COMADEM

International Journal of Condition Monitoring and Diagnostic Engineering Management

Wheel-rail squeal sound reduction using top of rail friction modifier: a case study

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ABSTRACT

The railway is an economical and environmentally friendly mode of transport for long distances, however, it creates a significant amount of sound from different parts. Squeal is one of the most disturbing noises from railways. Noise is one of the main factors that can have a damaging effect on the quality of the living environment. Therefore, infrastructure managers have to consider all possible actions that can reduce noise from railway traffic. Among the different types of sounds generating from railways, one of the most disturbing is squeal sound in the wheel-rail interface. The present paper focuses on the different squeal phenomenon in the wheel-rail interface. Several researchers have shown that friction modifier can significantly reduce the squealing sound. However, they can also cause low friction and hence cause safety issues. The present study discussed two field tests. The first test identifies the different location in the wheel-rail interface where squeal noise can be created. In the same field test, the friction modifier was applied to those location weathers, to check if friction modifier eliminate or minimise the squealing noise. The second field test was focused on friction reduction by applying friction modifier. In addition, the study has also reported the experience of the drivers about the braking capability when friction modifier is applied.

Keywords: Friction modifier, FM, braking distance, rail wear.

1. Introduction

Noise is one of the main factors that can have a damaging effect on the quality of the living environment. Reducing unnecessary sounds is desired, especially due to the growth of urban centres, increased traffic volumes and the greater use of noisy machinery and equipment [1]. Noise from railways can be divided into several categories, for example, rolling noise, ground vibration and noise, bridge noise, aerodynamic noise, squeal noise, and internal noise and vibrations. Wheel squeal noise is the most frequent and dominant disturbance in urban areas [2] and it is one of the most disturbing and loudest noises [3].

According to Muller and Oertli [4], approximately 1.5 million inhabitants are disturbed by rolling noise and squeal noise from railway operations in Europe. Therefore, it needs to be prevented to the greatest extent possible. Rudd [5] who explained the curve squeal sound in 1976, identifies three mechanisms, each due to stick-slip behaviours in the contact region. The first was lateral creepage at the contact between the wheel tread and the top of the railhead. The second is the wheel flange rubbing against the gauge face. The third is the longitudinal creepage at the contact on the wheel tread due to differential slip. However, these squeal sounds are not constant and sometimes they occur for only certain periods and amplitude of noise may vary.

Squeal phenomenon is strongly related to the properties of the adhesion coefficient. A small creepage with the positive slope of the force/friction curve maintained the stability of the system and suppressed squeal [6]. To achieve this positive slope on the friction graph and damp the stick-slip phenomenon, friction modifier (FM) is generally used, see figure 1. These products are claimed by their manufacture to provide a constant friction coefficient near 0.3 and damp the squealing noise by providing the positive slope on the friction graph. In addition to sound reduction, as claimed by manufacturers, the FM also reduces rolling contact fatigue (RCF), wear, corrugation, and fuel consumption. [7]

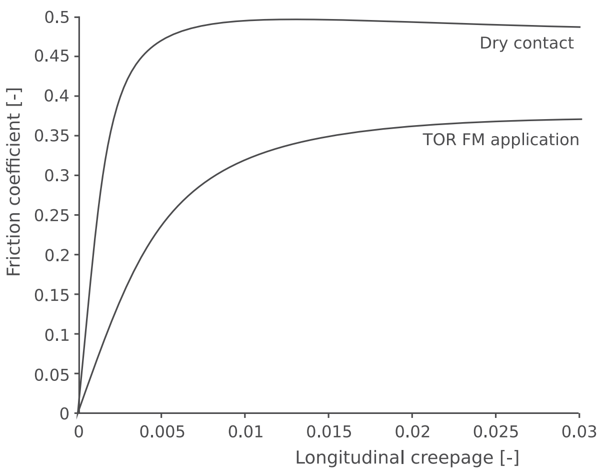

Figure 1. Relationship between friction coefficients and longitudinal creepage for the dry and applied-FM conditions. [7]

The present study consists of two field measurements, performed at two different locations in Sweden. The first test focuses on the sound sources in the wheel-rail interface and checking if FM is capable to reduce sound sources. The second test focuses on friction reduction due to FM application. Both the studies were followed by brake tests, in which, the driver evaluated the braking capacity by his experience.

Note: It is recommended by the manufacturer of FM, not to mix the gauge face grease with the FM, therefore, in the present study the FM is used for both top the rail and the gauge side.

2. State of the art

Previous research related to wheel-rail squeal sound reduction in Sweden have shown that by using FM at a tangent track can reduce the rolling noise [8]. They performed a vibro-acoustic study for two days and compared the vibration and sound levels with and without friction modifier. The different trains have different sound levels. The results also show that some train generated lower sound level in dry condition, when compared to the sound generated by similar trains in the presence of friction modifier. However, if we look at the overall picture an indication of lower sound levels after lubrication at higher frequencies. The results also indicated that there are many factors in addition to wheel-rail friction, which can contribute to the sound generation. Such factors can be wheel profile, bogie suspension.

Asplund et al [2] studied different reason that could minimise the wheel-rail sounds, and they stated that FM could reduce both vibration and squeal noise. By applying the FM only on the low rail, vibrations completely disappear and the squealing noise reduces by 13 dBA. Eadie et al [9] stated that friction modifiers can reduce overall noise in curves across a wide range of wheel-rail systems, which include trams, freight trains and metros. The authors classify different noises coming from the wheel-rail interface based on their frequency (Hz), which includes, rolling, flat spots, ground-borne vibrations, structure-born noise, top of rail squeal and flanging noise. The claim that by using FM, noise tends to be reduced across a broader part of the spectrum.

The manufacturer claims that by using their product there is an insignificant increase in the braking capability. They mention in their brochure that by using the FM the braking time increases from 11.1 to 11.5 seconds. That is approximately 4 % decrease in the braking capabilities. Contrary to that, Galas et al [10] claim that based on their laboratory and field investigation that it is difficult to achieve a reduction of the sound level without the increase of braking distance. If a small amount is used, it will not have any reduction in the sound, however, on increasing the amount of FM the braking capability decreases. Their results show that by using an excess amount of FM, the braking distance can increase by approximately 66%.

3. Problem statement

Swedish Transport Administration (Trafikverket), want to use this technique on the track near the residential areas, where they have received complaints about the squeal sounds. By doing these experiments they want to make sure that by using friction modifier squeal sound can be eliminated. At the same time, they want to determine the possible risk of using such a technique. The possible risk includes long braking distance, rail burn, and/or wheel flat, which can occur when friction on the top of the rail goes below 0.3.

4. Methods

4.1. *Friction modifier*

Top-of-rail friction modifier provides a protecting layer in the wheel-rail interface, which minimizes the friction forces. FM used in the railway applications is a thick liquid that consists of soft particles suspended in a solvent. It is applied between the top of the rail and the wheel tread as an additional third body. Friction modifier used in the present research was a black-coloured thick liquid that resembles black particles suspended in some solvent and appears like a conventional very soft grease that does not dry rapidly. An FM reduces abrasive contact with asperities at the wheel-rail interface and, specifically, reduces the friction coefficient from high levels (0.5–0.8) under dry and FM-free conditions to an intermediate friction coefficient (0.3–0.4) [11].

A wheel-rail interface where there is no FM and the third body consists mainly of brittle materials such as wear debris, oxides, sand, residue from trains, etc. On the application of an FM, the already present third body is mixed with the soft FM particles and carrier solvent. The carrier solvent helps in distributing the FM particles. In the case of the stationary FM application system, the FM is carried forward with the help of moving wheel. In the case of train-mounted system, FM is applied on one wheel (generally the first axle) and it is distributed to the following wheels of the train. The choice of solvent is critical, as the carry distance of the FM particles depends on the properties of the carrier solvent [12]. The carrier solvent can further provide a reduction of friction through a mixed lubrication mechanism according to the Stribeck curve [13].

4.2. *Friction measurement*

The tribometer used in the present study was a commercial tribometer, shown in Figure 2. It was designed by the British Rail Research, Derby [14]. It uses a spring-loaded wheel made of steel with a width of 9.2 mm (± 0.1 mm), diameter of 89.0 mm (± 0.1 mm) and a radius of the contact curve of 29 mm (± 0.1 mm). The steel wheel is connected to a magnetic clutch in such a way that the wheel is free to rotate the clutch. A manually adjusted variable resistor slides the clutch. When the content is reduced, the resulting force is transferred to an analogue weight scale. Increasing the clutch resistance also increases the wheel's rolling resistance. The friction at the top of the rail controls the point where the wheel will slide.

When the operator reaches a steady walking speed, the tribometer starts measurement sequence. At the end of each sequence, the coefficient of friction for the rail is displayed on the digital panel of the tribometer. The wheel speed is determined by measuring the pulse length generated by an optical encoder mounted on the measuring shaft support shaft. As the wheel speed increases, the pulse length or period decreases. When all initial conditions are met, the central processing unit (CPU) of the board will begin a six-step test cycle by applying a ramping braking force to the measuring wheel. The braking force is provided by an electromagnetic brake. An automatic ramp control circuit immediately detects the point at which the wheel slip occurs and automatically reduces the braking action of the gauge wheel to prevent the wheel from digging into the lubricant on the rail and generating artificially high friction readings.

Figure 2. Hand push tribometer used for the friction measurements. (Photo credit: Zakarias Zouhir, Jernhusen)

4.3. Investigation of different sound sources

The present study summaries two different field tests, which were performed at different locations. In both the tests, a remote-controlled two-axle vehicle was used and "A-skydd" was implemented. A-skydd means that an area is leased for work and no normal traffic may take place over the workplace. The vehicle used in test 1 is shown in Figure 3, in test 2 similar vehicle was used. In both the vehicles, block brakes were mounted. In such a brake system, a block is pressed again the wheel tread to stop the train. In both the tests, the FM was applied manually.

Figure 3. The vehicle used in test 1.

The first field test was performed at a railway yard in Hagalund, Sweden. At this location, Trafikverket has received squeal sound complains. The test was performed to identify the different squeal sound sources in the wheel-rail interface. After the identification of the squealing sound, friction modifier (FM) was applied to the location where the sounds were generated, to check whether the noise is eliminated or not. After it was ascertained that the sound is eliminated, friction coefficient on the top of the rail was measured by using a hand push tribometer. The friction measurements were performed to determine the possible risk of low friction due to the FM application. The friction measurement shows that at the location where friction modifier was applied, the friction coefficient drops below the theoretical safety limits of 0.3.

Due to limited time, intensive friction measurement could not be performed in test 1, therefore, the second field tests were performed in Boden, Sweden. These tests aimed to measure the decrease in friction coefficient with the increasing amount of friction modifier. In these tests, 15 measurements were performed on a section of 400 m railway track. Friction modifier was applied at a location (1 ml after each pass) and the locomotive was made to pass over it after that friction measurement was performed using a hand push tribometer. After that, the locomotive was moved back to the original position and the process was repeated. Since the locomotive used was having two-axle, it can be said that the friction modifier was applied after every 4 wheel pass, since while coming back, wheel passes that FM application location. The friction was measured after every two wheel-pass, since the friction is measured after the train has passed.

In addition, in both the field tests, locomotive drivers were interviewed. They were asked to share the experience in a reduction in braking capacities when friction modifier was used.

5. Results and discussion

5.1. Field test 1

Several sounds are generated from the shunting yard, among all of them a significant sound comes from the wheel-rail squeal. Shunting yard has a large number of switch and crossing, which makes it even more critical from the sound point of view. The track section between switch and crossing are generally sharp curve where the squealing occurs. Due to rubbing of wheel and rails, significant squeal sound was generating at the curve, crossing, checkrail (also known as checkrails) and switch area. In the present study, the locomotive was made to pass at a different location at (approx. 4, 8 and 16 Km/h). The friction coefficient was measured before applying the friction modifier, the friction coefficient was between 0.45 and 0.55 on both the rail.

Squealing was generated from the following locations, when no friction modifier was applied.

- Near the checkrails, squealing sound was generated both due to due to stick-slip phenomena on the curve and the backside of the wheel flange is sliding against the crossing and checkrails.
- At curves and switch area, squeal sound was generated at the speed of 8 km/hour or higher. However, at crossing and switch area, squealing sound was generated at all speeds.
- At walking speed (4 km/h) at the curve and switch area, low-frequency stick-slip sound was generated.
- Impact noise was generated when the wheel enters the crossing.

Figure 4 shows the locations where the squealing sound was generating. After identifying the location of the sound source, friction modifier was applied so that it can be assured that friction modifier is sufficient to suppress the squealing noise. The friction modifier was applied in different steps, so that it can be identified individually if the FM has eliminated (significantly reduced) the noise at that location.

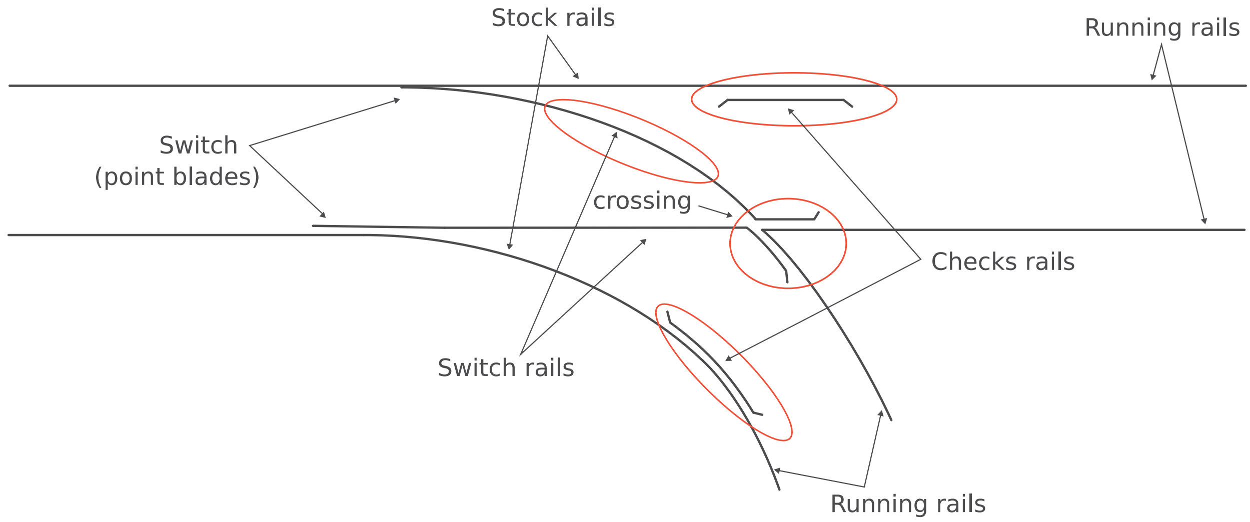

Figure 4. Schematic diagram showing the possible location where squeal sound can be generated.

Step 1: Application of the FM in the crossing: To eliminate noise from the crossing area, friction modifier was applied inside the crossing; see Figure 5, so that noise in the crossing area could be eliminated. The friction modifier was applied manually on the region where the backside of the flange slides against the crossing. By visual inspection, wear could be seen on the crossing where the backside of the wheel rubs against the crossing. The squealing sound was reduced, but not eliminated. By visual inspection, after the train has passed it was seen that the backside of the wheel has picked up the friction modifier. It was observed that after applying the friction modifier on the crossing area, the squealing sound from the crossing stop, however, there was squealing sound from the checkrails.

Figure 5. Picture of the crossing with friction modifier.

Step 2: Application of the FM near the Checkrail region: To eliminate squeal noise from the guard (check) rail, friction modifier was applied on the gauge face of the checkrail so that noise due to slippage between the backside of the wheel flange and checkrail; see Figure 6. The friction modifier was applied in a way that it is picked up by the backside of the flange. After applying the friction modifier on the checkrail, squeal sound was eliminated. The squealing sound was generated at both crossing and checkrails. By applying friction modifier on both checkrails and crossing the sound was eliminated. However, low-frequency stick-slip noise (on top of rail and wheel tread) was still there. This low frequency was expecting from the top of the rail and wheel tread.

Figure 6. Applying friction modifier on the checkrail.

Step 3: Applying friction modifier on the switch rail (outer): Near the switch area mainly the low-frequency, the stick-slip sounds were generating. At a higher speed, a little squeal sound was generating. To eliminate noise from the switch rail, friction modifier was applied to the gauge of the outer rail of the switch rail, starting from the edge of the switchblade; see Figure 7. By applying the friction modifier, both low-frequency squeal noise and stick-slip noise were significantly reduced.

Figure 7. Applying friction modifier on the switch rail.

Step 4: Applying friction modifier on the top of the rail before a curve: In this step, approximately 20 ml friction modifier was applied approximately 30 meters before the curve. After applying the friction modifier, the squealing noise due to slippage (both low-frequency stick-slip and high-frequency squeal sound) in the wheel-rail interface significantly reduced. For the all the three cases (where the flange was generating squeal sound) normal grease could be used instead of the friction modifier. However, FM application method needs to be investigated as in case one and two, FM/grease need to be applied at the backside of the wheel. In addition to that, manufacturer recommend, not to mix FM and conventional grease,

The friction was measured before and after applying the friction modifier using a hand push tribometer, as shown in Figure 2. After applying the friction modifier and train has passed over that location, the friction was measured from the location where friction modifier was applied, until the friction reaches 0.3. This was performed to identify the risk area, because friction below 0.3 can cause both reduction and braking capacity and wheel slippage. From the friction measurement, as shown in Figure 8, it is determined that approximately 60 m from the point of location (in both directions), the friction can be lower than 0.3. This could be due to the application of an excess amount of FM.

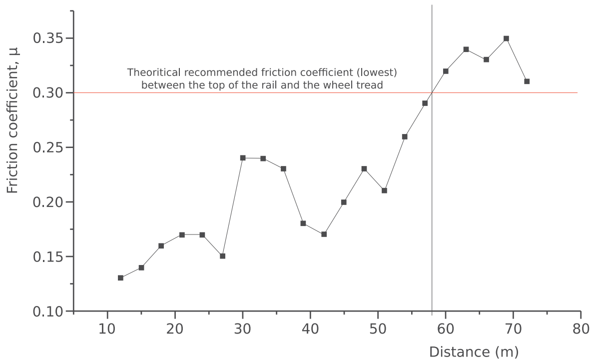

Figure 8. Friction coefficient measured using salient hand push tribometer after applying friction modifier at a location and distributed by the train

Note:

- *From previous experiments, it is known that the carry distance of such FM by using a stationary FM application system is approximately half kilometres. For details see reference [15].*
- *In context to squeal generation, curve section switch rails and stock rail behave similar to a sharp curve on a normal track.*

5.2. Field test 2

These measurements were performed to measure friction and braking capacity when a small amount (1 ml) of FM is applied after 4 wheel pass. Figure 9 shows all the friction measurement results, with every application the friction slightly decreases. However, after the 7th measurement, the friction coefficient starts to get saturated. For the last measurement (15th measurement), an excess amount of friction modifier 10 ml (excess) was applied, FM was applied on a spot and it was spread by the wheels. However, there was no significant difference between the run 14 and run 15.

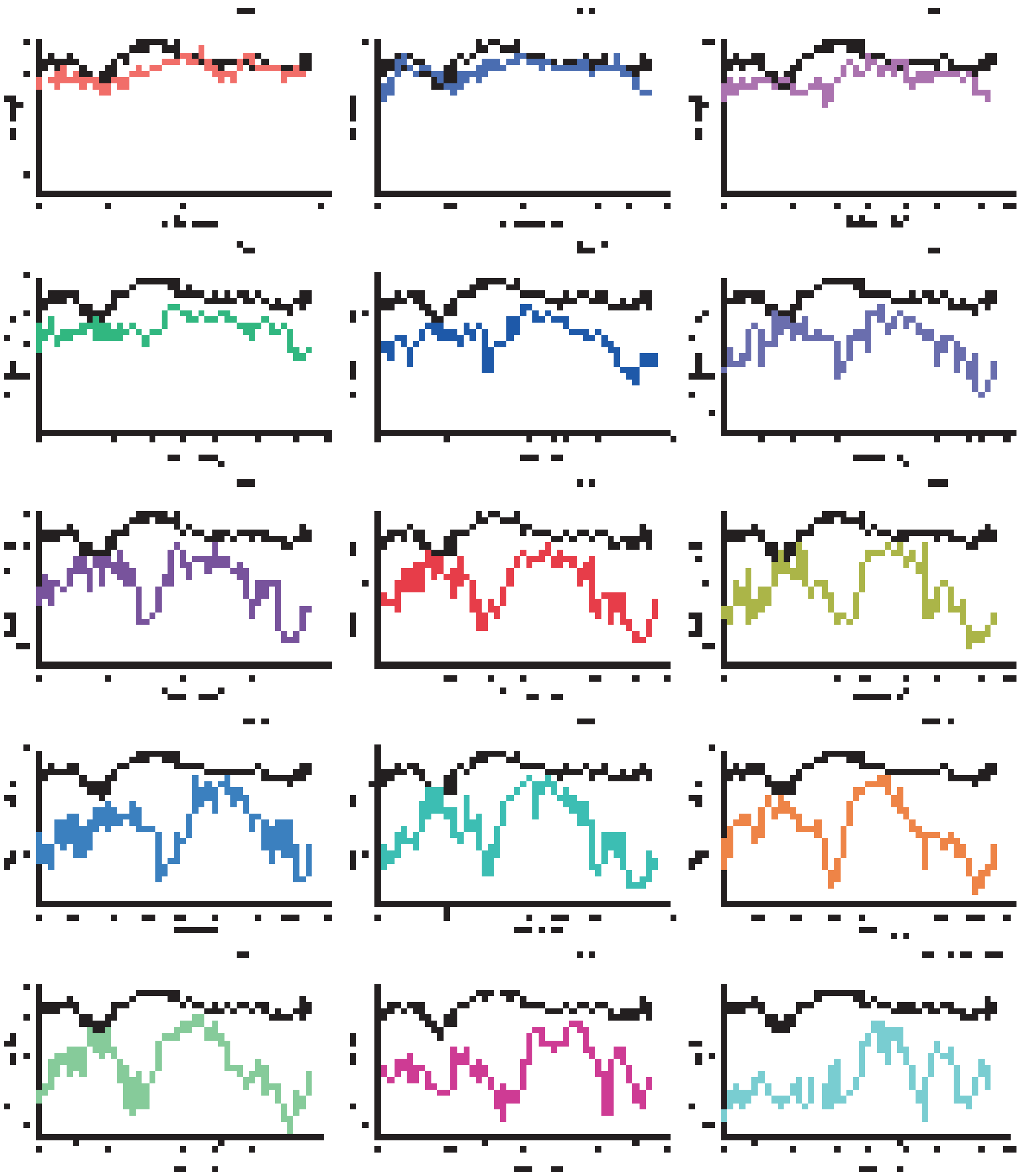

Figure 9. Graph showing all the friction coefficients.

During the 5th, 7th, 14th, and 15th measurements, a brake test was executed in the middle of the track and during all the measurements brake were used at the end of the 380 meters. When the wheel is passed over the pool of FM, it also sticks to the border of the contact band, which does not come in the wheel-rail interface, see Figure 10. During braking, the brake pad press and distributes the FM sticking on the border of the contact band of the wheel, which is the reason for lower friction in the middle and last part of the graph. In the brake test, the driver applied brakes and evaluated the braking capacity by his experience.

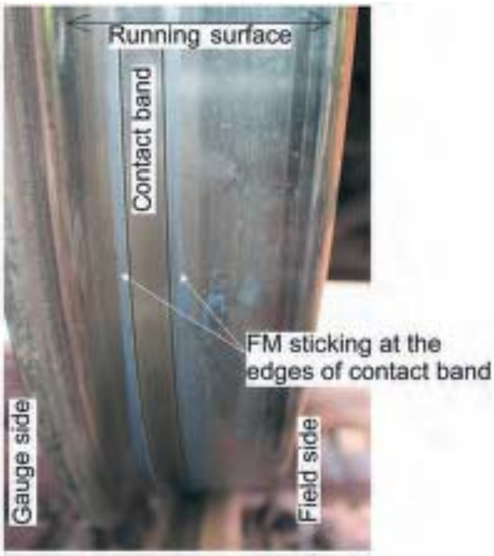

Figure 10. Image showing FM sticking on the border of the contact band.

Excess application of friction modifier as in the case of field test 1 at Hagalund, the friction can go down as 0.13. In test 1, it was calculated approximately 60 m from the point of application the friction was below 0.3. To have a clear picture of the friction measurement box plots are made for all the measurements, see Figure 11. As shown in Figure 9, in the first 100 m of the measurement, the friction coefficient is reached below 0.3. Since starting few meters from the point of FM application, are more critical, a box plot graph for first 100 m is shown separately in Figure 12.

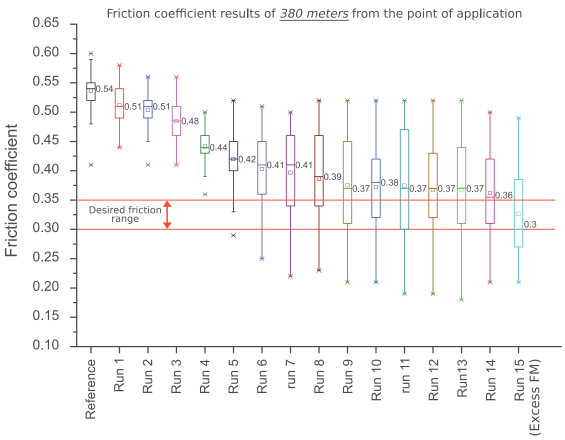

Figure 11. Friction coefficient results (box plot) of 380 meters from the point of application.

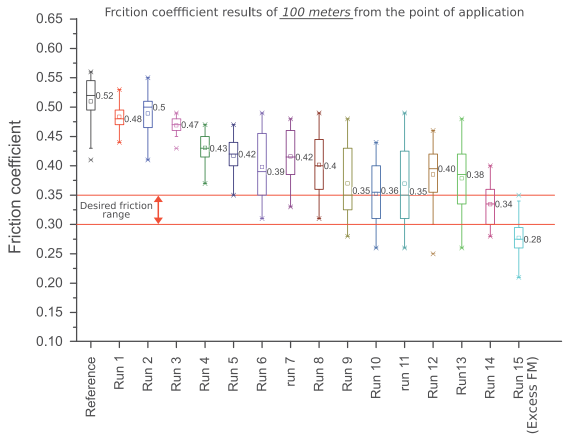

Figure 12. Friction coefficient results (box plot) of 100 meters from the point of application.

As seen in Figure 11 and 12, the friction is decreasing with the application of FM, but until the 6th run, the average friction coefficient is above the desired range. From the 7th run the average friction coefficient the desired friction range, start achieving. In addition, even the friction coefficient starts to being saturated. Some of the measurement points are below the desired value, however, the average values are mainly above the 0.3 value.

It should be noted that even the friction modifier is not present on the track, the friction modifier sticks on the wheel. When the brake is applied, there is a possibility that friction comes in the wheel-rail contact. However, this friction modifier is generally small in amount and wear off immediately without affecting the braking capacity.

5.3. *Brake test*

Feedback from the driver during test 1

- According to the driver at the location were FM was applied, the conditions were extremely slippery (below acceptable limit). However, at a distance of approx. 80 meters from the point of application, there was not a significant difference in the braking capabilities. The conditions were almost the same as no FM conditions.

- The driver was changed in the last hour of the measurement (after 3-4 passes of friction modifier application) and the second driver claims that the track is slightly slippery; however, the braking distance was not measured by him.

Feedback from the driver during test 2

- According to the driver, at the speed of approx. 30 km/h, the braking capacity decrease by approximately 20%. The friction in the region, where the brake was applied, was near 0.3. The driver also claimed that after 6-7 measurements, he feels that the vehicle was running more smoothly (he feels lesser vibrations) when compared to the reference measurement (without FM).

6. Conclusions

The conclusions are divided based on two different tests.

Conclusions from test 1

- High-frequency squealing noise was generated at
  - Checkrail rubbing against the backside of the wheel.
  - Crossing frog rubbing against the backside of the wheel.
  - In the curve, gauge face rubbing against the wheel flange and squealing due to stick-slip on the top of the rail and wheel tread.
- Low-frequency stick-slip sound was generated at
  - Top of rail and wheel tread (probably also wheel flange and rail gauge) in the curve at walking speed.
  - Top of rail and wheel tread (probably also wheel flange and rail gauge) in the curve at walking speed.
- By applying friction modifier on the backside of the wheel, squeal noise near the crossing area and checkrail area were eliminated.
- By applying FM on the gauge face, squeal generating from the flange rubbing again the flange was eliminated.
- By applying FM, squealing due to stick-slip on the top of the rail and wheel tread was eliminated.
- In case we apply an excess amount of FM (in this case it was 20 ml), friction can drop down to 0.13. However, it gradually increases with distance. Up to approximately 60 m from the point of application, the friction was below 0.3.

Conclusions from test 2

- By applying a small amount (recurring) of FM, the friction does not go below 0.2.
- Assuming that friction coefficient of 0.35 and below will provide sound damping. This distance is calculated approx. 200 m.
- FM application may decrease the braking capacity. In the case of the block brake against the wheel trade, the reduction in braking capacity is approx. 20 %, however, it is expected that this would be less than 20% (or maybe insignificant effect) in the case of trains with disc brake or regenerative braking.

Acknowledgement

The study have been funded within the European Union's Horizon 2020 research and innovation programme in the project In2Track2 under grant agreement No. 826255.

The authors gratefully acknowledge the support BDX, SWECO and EuroManit for assisting with locomotives, security staff and implementing A-skydd. The authors would also like to thank Zakarias Zouhir from Jernhusen, Julia Bermin from Trafikverket and Lars Nygren from SJ for providing technical assistance during the experiments.

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