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RESEARCH REPORT

Top-of-rail friction modifier – a vibro-acoustic measurement study

JVTC Projectnr XXX

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Teknisk rapport

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2013-12-19

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Introduction

In the railway industry; the wheel rail interphase plays an important role for the system in terms of system deterioration rates and the possibility of providing an efficient transport system with a low rolling resistance. To control the contact interphase between the rail and wheels, different maintenance actions can be applied. Firstly grinding and turning operations can be performed to produce matching rail and wheel profiles enabling an adequate steering ability of the wheel setts and a proper contact pressure to reduce the risks of rolling contact fatigue (RCF). Secondly the surface properties in terms of lubrication can be controlled also to reduce RCF due to excessive contact forces and to keep the ware on a controllable rate.

From a friction management point of view; the side of the railhead, which is in contact with the wheel flange, shall ideally have as low friction values as possible whiles the top of the rail needs a higher friction value to enable the braking and traction performance. Lubricants used to modify and set the friction value to a specific value are normally called friction modifiers. If a rail section suffers from high friction values, the friction forces could exceed the limits where the probability of RCF could increase. On the other hand if the friction values are to low; safety issues like lack of braking capacity and issues caused by halted train due to inadequate traction can occur.

This report describes a case study of the vibro-acoustic properties of a top-of-rail friction modifier when applied to a heavy haul railway line. Vibrations and sound was measured to establish the vibro-acoustic effect of the applied friction modifier.

Method

Measurement location and traffic condition

The vibro-acostic study was performed during two days at the Luleå Railway Research station (JVTC) located the line section 119 along the iron ore track in the northern part of Sweden. During the measurements the line was trafficked by a set of trains (mixed traffic) including passenger trains, freight wagons, loaded and unloaded heavy haul iron ore trains and steel shuttles.

Table 1 Measured trains prior and after the application of the friction modifier

Train type	Time	Direction
Measurements without friction modifier Date (2013-05-27)		
Passenger train SJ	09:15	Luleå
Passenger train Norrtåg	09:20	Luleå
Passenger train Norrtåg	10:21	Boden
Passenger train SJ	10:33	Boden
Freight train	10:50	Luleå
Freight train	11:38	Boden
Freight train	11:52	Boden
Passenger train SJ	12:16	Luleå
Passenger train Norrtåg	12:55	Luleå
Passenger train Norrtåg	13:49	Boden
Passenger train SJ	16:40	Luleå
Passenger train Norrtåg	16:48	Boden
Passenger train SJ	16:57	Boden
Iron or train loaded	17:17	Luleå
Measurements with friction modifier Date (2013-05-28)		
Passenger train SJ	09:18	Luleå
Passenger train Norrtåg	09:27	Luleå
Passenger train Norrtåg	10:19	Boden
Passenger train SJ	10:32	Boden
Steel shuttle no load and freight wagons	11:10	Luleå
Passenger train SJ	11:13	Luleå
Steel shuttle loaded	12:27	Boden
Freight train	12:43	Boden
Passenger train Norrtåg	13:06	Luleå
Passenger train Norrtåg	13:53	Boden
Iron or train loaded	15:56	Luleå
Passenger train Norrtåg	16:36	Luleå
Passenger train SJ	16:50	Boden
Passenger train SJ	17:06	Boden
Freight train	17:15	Boden
Passenger train SJ	17:26	Luleå
Passenger train Norrtåg	17:5?	?????

Friction modifier

The friction modifier used in this study will according to the specifications produce a friction coefficient µ of 0,3. The friction modifier was applied using manual rollers.

Friction measurement

The friction values of the considered rail section of approximately 300 meters was measured by the use of a manually operated portable friction measurement tonometer manufactured by LB Foster, see Figure 1. The friction coefficient was measured before and after the application of the friction modifier.

Figure 1 Friction measurement trolley LB Foster Tribometer[1].

Vibro-acoustic Measurement setup

Vibration and sound measurements where performed at different locations in the centre of the examined line section. Two types of sound measurements were performed. One microphone setup was used to measure the sound according to the standard (SS-EN ISO 3095:2005) where tow microphones on each side of the track was positioned 7,5 m from the track centre and 1,2 m above the top of the rail head, see Figure 2 and Figure 3. A second microphone setup was mounted closer to the rain in order to focus in on the sound generation from the wheel and rail contact interphase. These two microphones were mounted on the sleepers 0,5 m from the rail web, see Figure 2 and Figure 3. The measurements were performed prior and after the application of the friction modifier. The measurement setup can be seen in Figure 2 and Figure 3. The description of the sampled channels, sample frequencies and filter-settings is listed in Table 2.

[1] www.lbfoster-salientsystems.com/Portable_Tribometer.asp

Table 2 Measurement channels

Acceleration (Sample frequency 8096 Hz, BP-filter 20-300 Hz)	
Channel 1	Inner rail X-direction (along the sleeper-direction)
Channel 2	Inner rail Y-direction (Along the rail-direction)
Channel 3	Inner rail Z-direction (Upwards)
Channel 4	Outer rail X-direction (along the sleeper-direction)
Channel 5	Outer rail Y-direction (Along the rail-direction)
Channel 6	Outer rail Z-direction (Upwards)
Sound pressure (Sample frequency 65536Hz)	
Channel 1	Outer rail 7,5 m from track center
Channel 2	Outer rail 0,5 m from the rail web
Channel 3	Outer rail 7,5 m from track center
Channel 4	Outer rail 0,5 m from the rail web

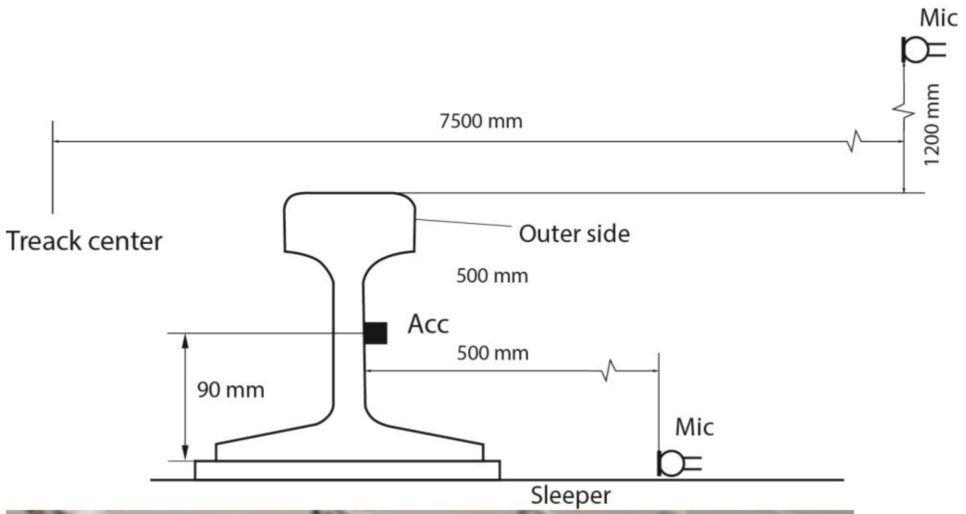

Figure 2 Drawing in the top: Measurement setup illustrating the accelerometer mounting for both Acc1 and 2 on the outer side of the rail. The figure also shows the microphone settings of both microphone pairs Mic 1&3 and Mic 2&4. Photo in the bottom: Accelerometer mounting.

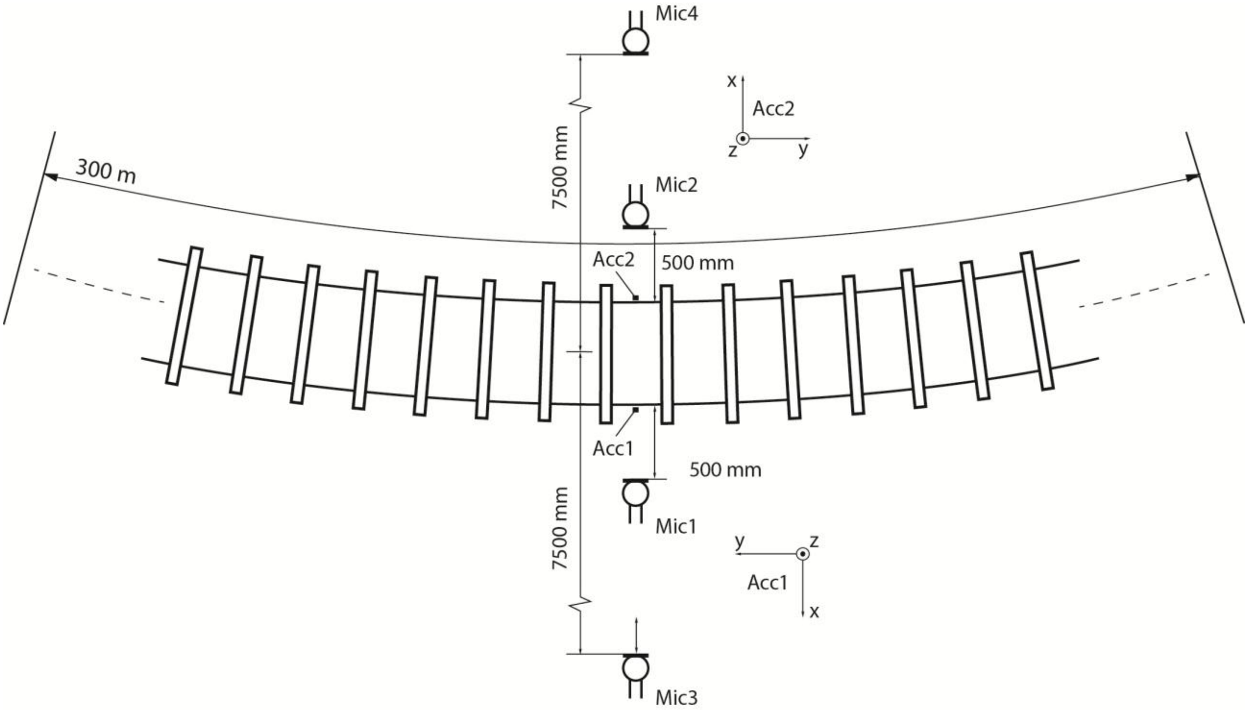

Figure 3 View from above of the measurement setup illustrating the accelerometer mounting for both Acc1 & 2 and Mic 1-4.

Measurement conditions

The measurements were performed during daytime with a mixed sunny and cloudy conditions and a temperature of approximately 17-20 C°.

Result

Friction measurements

In Figure 4 the friction measurement performed prior to the lubrication can be seen. The graph shows the how the friction coefficient varies along the track. A Section of 300 meters where measured for both the outer and the inner rail. The mean values and the standard deviation for the lubricated and the un-lubricated case can be seen in Table 3. From the table it can be seen that the friction coefficient of the inner rail has a larger standard deviation compared to the outer rail prior to the lubrication. In the table it can also be seen that after lubrication the friction coefficient is reduced to a level close to the specification of the friction modifier of μ=0.3.

Table 3 Mean values and standard deviation of friction measurements fefor and after the application of friction modifyers.

	Before lubrication		**After lubrication**	
[μ x 100]	Outer Rail	Inner Rail	Outer Rail	Inner Rail
Average	67,0	61,0	32,0	31,3
Standar deviation	5,9	11,3	7,7	5,3

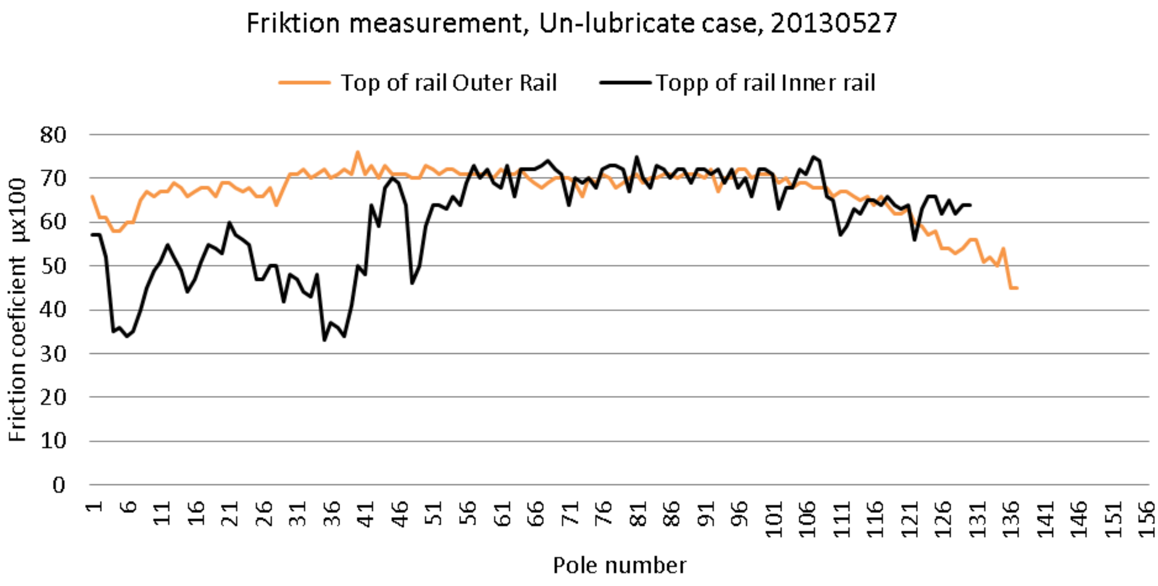

Figure 4 Friction coefficient versus track location before lubrication. Track location is defined by the poles of the electrical power system. Measurement date 130527 time 09-10, Air temperature 17,5 C°, Rail temperature 24,5 C°.

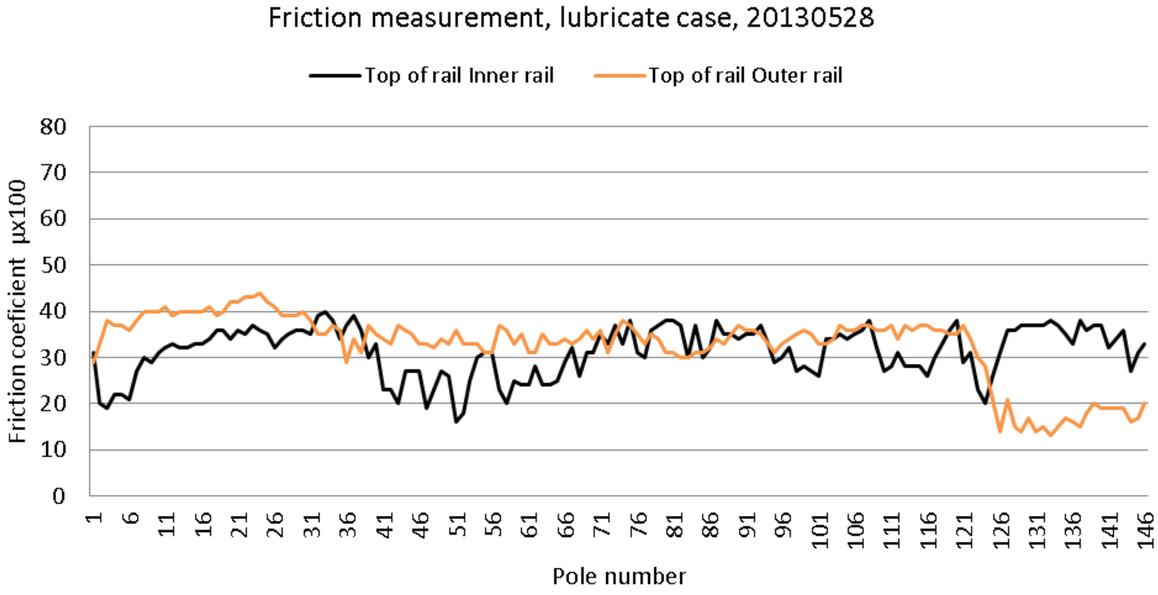

Figure 5 Friction coefficient versus track location after lubrication. Track location is defined by the poles of the electrical power system. Measurement date 130528 time 16-17, Air temperature 20,5 C°, Rail temperature 38,5 C°.

Sound measurement using microphone 3 and 4

The presented sound measurement in this section is displayed in dB within the octave bands 16-16000 Hz. The microphone setup above the rail is averaged into one measurement representing both microphones Mic 3 and 4.

Passenger train (Norrtåg)

In Figure 6 the sound measurements of 11 passing passenger trains is plotted. Five trains were measured before, and six after the application of friction modifier. In the figure, it can be seen that the measurements performed of a passing passenger train on a lubricated track resulted in a decrease in sound level for frequencies above 3000 Hz, with the exception of one passing rain for the lubricated case.

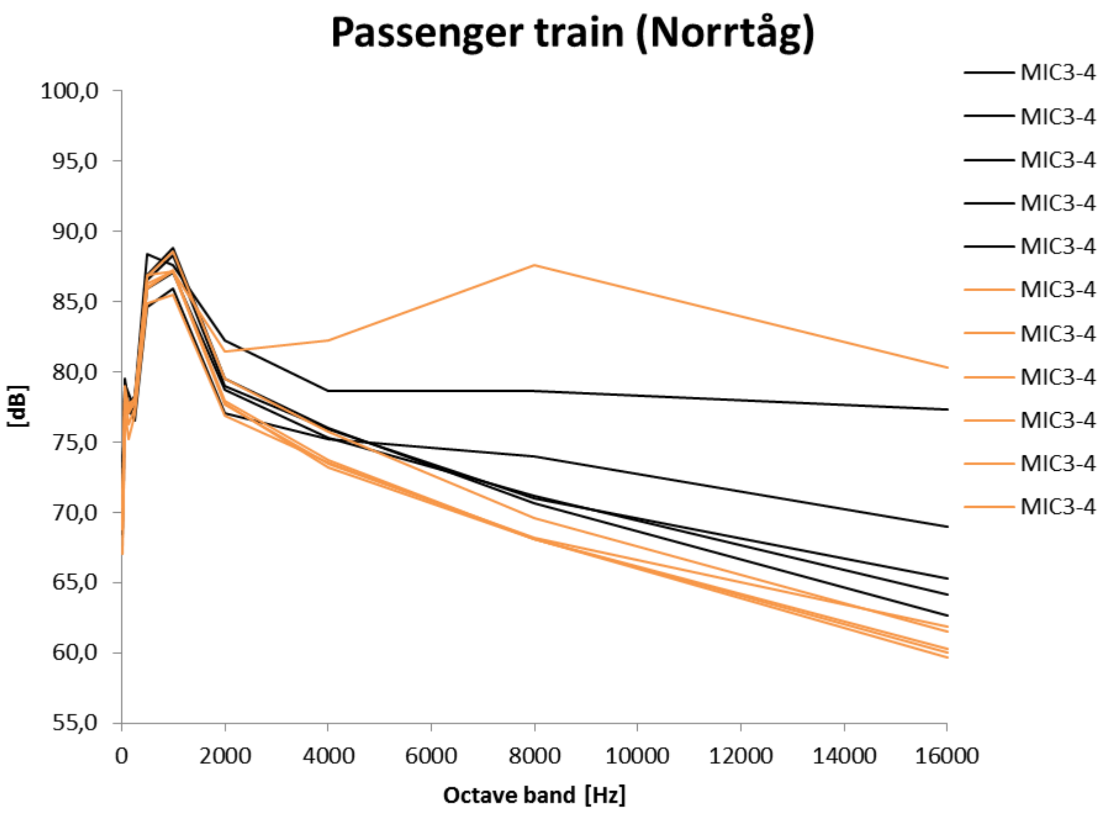

Figure 6 Measurements of passing passenger trains (Norrtåg). Black lines represent measurements of trains without friction modifier. Orange lines represent measurements of trains with friction modifier.

Passenger train (SJ)

In Figure 7 measurements performed for 11 passenger trains (SJ) is shown, five trains before and six after lubrication. In the figure a lower sound level can be seen for the majority of the trains for the lubricated case compared with a majority of the trains for the non-lubricated case. The measurement results for this operator showed a larger deviation from the expected outcome which would be a reduction in sound level for a lubricated track. The result also shows a higher value around 1000 Hz for this operator compared to Norrtåg. Figure 11 shows the sound levels for microphone 1 and 2. No specific difference can be detected compared to microphone 3 and 4.

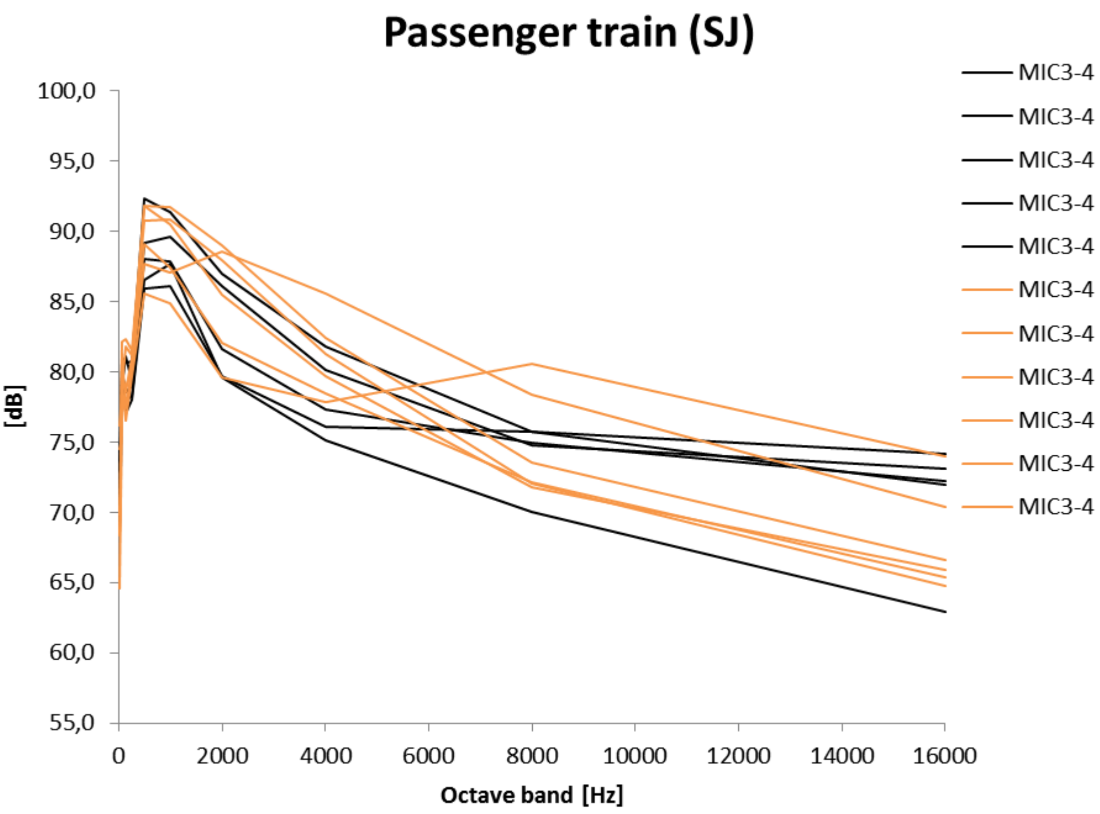

Figure 7 Measurements of passing passenger trains (Norrtåg). Black lines represent measurements of trains without friction modifier. Read lines represent measurements of trains with friction modifier. The line types within each colour represent a passing train.

Freight train

In Figure 8 the sound measurements obtained for during the passage of regular freight trains is shown. The figure does not show any specific difference between the lubricated and the non-lubricated case. One measured train for the non-lubricated case shows a higher sound level for the high frequency region 8kHz-16kHz. However the overall sound level is approximately 5-10 dB higher compared to the passenger trains.

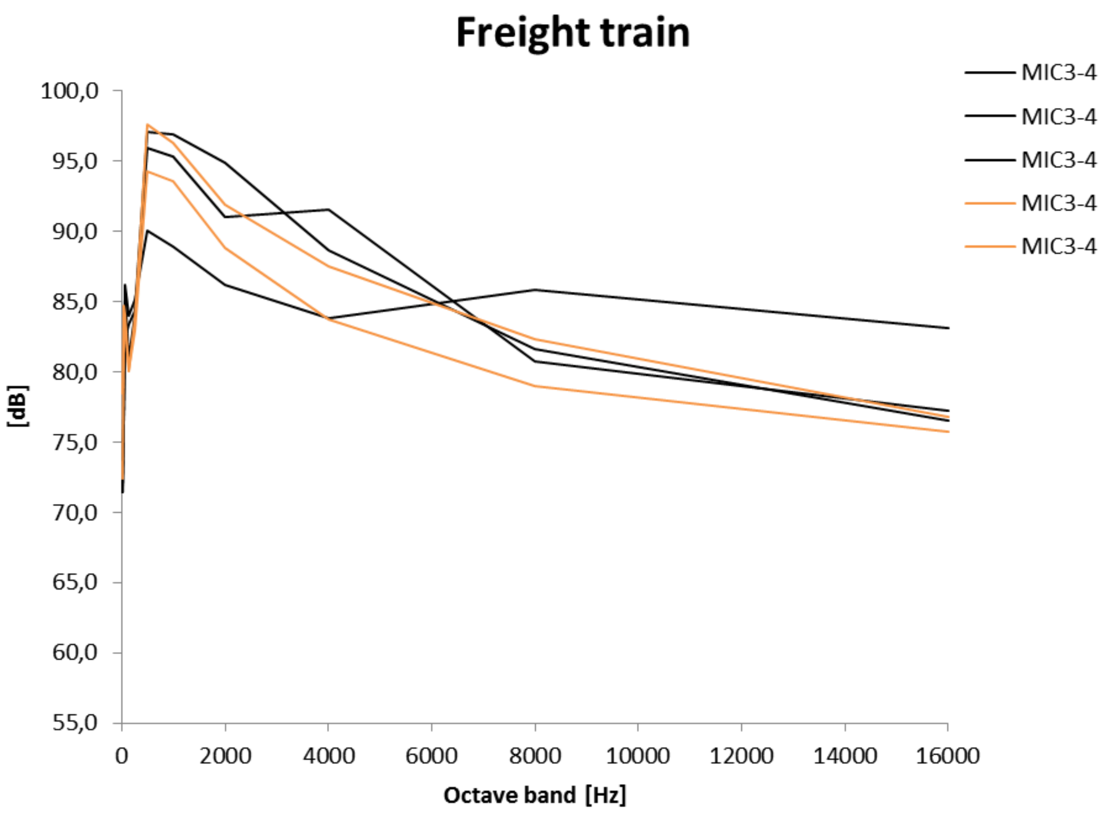

Figure 8 Measurements of passing cargo trains. Black lines represent measurements of trains without friction modifier. Orange lines represent measurements of trains with friction modifier.

Steel shuttle

No steel shuttle trains passed the measurement station during the measurement of the non-lubricated case. For the lubricated case two steel shuttles passed, one loaded and on unloaded. Figure 9 displays the result of obtained from the sound measurements of the loaded and unloaded steel shuttle. The dashed line represent the loaded train while the solid line represent the unloaded. It can be seen from these two measurements that the loaded train resulted in a higher sound level compared to the unloaded train in the interval between 4kHz and 16kHz. In the frequency interval between 125Hz-4kHz the unloaded train showed a higher level than the loaded train. Furthermore the steel shuttle resulted in a similar over all sound level compared to the regular freight train.

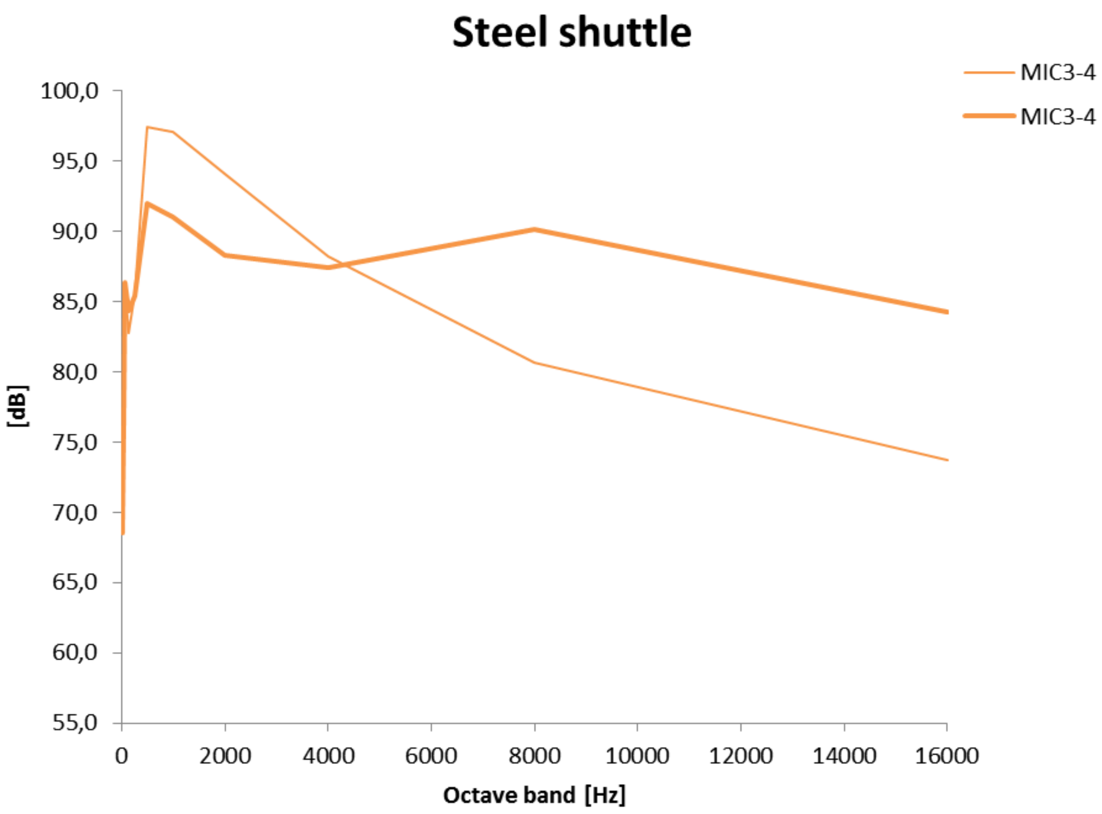

Figure 9 Measurements of two passing steel shuttle trains for a lubricated track. The thick line represents the measurement of a loaded steel shuttle and the thin line represents measurements of an unloaded train.

Iron ore train

The measurement of the iron ore trail showed a lower overall sound level compared to the regular freight and steel shuttle train. However the two measurements resulted in higher sound levels for the lubricated case.

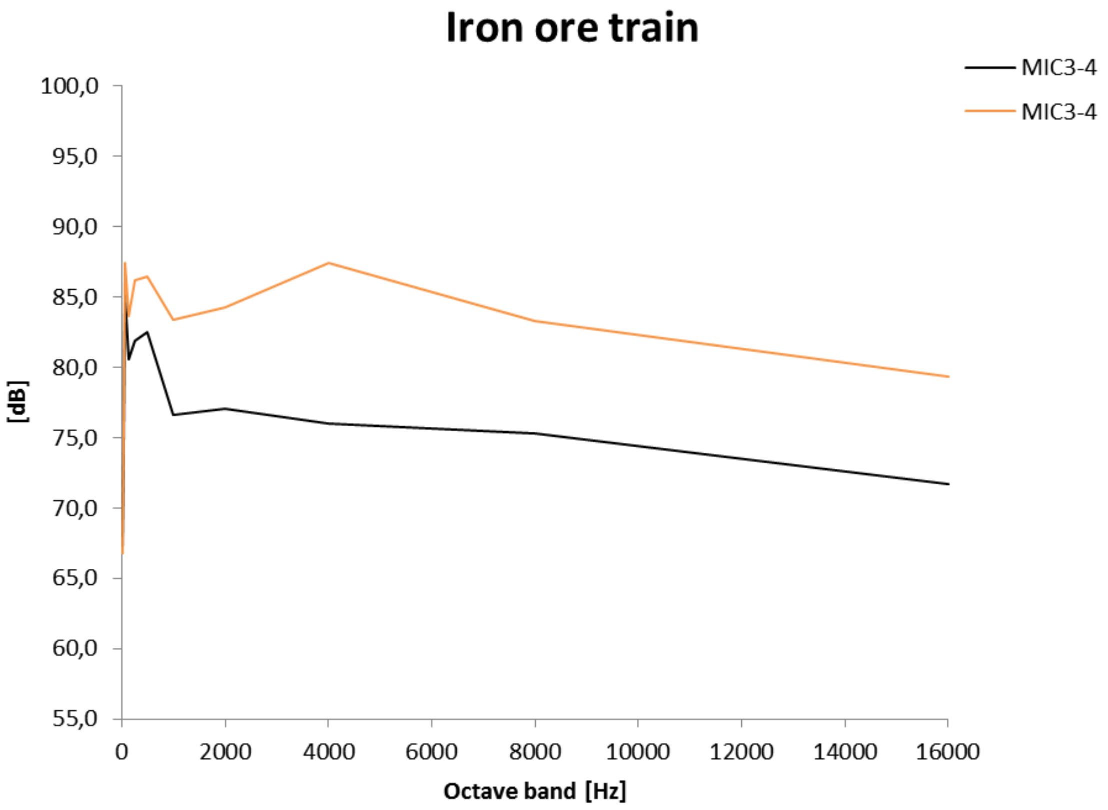

Figure 10 Measurements of passing two loaded iron ore trains. Black lines represent measurements of trains without friction modifier. Orange lines represent measurements of trains with friction modifier.

Sound measurement using microphone 3 and 4

And the four following figures shows the sound levels for the microphone closer to the rail (Microphone 1 and 2) for the 5 different train types. No specific difference can be detected compared to microphone 3 and 4 for each train type.

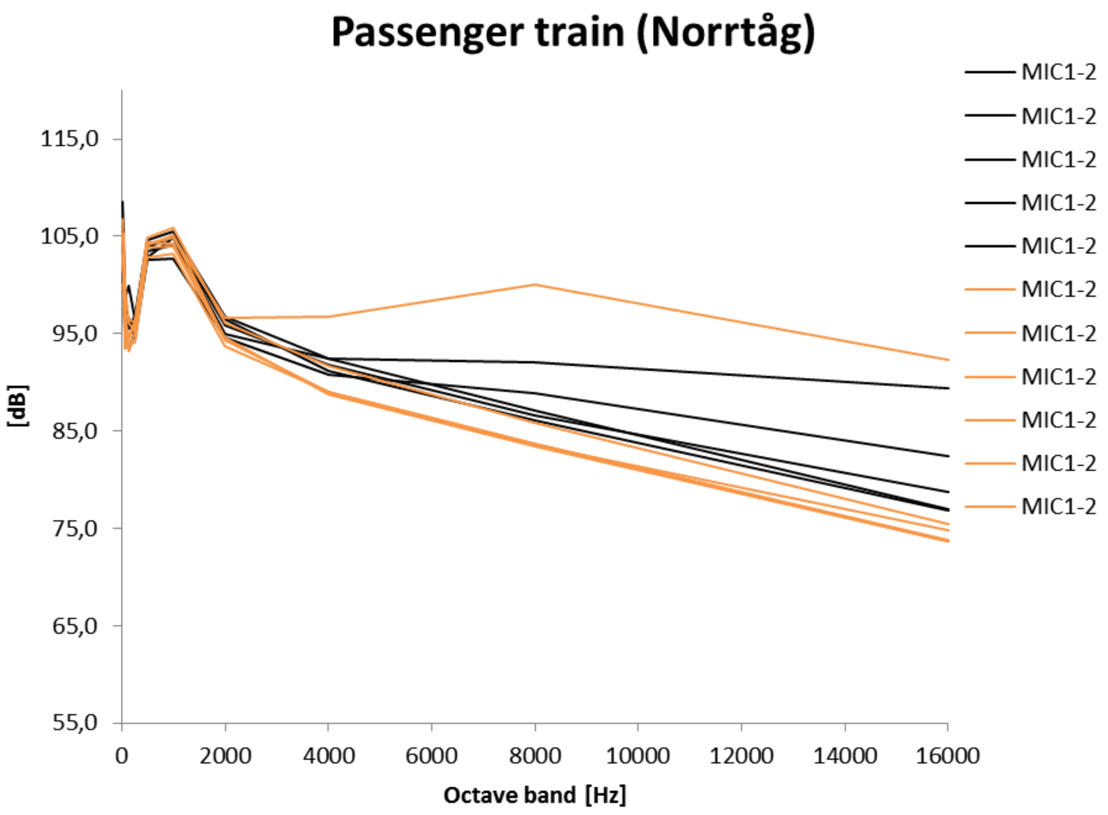

Figure 11 Measurement with microphone setup close to the rail (Microphone 1-2)

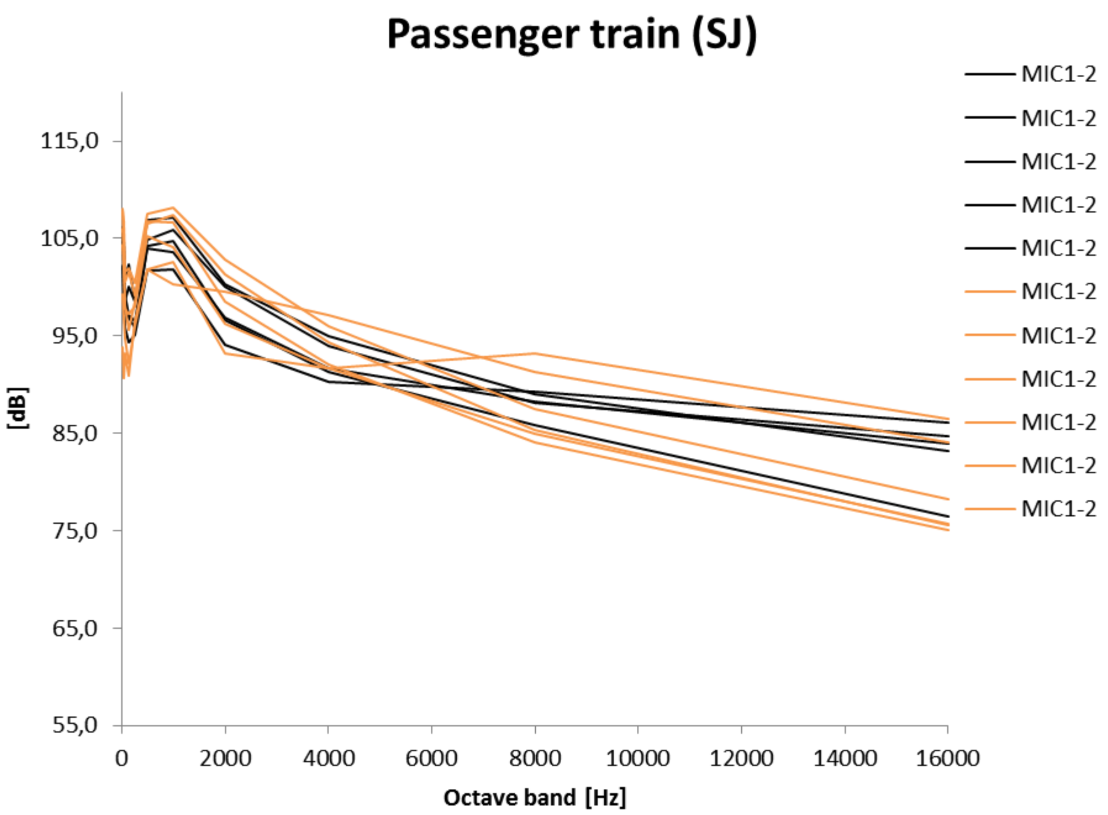

Figure 12 Measurement with microphone setup close to the rail (Microphone 1-2)

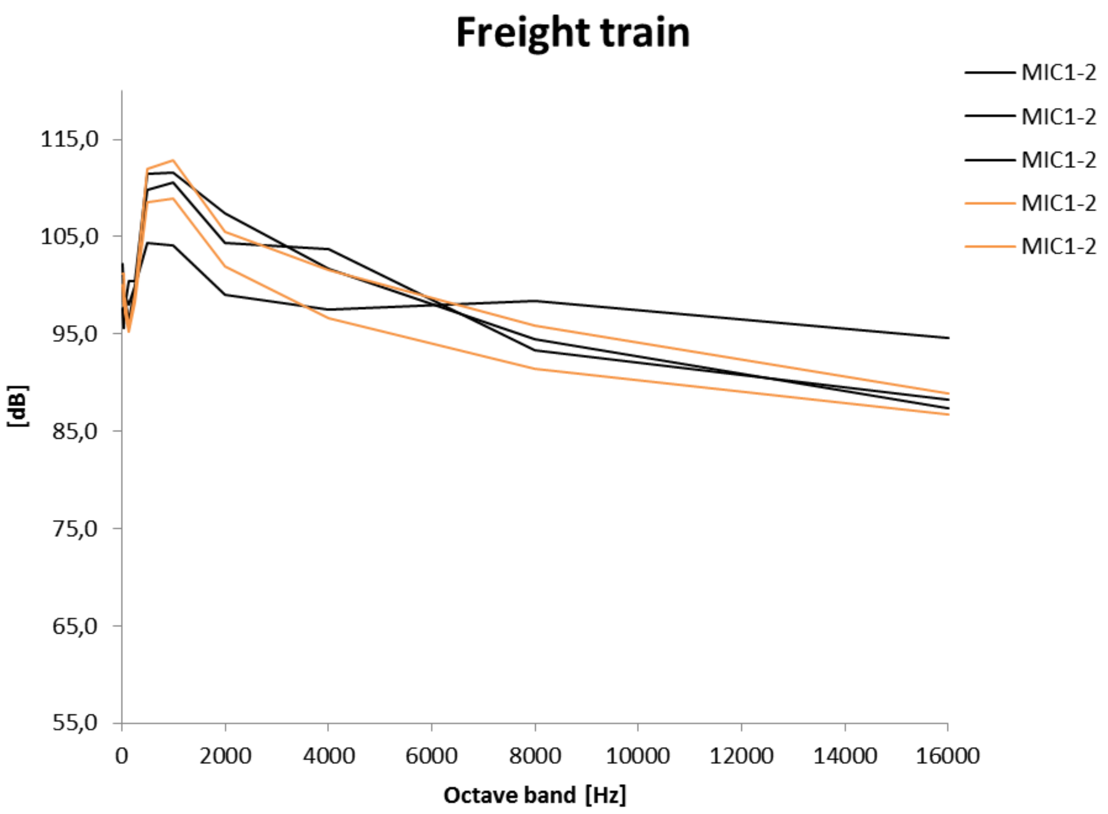

Figure 13 Measurement with microphone setup close to the rail (Microphone 1-2)

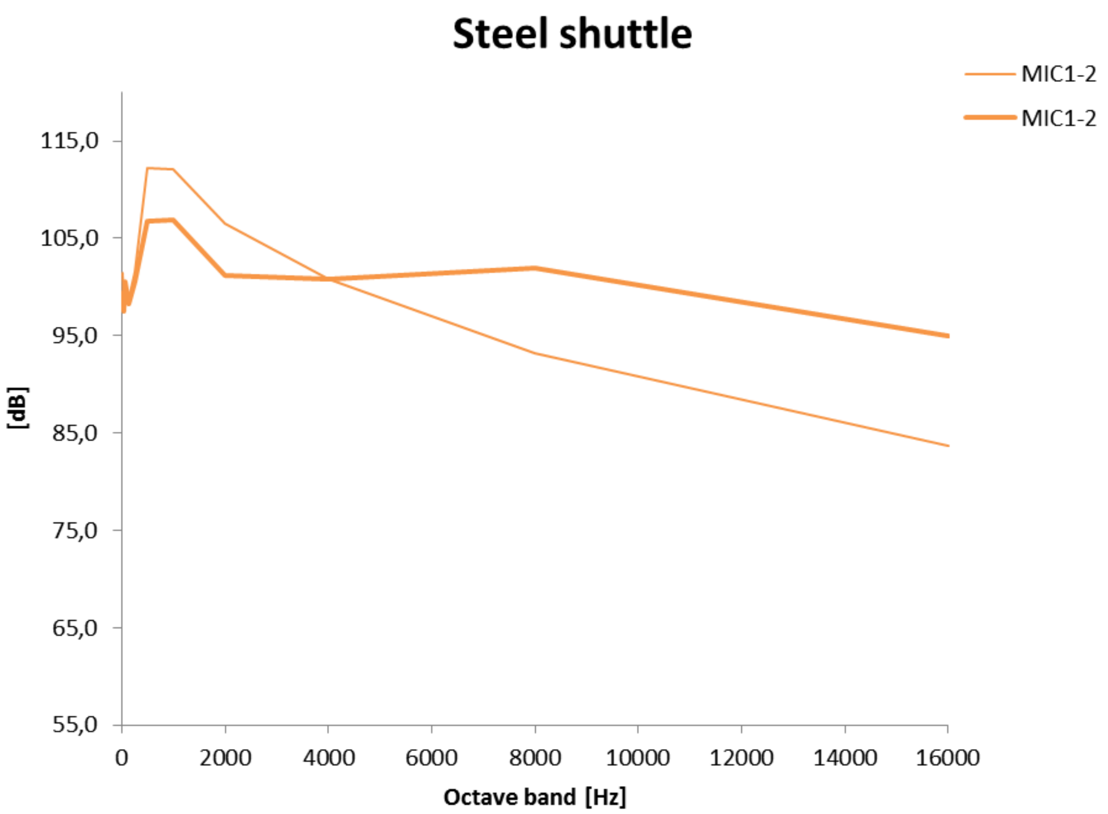

Figure 14 Measurement with microphone setup close to the rail (Microphone 1-2)

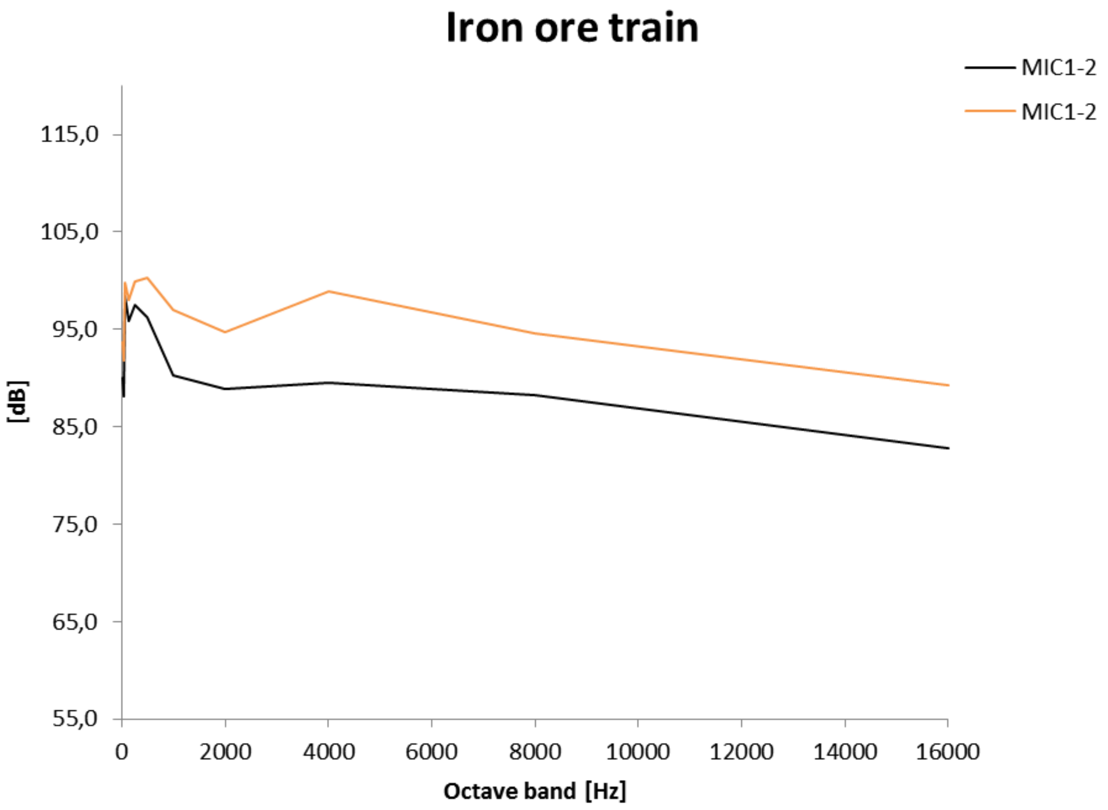

Figure 15 Measurement with microphone setup close to the rail (Microphone 1-2)

Vibration measurement of passenger trains

From the sound measurements it could be seen that the two passenger trains Norrtåg and SJ showed an indication of a lower sound levels after lubrication at higher frequencies. In this section the corresponding vibration measurements for the Norrtåg passenger train is shown. The green curves in the plots represents the vibrations in the x-direction (in the direction along the ground perpendicular to the track direction) and the black curve the vibration in the y-direction (along the track direction). The grafts in the left column represent the vibrations measured at the inner rail of the curve. The graphs in the right column represent the vibration measurements of the outer rail. The vibration measurement in the z-direction was not considered in this study.

Passenger train (Norrtåg)

In Figure 16 the Rail vibration measurements of five passing passenger trains (Norrtåg) for the non-lubricated case is plotted. In the figure it can be seen that the vibration level along the track is lower compared to the vibration level in the x-direction out from the track. High peeks can also be seen in the vibration signal of the inner rail. These peaks coincide with the number of bogies and wheel sets of the Norrtåg train (Five bogies with two axels each). In Figure 17 the Rail vibration measurements of five passing passenger trains (Norrtåg) for the non-lubricated case is plotted Figure 18 shows the RMS value of the vibration signal for the passenger train (Norrtåg). The RMS of the measurements of the outer rail showed generally a lower RMS value compared to the inner rail measurements. Figure 19 shows the corresponding graph for the lubricated case. It can be seen in the figure that the deviation in the RMS between different trains increased for the lubricated case.

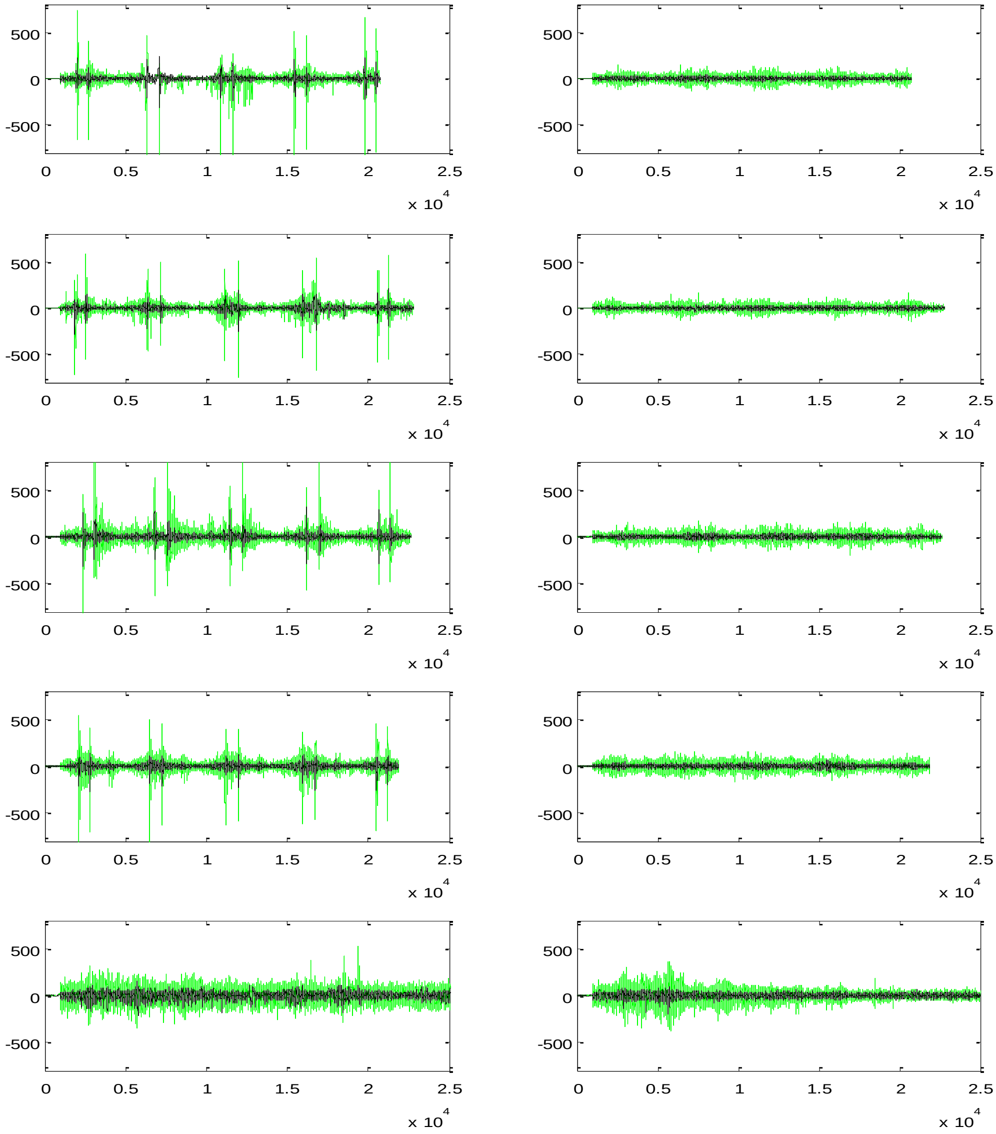

Figure 16 Rail vibration measurements of passing passenger train (Norrtåg) for the un-lubricated case. Green curve represents the vibrations in the x-direction and the black curve the vibration in the y-direction. The grafts in the left column represent the vibrations measured at the inner rail of the curve. The graphs in the right column represent the vibration measurements of the outer rail. The unit of the x-axes is sample points and the unit of the y-axis is m/s^2

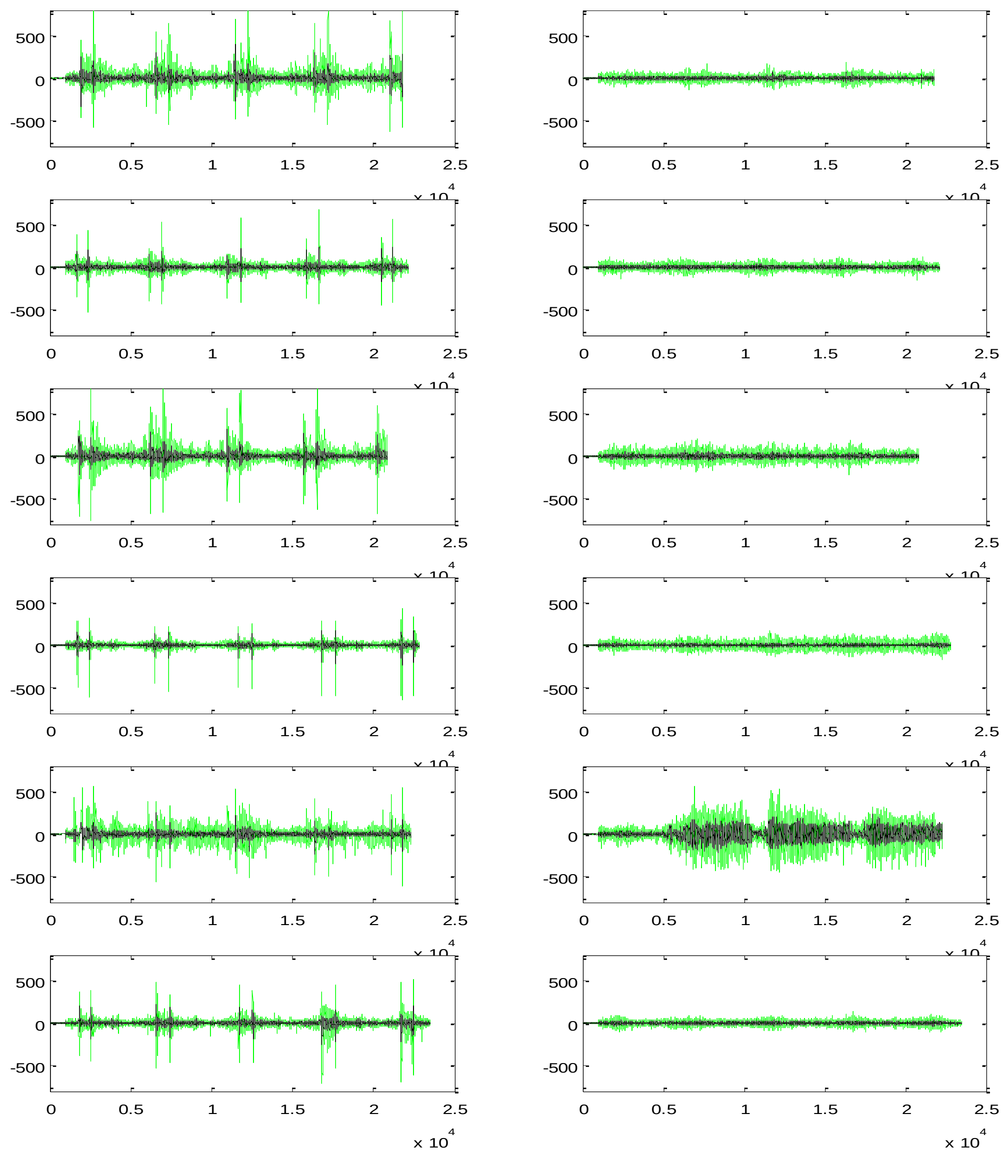

Figure 17 Rail vibration measurements of passing passenger train (Norrtåg) for the lubricated case. Green curve represents the vibrations in the x-direction and the black curve the vibration in the y-direction. The grafts in the left column represent the vibrations measured at the inner rail of the curve. The graphs in the right column represent the vibration measurements of the outer rail. The unit of the x-axes is sample points and the unit of the y-axis is m/s^2

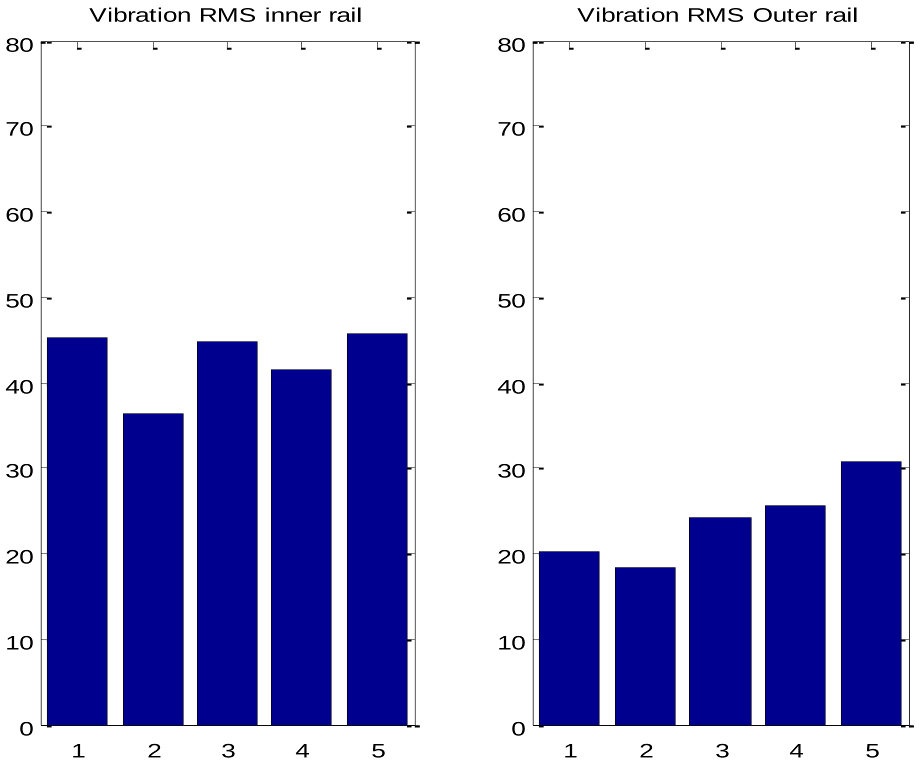

Figure 18 RMS value for each passing train for the un-lubricated case. Left graph shows the values for the inner rail and the right shows the values for the outer rail.

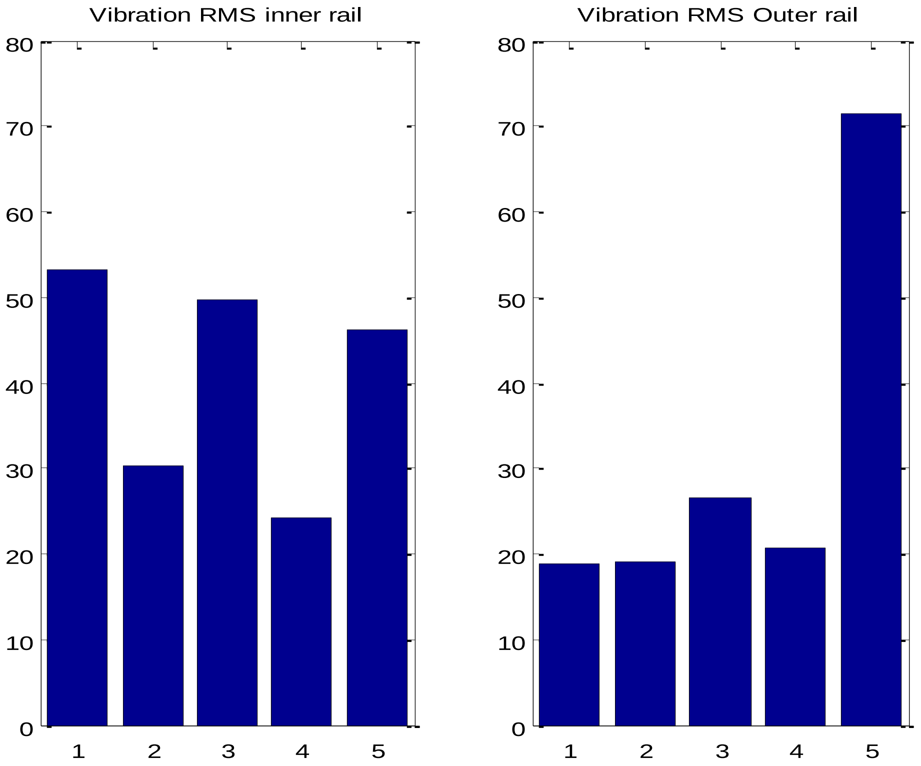

Figure 19 RMS value for each passing train for the lubricated case. Left graph shows the values for the inner rail and the right shows the values for the outer rail.