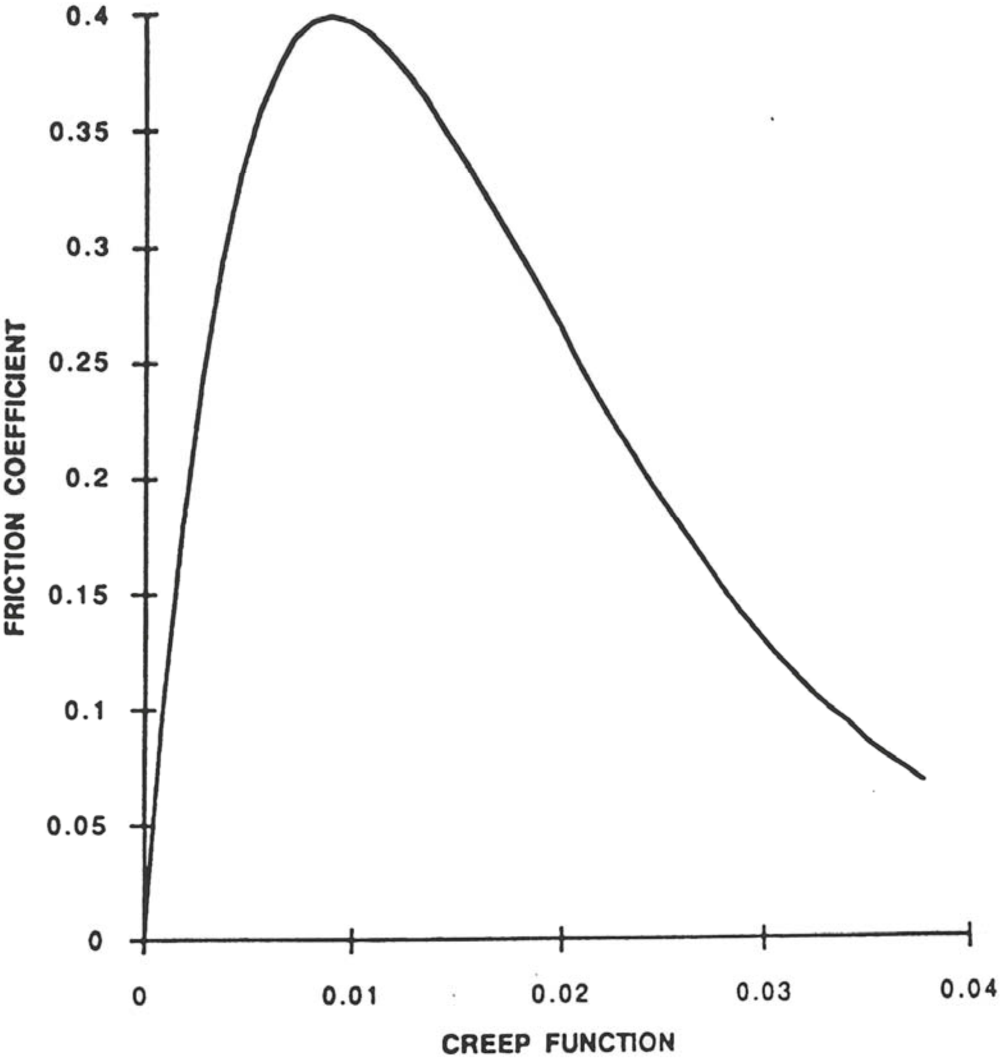

Figure 1 FRICTION VERSUS CREEP

NOISE PROBLEM

The specific noise problem that was addressed here was a wheel squeal noise problem on the Southern Pacific Railroad (now part of the Union Pacific Railroad) in Southern California. A particular problem curve was a 5 degree curve (******meter radius) at MP 391, North of Los Angeles, in the vicinity of Faria Beach, California. The curve was located adjacent to a community at Faria Beach, with numerous complaints about the wheel squeal noise reported by the residents.

The curve was supere1evated (canted) 4-1/2 and was maintained as an FRA Class 3 track with passenger speeds of 60 mph and freight speeds of 40 mph. Traffic consisted ofapproximate1y 4 to 6 freight trains per day and 10-12 passenger trains day (8 commuter trains and 2 Amtrak Inter-urban trains).

Initial reports were that the "loudest" noise came from 89' flat cars as well as from Double Stack equipment. Note: There was a high percentage of intermodal trains on this line.

Noise measurements as high as 107 dB were reported, with numerous occurrences of noise levels above 100 dB (measured 100' from track).

Early attempts to control the noise included:

- Conventional grease application to the wheel; flange (rail gage face) using wayside lubricators
- Changing elevation (cant)
- Reducing train speed
- Profile grinding of the curve to improve wheelset steering and reduce flanging

All proved ineffectual in noise reduction.

PROPOSED SOLUTION

The solution that was proposed was the application of two distinct friction modifiers to the wheel/rail interface:

- A high positive friction modifier (Kelsan HPF) applied to the head of the, rail/tread of the wheel
- A low friction modified-friction modifier (Kelsan LCF) applied to the gage face of the rail/flange of the wheel.

The high friction modifier is designed to flatten the friction-creep curve, and improve adhesion, thus reducing lateral stick-slip of the wheel tread across the rail head.

Note: according to the manufacturer, the high friction modifier, HPF, generated coefficient of friction (μ) as follows:

μ = .17 at 2 1/2% creep
μ = .36 at 30 % creep

The low friction modifier is designed to reduce the flanging effect of the axle of the trucks (bogies).

Note: according to the manufacturer [4], LCF generated coefficient of friction (μ) as follows:

uncontaminated μ= 0.06
contaminated μ = 0.12 - 0.16

This approach has been used successfully in transit applications, with a solid "stick" friction modifier mounted on the car [3]. In this configuration, every car is equipped with a set of friction modifiers applying the respective modifier to the proper location (i.e. positive friction modifiers to the wheel tread and low friction modifiers to the wheel flange).

This approach could not be used in this environment because the vehicle, particular the freight vehicles were not route dedicated, but rather roamed throughout North America as part of the free interchange system. Thus, there was no possible way to mount friction modifiers to the vehicles.

The approach that was then taken was to develop a liquid form of the two friction modifiers and use a hi-rail mounted applicator to apply the liquid friction modifiers to the rail. Separate applicator systems and nozzles were required to apply the high positive friction modifiers to the head of the rail (on both rails) and the low friction modifiers to the gage face of the high (outside) rail. The applicator was mounted on the track supervisor's vehicle so that he was able to apply the modifiers to the rail head as he inspected his territory. (Note: This use of a hi-rail Friction Modifier applicator is extensively used in North America on low to moderate density lines, however has been confined to the application of friction modifiers to the gage face of the rail.) Because of the different characteristics of the high positive friction modifiers (in liquid form) a new design applicator had to be developed. (A wayside mounted version was not possible because of the very high accuracy in application needed for the two friction modifier approach.)

Because the friction modifiers were applied on a periodic basis, the effective life of the friction modifiers were a critical factor in defining the application interval. The original friction modifiers had a "design" life of 3000 axles. Based on an average daily traffic of approximately 1200 axles this corresponded to a reapplication every 2-1/2 days. This was not a practical frequency, and as such testing and development were undertaken to extend the life of the friction modifiers and to more accurately determine the rate of degradation of effectiveness (in noise reduction).

The resulting longer life friction modifiers, had a design life more than double the original formulation. Based on the average daily traffic of 1200 axles, this formulation required a reapplication every 5+ days. A more realistic frequency in light: of the ongoing inspection and maintenance activities at the noise site.

In order to assess the effectiveness of these two formulations, a series of field tests were conducted.

TEST RE5ULTS

in order to examine the effectiveness of the frfQti0,n m0,difiers approach and to determine the rate of degradation in perf0rmance a noise monitoring test program was performed at the Faria Beach site (5 degree curve) in October 1996 and again in March 1997 (with a revised formulation).

Noise was recorded 100 feet from the track in the frequency range 20 - 20,000 Hz. Full digital recording *of* the signal was carried out with both real time monitoring of the maximum readings and post test analysis of a range of noise measures.

Testing was carried out using the following friction modifiers applied by direct application to the rail via hi-rail mounted applicators and positioning nozzles:

HPF (High Positive Friction) on head of high and low rail on curve
LCF (Low Coefficient of Friction) on gage face of high rail.

Prior to the application of the frictionn1odifiers, maximum noise levels were recorded for a "dry" (no friction modifier' Tail condition. (Note; friction modifiers had been applied' 5 days previously, corresponding to approximately 6000 axle passes.) The maximum “dry” noise measurements were as follows:

	Noise Measurements dBA		
	Freight Squeal	Passenger Squeal	Other Non-squeal
Maximum	93	92	95

The initial October 1996 tests were performed with a formulation of HPF and LCF with a theoretical (and laboratory) life of 3000 axles.

During the tests, Friction Modifiers were applied to the test curve using the hi-rail applicator system. The friction modifiers were applied at a speed of approximately 12 mph. HPF was applied to the rail head and formed a 1/8" HPF bead on the rail head (corresponding to the 13 ozlkri1 recommended level). The HPF dried within 5 to 10 minutes after applications. The LCF was applied to the gage face of the rail concurrently. (The gage face application was not as consistent due to applicator problems, however LCF was applied to most of the curve at. the gage face location.)

Table 1 presents a summary of several days of noise measurements following the application of the friction modifiers. Note: F refers to a freight train and P denotes a Passenger train. The number of axles per train were determined as follows:

Double stack equipment has 12 axles for 5 platforms
TTX equipment has 4 axles/platform
Assume 50/50 ratio distribution for Intermodal Trains (DS/TTX)
All mixed cars have 4 axles/car
Assume freight engines 6 axle
Passenger engines assumed to have4 axles

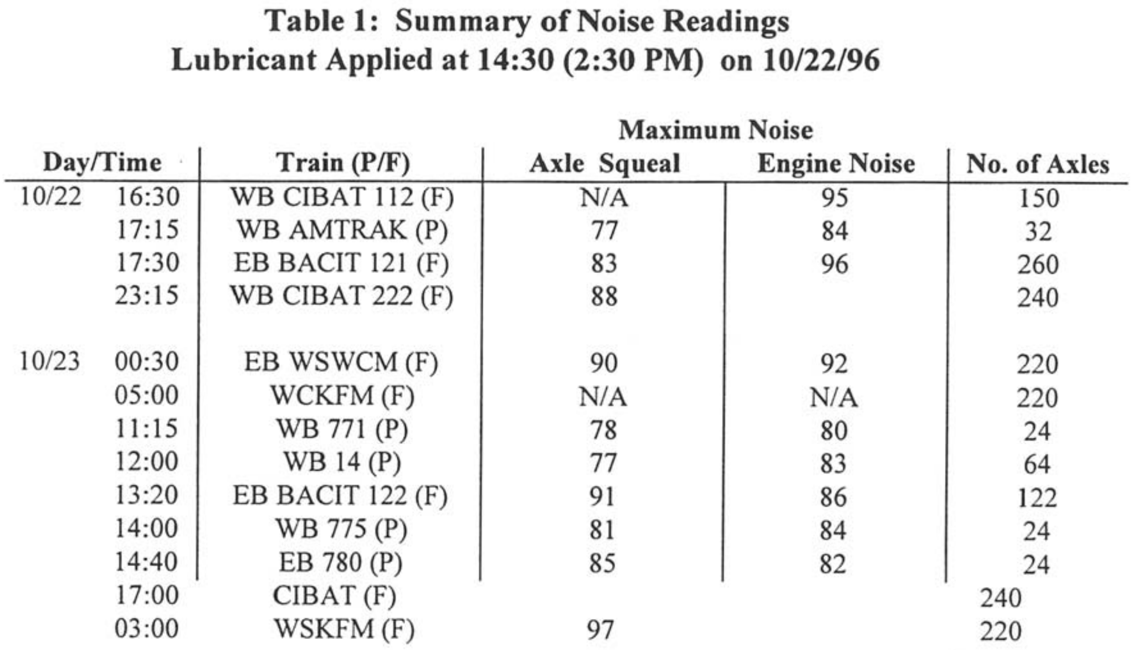

Table 1: Summary of Noise Readings
Lubricant Applied at 14:30 (2:30 PM) on 10/22/96

		Maximum Noise		
Day/Time	**Train (P/F)**	**Axle Squeal**	**Engine Noise**	**No. of Axles**
10/22 16:30	WB CIBAT 112 (F)	N/A	95	150
17:15	WB AMTRAK (P)	77	84	32
17:30	EB BACIT 121 (F)	83	96	260
23:15	WB CIBAT 222 (F)	88		240
10/23 00:30	EB WSWCM (F)	90	92	220
05:00	WCKFM (F)	N/A	N/A	220
11:15	WB 771 (P)	78	80	24
12:00	WB 14 (P)	77	83	64
13:20	EB BACIT 122 (F)	91	86	122
14:00	WB 775 (P)	81	84	24
14:40	EB 780 (P)	85	82	24
17:00	CIBAT (F)			240
03:00	WSKFM (F)	97		220

Tables 2A and 2B present these results as a function of cumulative axle passes for freight and passenger trains respectively. Figure 2 shows this data graphically.

As can be readily seen in both Tables 2A and 2B and in Figure 2, the application of the friction modifiers reduces the axle squeal noise levels by 10 + dB for both freight cars and passenger cars. However, the data shows a rapid return of the noise with traffic, in terms of number of axles passed. The friction modifier solution did appear to work but degradation of friction modifiers performance occurred with axle passes.

For this test, the total number of axles {estimated) for the period from 14:30 on 10/22 when friction modifiers were applied to 13:20 on 10/23 when freight EB BACIT 122 passed, approximately 24 hours, was 1600 axles as follows: Total number of axles (estimated) for period from 14:30 on 10/22 when friction modifiers were applied to 03:00 on 10/24 when freight WSKFM passed (approximately 36 hours) was 2250 axles.

For the formulation used on the 10-22-96 test, the manufacturer predicted a "life" of the friction modifiers of up to 3600 axle loads, based on lab tests. The above field test data showed that in the 24 hour period, (one day), after ~1600 axles, the wheel squeal on freight increased from 83 dB to 91 dB. Wheel squeal on passenger cars increased from 77 dB to 85 dB. Both levels were lower than the pre-friction modifier noise levels. However, after 36 hours (1 1/2 days) and ~2300 axles, wheel squeal for the freight traffic increased to the pre-friction modifier levels. The resulting "life" of the friction modifier, approximately 2 days (based on an average daily traffic level of 1200 axles) was too short for a practical solution to the noise problem. This is in light of the 2 times a week inspection schedule for the line (during which the inspector could apply friction modifiers from his hi-rail vehicle.)

In order to extend the life of the friction modifiers, the friction modifier manufacturer, Kelsan, developed an improved formulation designed to increase the time interval (in terms of axle passes) between reapplication of the friction modifiers.

Table 2

2A: Summary of Noise 10/22/96 : Freight Only

					Noise	
Day/Time		Train	Intermodal (I) Mixed (M)	Est. # of Axles	Wheel Squeal	Engine
10/22	16:30	WB CIBAT 122	(I)	150		95
	17:30	EB BACIT 121	(I)	260	83	96
	23:15	WB CIBAT 222	(I)	240	88	
10/23	00:30	EB WSWCM	(M)	220	90	92
	05:00	WCKFM	(M)	220	N/A	N/A
	13:20	EB BACIT	(F)	240	91	86
	17:00	CIBAT (F)		240		
	03:00	WSKFM (F)		220	97	

2B: Summary of Noise 10/22/96 : Passenger Only

					Noise	
Day/Time		Train	Interurban (IU) Commuter (C)	Est. # of Axles	Wheel Squeal	Engine
10/22	17:15	WB	C	32	77	84
10/22	11:15	WB 771	C	24	78	80
	12:00	WB 14	IU	64	77	83
	14:00	WB 775	C	24	81	84
	14:40	EB 780	C	24	85	82

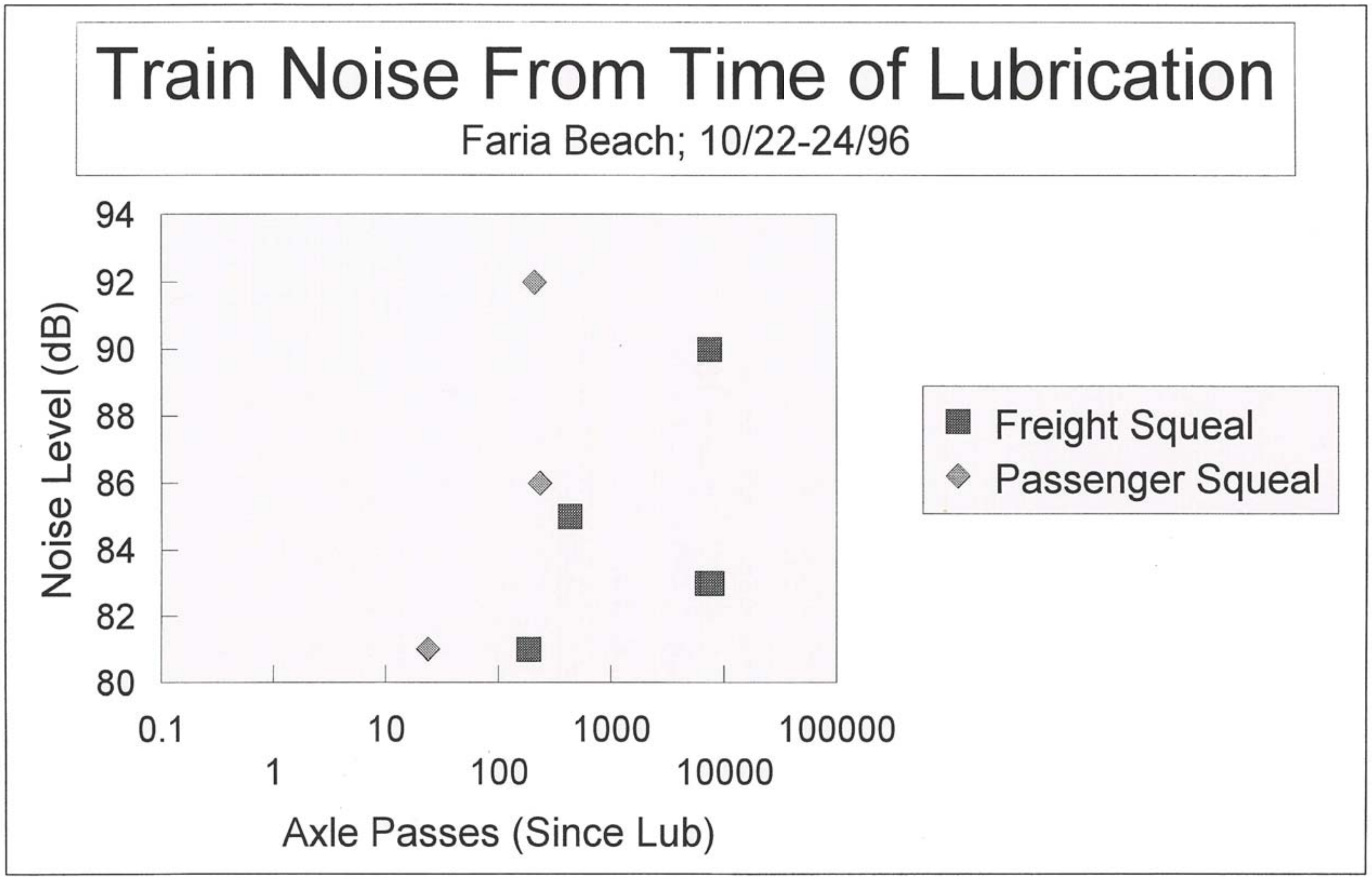

Figure 2 TRAIN NOISE FROM TIME OF LUBRICATION

The improved friction modifiers were tested at the same site in March 1997. The same measurement set up and recording system was used.

Initial, non-friction modifiers squeal measurements were of the order of 93 dBA, similar to those measured previously. The improved formulation was applied, using the same hi-rail system used previously. The friction modifiers were applied at 16:36 hours on March 6, 1997. Table 3 presents a summary of the train passes and noise measurements, both wheel squeal and other noise. It should be noted that the site was left unmanned for a period of 6 days (between March 8 and March 13, 1997). During this period, noise measurements were taken above a defined threshold level. Axle counts were using a wheel detector located on the same Line, over which the trains had to pass. During this period a total of 6600 axles passed (an average of 1100 axles per day). Manned measurements resumed on March 14, 1998.

Figure 3 presents this noise data graphically for the full time period (approximately 8000 axles in 7-1/2 days). As can be seen in this Figure, the other train noise, which included engine noise, engine horn, etc., produced noise levels equal to or greater than the highest wheel squeals. Removing these other non-squeal noises, generates the data shown in Figure 4. A well defined trend can be seen for both the freight and passenger wheel squeals.

Further analysis of the freight squeal noise (which had the highest noise levels) showed, a well defined growth behavior in the noise revel with axle passes. This is illustrated in Figure 5, which presents a fog-linear regression of the freight squeal noises (the envelope, of maximum noise at each axle pass level was used). As can be seen in this Figure, this is a well defined and well behaved relationship between increasing noise and increasing axles since friction modifiers. The statistical fit of this data is excellent with a R^2 of 91 %. The resulting regression equation is given by:

Noise level (dBA) = 7.76*log(AP)+65.7

Where AP = number of axle passes since friction modifier.

Thus, based on this regression, the threshold (set for the residents of the curve site) of 95 dBA is reached after 6000 axles or 5.5 days. The relationship between wheel squeal noise and time (in days) is presented in Figure 6 for both the old and new formulations.

Based on these results, if the curve was friction modified twice a week (a maximum of four days interval), the noise level would not go above 94 dBA. In light of the twice a week inspection schedule for this line, a twice weekly friction modifier schedule (where the friction modifiers are performed by the inspector as he passes the site in his hi -rail vehicle) is practical and achievable.

Table 3: Summary of Noise Readings- Improved Formulation Friction Modifiers Applied at 16:36 (4:36 PM) on 3/6/97

					Noise Measurements (dBA)		
				Cumulative	Freight	Passenger	Other
Day/Time	Train	P/F	Axles	Axles	Squeal	Squeal	Noise
3/6/97							
04:36 PM	Lubricant Applied			0			
06:03 PM	Amtrak 779	P	24	24		81	
06:30 PM	CIBAT 107	F	162	186	81.5		86.75
3/8/97							
09:54 AM	Amtrak 776	P	24	210		92	95
12:07 PM	WB	P	24	234		86	94
01:09 PM	BACIT	F-I	198	432	86		85.5

Unmanned recording until 3/14/97 (only noise above thresholds recorded)
Based on AEI detector: Number of axles per day= 1100 axles/day

3/8			550				
10:47 PM				982	91		
3/9			1100				
09:07 PM				2082	92.5		
09:07 PM				2082			100.5
09:25 PM				2082	92.5		
3/10			1100				
05:16 AM				3182	91.5		
3/11			1100				
04:41 AM				4282	91		
3/12			1100				
12:33 AM				5382	90.5		
04:28 AM				5382	90.5		
3/13			1100				
3/14			550				
03:14 AM				7032	94		

March 14, 1997 (resume manned measurements)

10:46 AM	EB Freight	F	258	7290	83.75		85
11:56 AM	Amtrak WB	P	32	7322			
01:03 PM	Amtrak WB	P	32	7354			
01:15 PM	EB Freight	F	342	7696	95		91.25
02:17 PM	Amtrak WP	P	32	7728			
02:42 PM	Amtrak WB	P	32	7760			
03:20 PM	WB Freight	F	278	8038	82.75		90.25

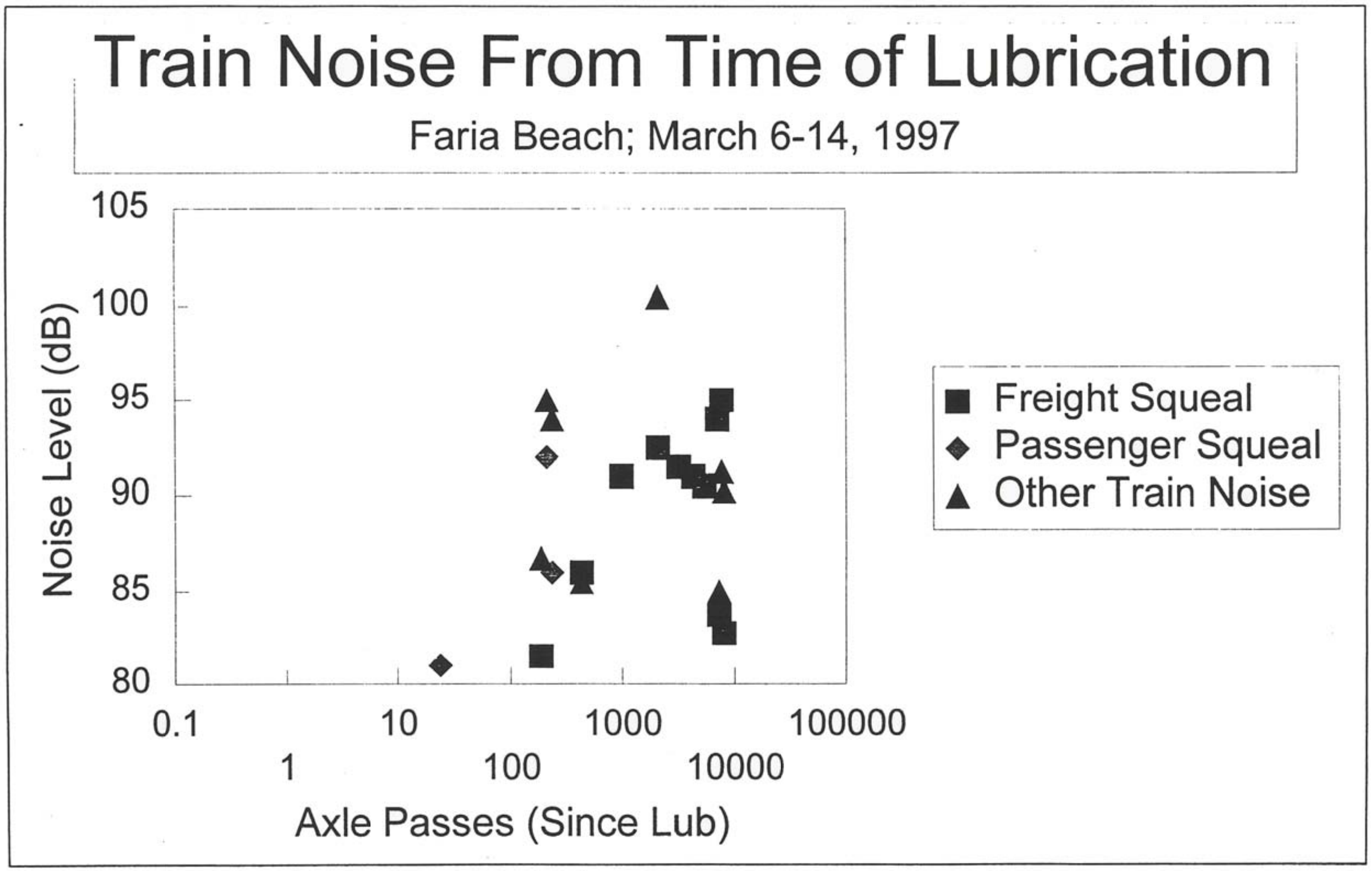

Figure 3 TRAIN NOISE FROM TIME OF LUBRICATION

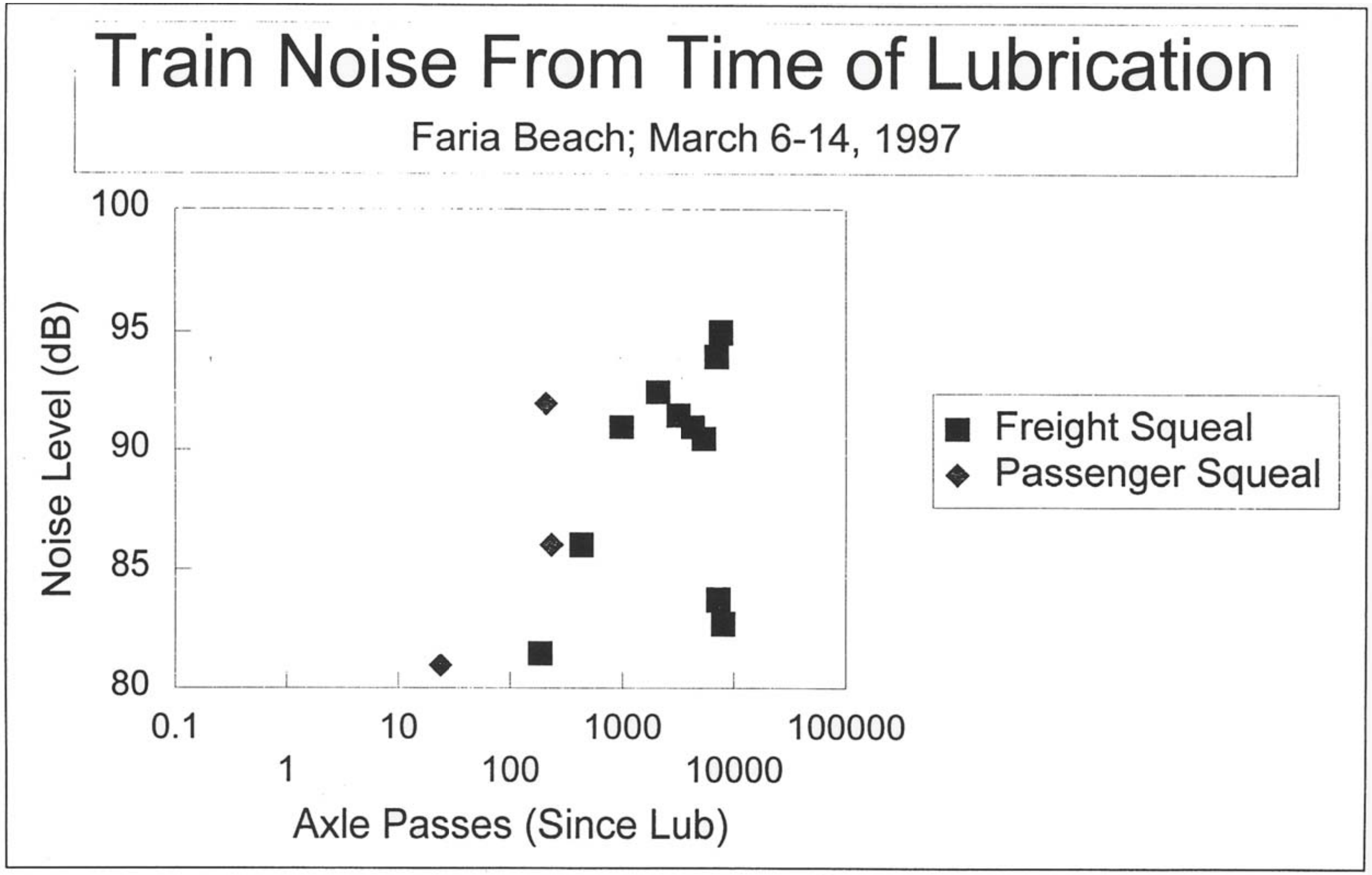

Figure 4 TRAIN NOISE FROM TIME OF LUBRICATION

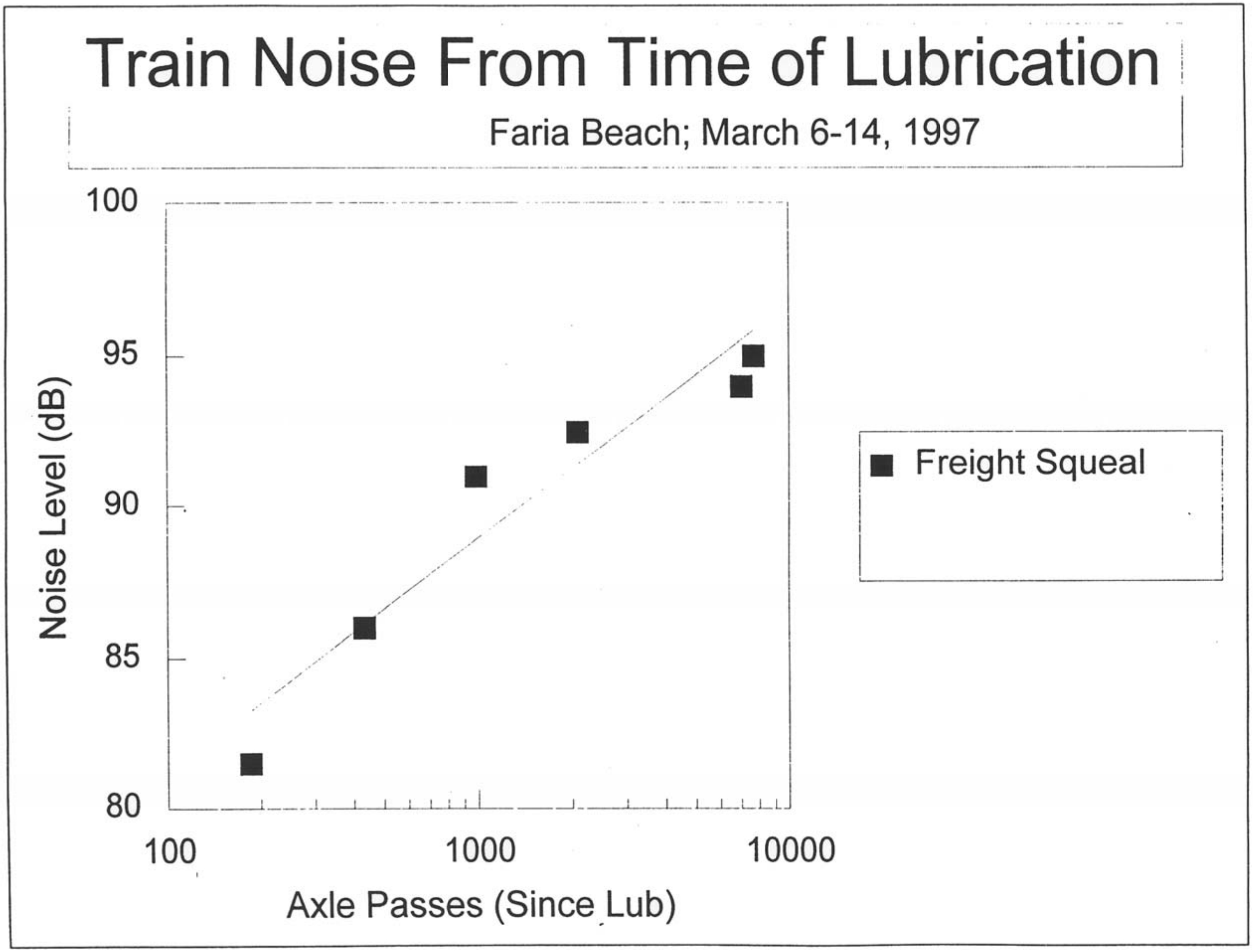

Figure 5 TRAIN NOISE FROM TIME OF LUBRICATION

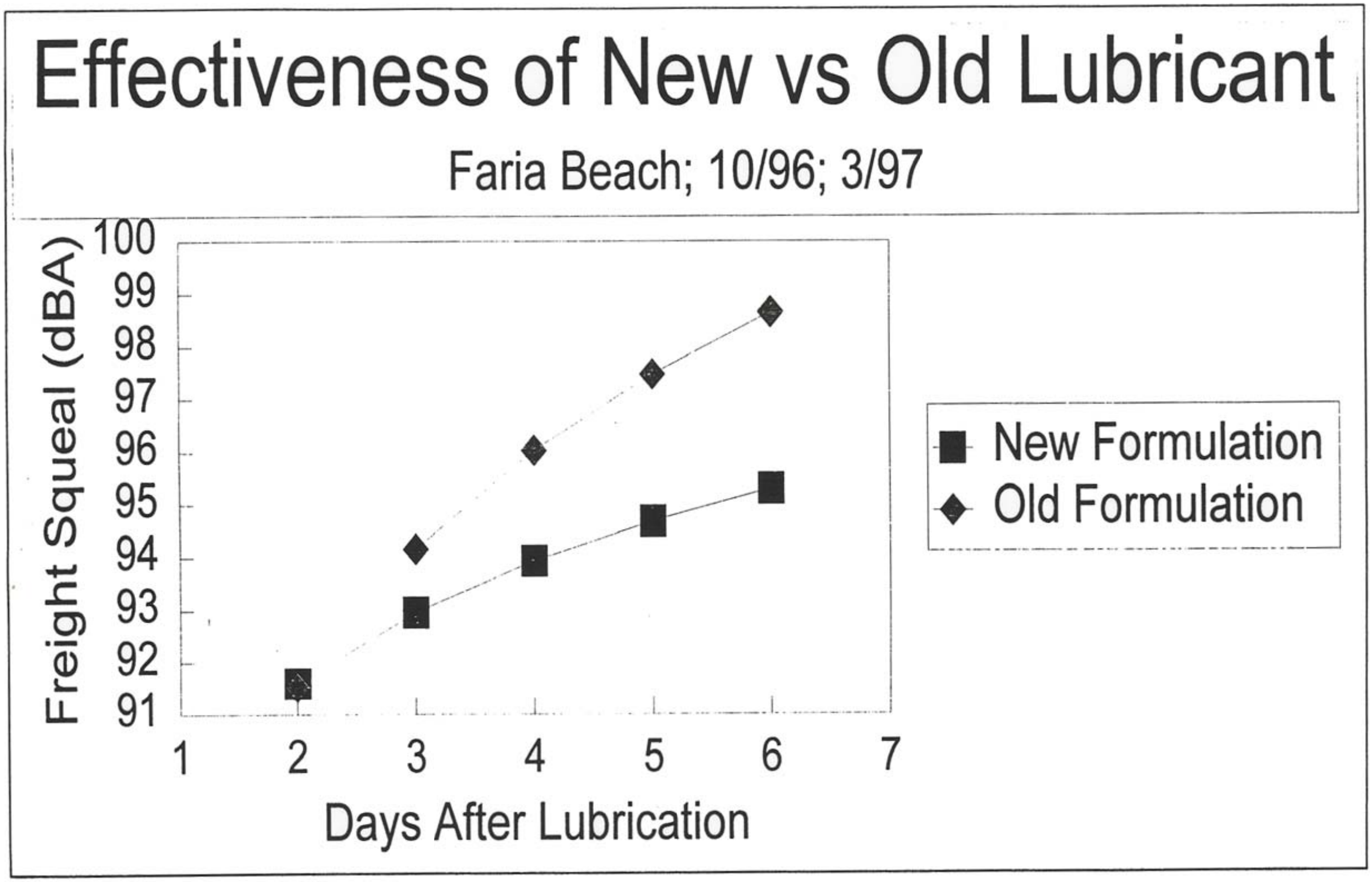

Figure 6 EFFECTIVENESS OF NEW vs OLD LUBRICANT

CONCLUSIONS

The use of friction modifiers applied to the top and side of the rail head appears to be a practical approach to controlling wheel squeal in moderate to sharp curves. This is particularly true for freight cars, including the heavy axle load and articulated cars found in North American service.

Two sets of friction modifiers are required; a high coefficient of friction modifier placed on the top of both rails in the curve, and a low coefficient of friction modifiers applied to the gage face of the high rail of the curve. [It should be noted here that no measurements of wheel forces were taken in this test. Other research has indicated that a significant friction differential between high and low rails in a curve can result. In excessive lateral wheel rail forces. This was not addressed here-in.] The friction modifiers were applied, with a high degree of accuracy, using a hi-rail vehicle mounted application n system. Using two sets of nozzles (one for each friction modifier type), beads of friction modifiers were applied uniformly through the curve on the head and gage face respectively.

The use of the modifiers, particularly the improved, longer life formulations developed by, Kelsan, resulted in a measurable decrease in noise, of the order of 10 dBA for freight squeal and higher for passenger squeal (up to 15 dBA was recorded). Furthermore, the improved formulation; remained effective for approximately 6000 axle passes (5.5 days for the test site). This made the hi-rail based approach practical for field use, since most high density rail lines in North America (and all passenger carrying lines) are inspected a minimum of twice weekly. Mounting the application system on the inspector's on track hi-rail vehicle allows for a twice weekly application, which is within the effectiveness period of the friction modifiers (improved formulation).

The study also developed a definition of the rate of degradation of the friction modifiers, which were defined in terms of a log-linear relationship which showed excellent statistical correlation.

Finally, the results of the tests suggest that the two mechanism for the development of wheel squeal appear to be valid. The use of a high coefficient of friction modifiers on the rail head to reduce lateral wheel/rail slip, in combination with the low friction modifiers on the gage face (to reduce flanging effects) suggest that the postulated noise mechanisms have validity.

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Figures and Tables