DEVELOPMENT OF A NOISE RELATED TRACK MAINTENANCE TOOL

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The purpose of this work-package within the Quiet-track, FP7, is to develop a noise related track maintenance tool, in the form of an on-board measurement system. As a first step, lab scale tests using a pin-on-disc tribometer were used in order to distinguish how noise changes when the wear mechanism in a sliding contact shifts from normal wear to severe wear. Once the potential for using sound as an indication of severe wear transitions was established, full scale tests were carried out with a rapid transit (metro) train, type C20. The train was equipped with microphones that continuously measured the sound pressure near the wheel rail contact. In order to provoke severe wear, the test train was run in a curve with small radius, and the rails and wheels were carefully cleaned before the tests. The same kind of transfer from mild to severe wear was identified on the full scale test as in the laboratory scale test, confirmed by studying the surface topography and the morphology of the wear particles. Moreover, the full scale test results showed that the sound pressure changed significantly when transferring from mild to severe wear in agreement with the pin-on-disc test results. By comparing noise from the inner wheel/rail contact to noise form the outer wheel/rail contact a wear indication value for the outer wheel/rail contact is suggested in this study. This value can be seen as an advanced parameter from which the probability of severe wear, in the wheel flange/rail gauge face contact of the outer contact, can be estimated. At present, a real time condition monitoring system is set up in Stockholm (Metro line 1) in order to validate the results.

1. Introduction

We are all exposed to noise from roads, aviation, industry and railways. Action plans to manage this require noise mapping, such as the European Directive 2002/49/EC [1]. There are some national standards for predicting railway noise, e.g. the Dutch "interim method", the Nordic prediction model NMT96 [2], or "Calculation of Railway Noise 1995" (CRN) from the UK. However, as with all models trying to simulate reality, these have shortcomings. For example, as discussed by Hardy et al. [3] the CRN method does not allow the variability of rail head roughness. Neither does it include wheel squeal noise nor rail gauge wheel flange contact noise. A rough track can lead to a significant increase in rolling noise. Roughness is just one of many parameters that influence noise. Others include speed, the number of wheelset passages and ballast vertical stiffness. In the Netherlands, rail grinding (or acoustical grinding) for decreasing rolling noise from the rail head has been tried. Methods to grind the rails to reduce the sound have also been developed in Germany [4]. Kuijpers [5] discuss development of such monitoring method to assess the noise reduction due to rail grinding. Recently, Jiang et al [6] presented a framework for integration of different models to enable noise growth predictions based on rail roughness growth mechanics. Our study, on the other hand, tries to enable rail gauge corner and wheel flange wear growth predictions based on noise growth. Noise signals have been shown to have the potential to indicate wear transitions [7]. However, there is not much evidence to show that sound measurements have been used to predict this type of damage. According to Hardy et al. [3], corrugations (periodic wear patterns with a wavelength typically ranging from 30 mm – 80 mm) on the rail head can lead to an increase of 20 dB or more in *A*-weighted rolling noise Previous laboratory scale tests [8], linked to this Quiet-track project, show a similar increase from mild or normal wear to severe wear. Bolton and Clanton [9] revealed that sudden transitions in the wear rate in the wheel-rail contact can occur, which they classified into three wear regimes: type I – mild wear, type II – severe wear, and type III – severe wear. These regimes are based on classification of the wear rate in comparison with the surface appearance and the morphology and size of the wear particles. Using field and laboratory data, Lewis and Olofsson [10] drew a wear map of wheel-rail contact showing the area of the three wear regimes in a velocity contact pressure space.

The purpose of this study is to scale up the laboratory scale results in [8] to a full scale test following the wear transitions using a train instrumented with microphones on a dedicated test track. Two pin-on-disc tribometers were used in the laboratory scale tests to study the relationship between wear transitions, surface topographies and emitted noise. A wear transition was always accompanied by a sharp increase in sound pressure (10 dB). In addition, the sound pressure amplitude distribution can be used to identify different wear mechanisms showing a narrow initial distribution in the mild wear regime and a broader distribution in the severe wear regime. In this study, the measured noise from inner and outer rail and wear from outer rail was analysed and comparisons drawn between the rail being cleaned and exposed to severe wear and when the rail was lubricated. From this, a wear indication value is suggested that can be seen as an advanced parameter from which the probability of severe wear can be estimated. The hypothesis is that this parameter is suitable for describing the shift from normal to severe wear in the rail gauge wheel flange contact.

2. Test set up

The full scale tests were carried out with a rapid transit train, type C20 (eight axles), equipped with microphones that continuously measured the sound pressure near the wheel rail contact, Figure 1. In addition to the on-board monitoring microphones mounted under the vehicle (located at both the inner and outer rail), eight additional microphones were used to measure the noise close to each wheel on the outer rail. . A stationary microphone was also utilized in this test set up. In order to provoke severe wear, the test train was run back and forth in a curve with a 200 m radius. The track plan is shown in Figure 2. The test procedure is described in Table 1. Note that rails and wheels were carefully cleaned before the tests.

The wheels were photographed and replicas of the wheel surfaces made using blue laser coursing moulds (Technovit Blue LED). Form measurements of the wheel profiles were performed before and after each test using a Miniprof system. Figure 3 presents photographs of the used track measurement techniques.

The rail surface was photographed and the surface replicas made at three track locations, denoted A, B and C. Form measurements of the rail profile before and after each test were made at location B. Particles were collected with scotch tape at location C. In addition, a slip resistance meter was used to measure the rail gauge corner adhesion level at location B. The slip resistance meter is used as an indication of the lubrication functionality, further described in Lewis et al. [11].

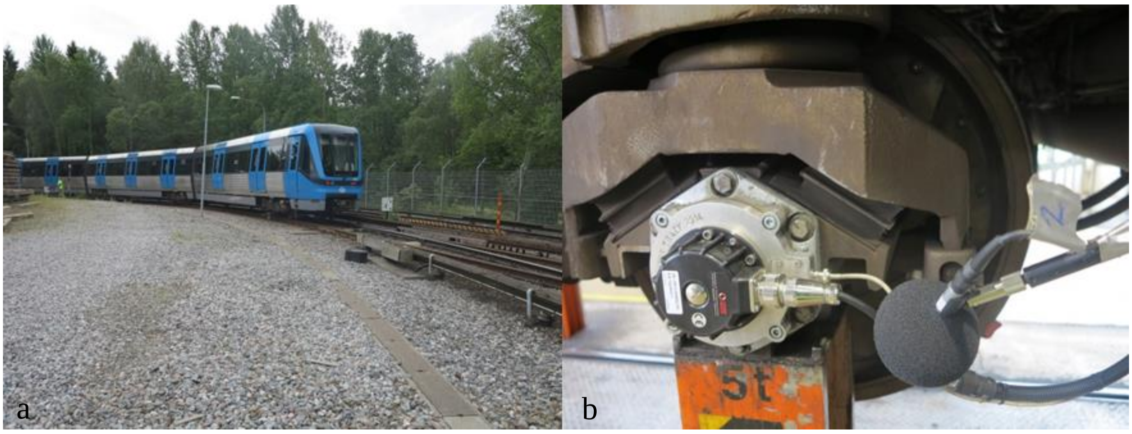

Figure 1. The instrumented C20 rapid transit train running on the test curve (a) and the mounted microphone instrumentation near the wheel (b).

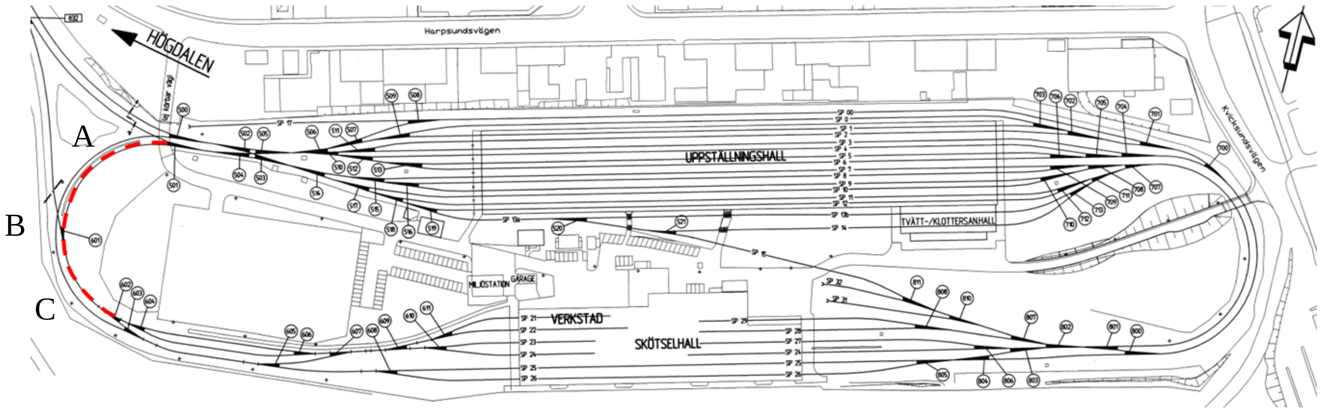

Figure 2. Track plan. The used test curve is marked with a hatched red line along with the three track locations denoted A, B and C.

Table 1. Test procedure. The tests were performed in the following described order.

Description	Train passes (total)	Comment
Initial test	0	Clean rail and wheels
After 12 passes of train	12	
After another 12 passes	12 (24)	
After another 12 passes	12 (36)	
Manual application of oil to rail	0 (36)	Oil applied with brush (no additional trains ran)
Track oil lubricator used	6 (40)	Train ran through oil lubricator and oil applied with brush

Figure 3. Pendulum slip resistance measurement (a), wear particle collection (b), Miniprof rail profile measurement (c) and surface replica molding (d).

3. Results

The following results are based on a full scale test at Högdalen. Note that this paper does not cover the whole extent of the collected data.

3.1 Slip resistance and Wear

Table 2 presents the results of the slip resistance measurements. In total, six slip resistance measurements were done on each occasion and an average value is presented. Table 2 also shows the metrological conditions for the test day. As expected, the slip resistance measurements show a stable value during the test period and a decrease in the slip resistance value when the rail was lubricated again. Photo (a) in Figure 4shows the worn rail gauge corner after testing - note the severe worn surface and the amount of wear particles on the rail foot. Photo(b)shows the wheel flange after test, and the severe wear is noticeable here too. Figure 5 shows optical micrographs of wear particles, collected at the end of the test from location C. The wear particles also show evidence of severe wear.

Table 2 Results from slip resistance measurements with metrological data for the test day.

									Slip resistance value						
Test Number	Location	Time	Description	Train passes	Axle passes (trains x 8)	Weather	Environmental temp	Humidity	1	2	3	4	5	6	Average
001	B	9:55	Initial test	0	0	Cloud	19,2	29,3	48	48	49	50	50	50	49
002	B	11:45	After 12 passes of train	12	96	Cloud	19,9	35,8	47	48	49	49	52	50	49
003	B	12:10	After another 12 passes	12	192	Cloud	19,6	32,5	46	44	46	44	44	46	45
004	B	12:20	After another 12 passes	12	288	Cloud	18,4	40,4	46	48	50	49	48	50	49
005	B	12:45	Oil applied with brush (no additional trains ran)	0	288	Cloud	19,4	46,9	30	30	32	32	32	30	31
006	B	13:15	Train ran through oil lubricator + rail brushed with oil - 6 train passes	6	336	Cloud	19,5	44,3	25	24	26	27	26	27	26

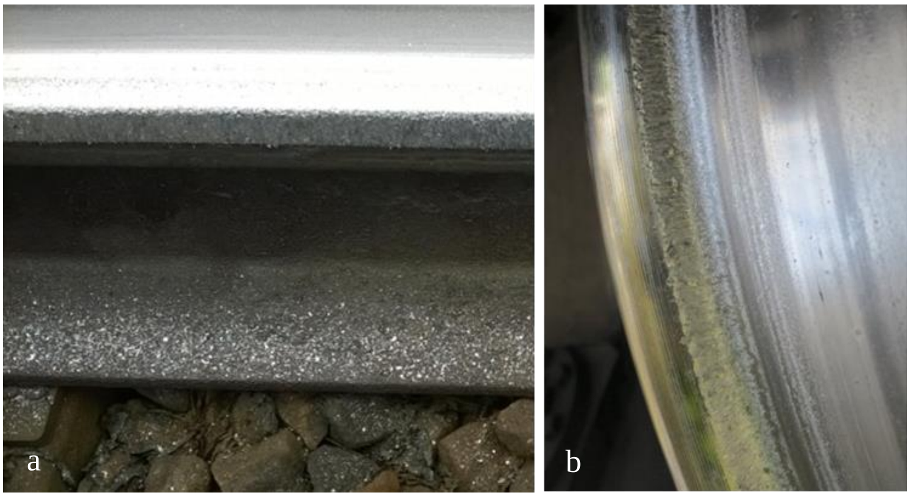

Figure 4. Photograph of severe wear at rail gauge wheel flange contact. Particles at rail foot (a) and of severe wear on wheel flange (b).

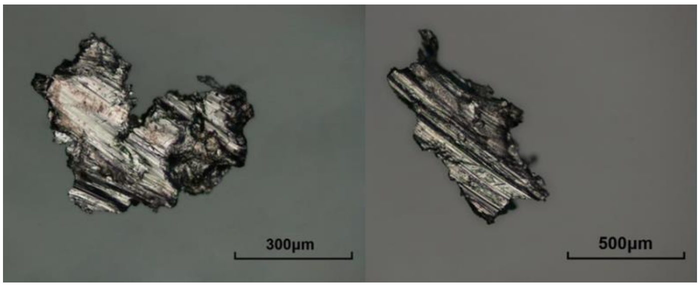

Figure 5. Photographs of wear particles from site C.

Figure 6 presents form measurements for both the rail and wheel profile, and shows that the accumulated amount of wear during the entire test on both the high rail in the curve and the wheels was rather small. At the wheel closest to the microphone mounted on the outer side of the curve, the maximum vertical wheel wear was approximately 0.4 mm (Figure 6b). Due to the inclination of the wheel profile at that position it corresponds approximately to 0.15 mm wear depth perpendicular to the surface (Figure 6c). The wear of the outer rail (not shown) was somewhat lower; approximately 0.1 mm was measured as a maximum wear perpendicular to the rail surface.

Figure 7 and Figure 8 present results of surface topography measurements of the replicas using a Taylor Hobson Form Talysurf PGI 800 with a stylus tip radius of 2 µm. The areas measured on the replicas were 9 x 11 mm^2 for the rail gauge and 6 x 10 mm^2 for the wheel flange. The results visualize the transfer to a rougher surface after test compared to before test. Note the slight profile change after test in Figure 7b.

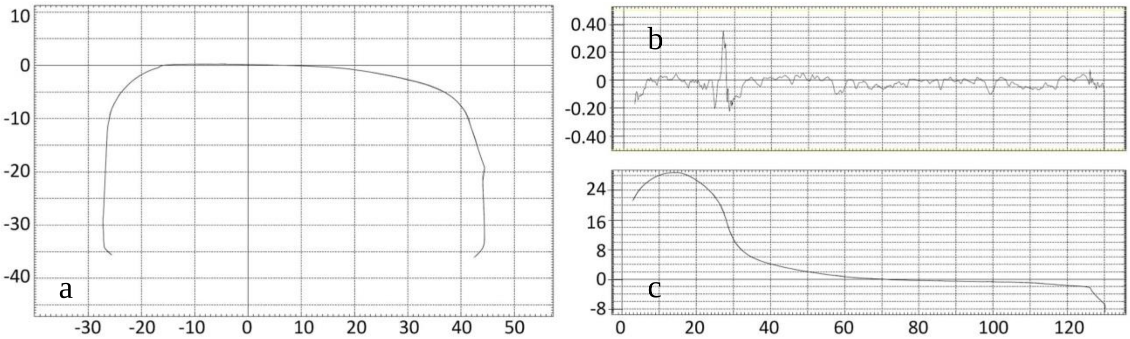

Figure 6. (a) Measured profile of the high rail at the test site before and after testing – no visual difference; (b) calculated vertical wheel wear accumulated during the test; and (c) the measured wheel profile for the wheel closest to the microphone on the outer side of the curve. All units in mm.

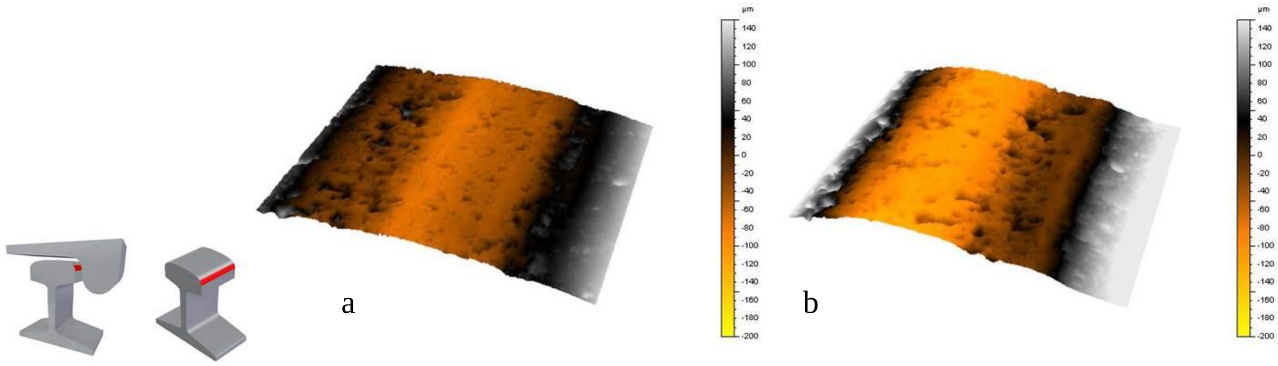

Figure 7. Surface topography measurements of rail replicas before (a) and after (b) using centred scaling from -200 to 140 µm, note that the measurements of the replicas are turned upside down. The illustration next measurements show where the replicas were made on the rail.

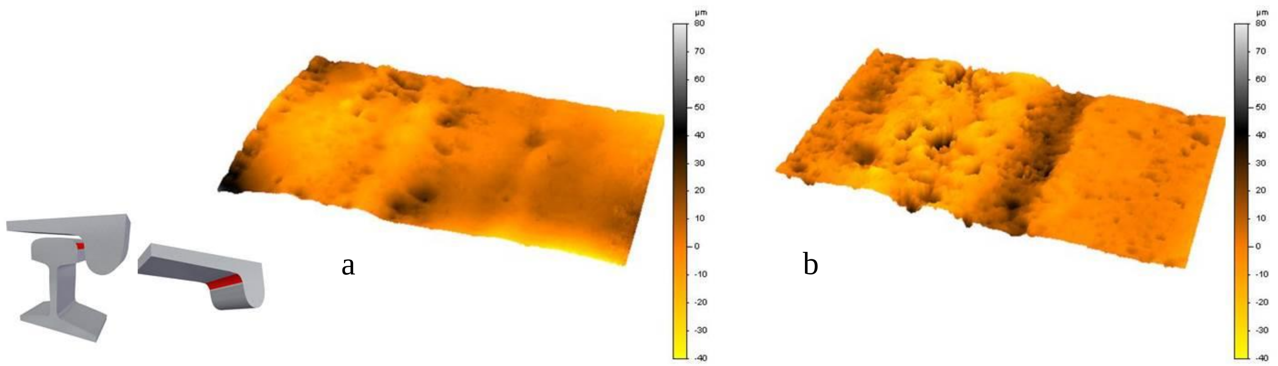

Figure 8. Surface topography measurements of wheel replicas before (a) and after (b) using centred scaling from -40 to 80 µm, note that the measurements of the replicas are turned upside down. The illustration next measurements show where the replicas were made on the wheels.

3.2 Sound

In Figure 9, the measured A-weighted sound pressure level, registered in two positions under the vehicle, is shown for two different passages during the tests. The data to the left in Figure 9 represents a measurement with severe or severe wear, whilst the data to the right represents a measurement after lubrication. P1 is located close to the wheel/rail contact for the outer rail and P2 is located close to the wheel/rail contact of the inner rail. For the first 55 seconds, the data to the left in Figure 9, the noise measured at P1 is higher than the noise measured in P2. This means that the noise from the outer rail, caused by severe wear in the contact between the rail head and the wheel flange, is dominating. The higher levels towards the end of the measurement are dominated by P2 and represent squeal noise from the inner rail. The data to the right in Figure 9 shows the same type of behaviour but after lubrication of the track. The outer rail does not dominate the noise, and there is no wear or minimal wear in the contact between the wheel flange and the rail head. The wear indication value, which has been developed within the Quiet track project, shows much lower levels. The wear indication value compares the noise coming from the inner and the outer wheel/rail contact and estimates the probability of severe wear based on difference between P1 and P2, amplitude of the noise. In the comparison between the two signals frequencies representing the wheel resonances are ignored.

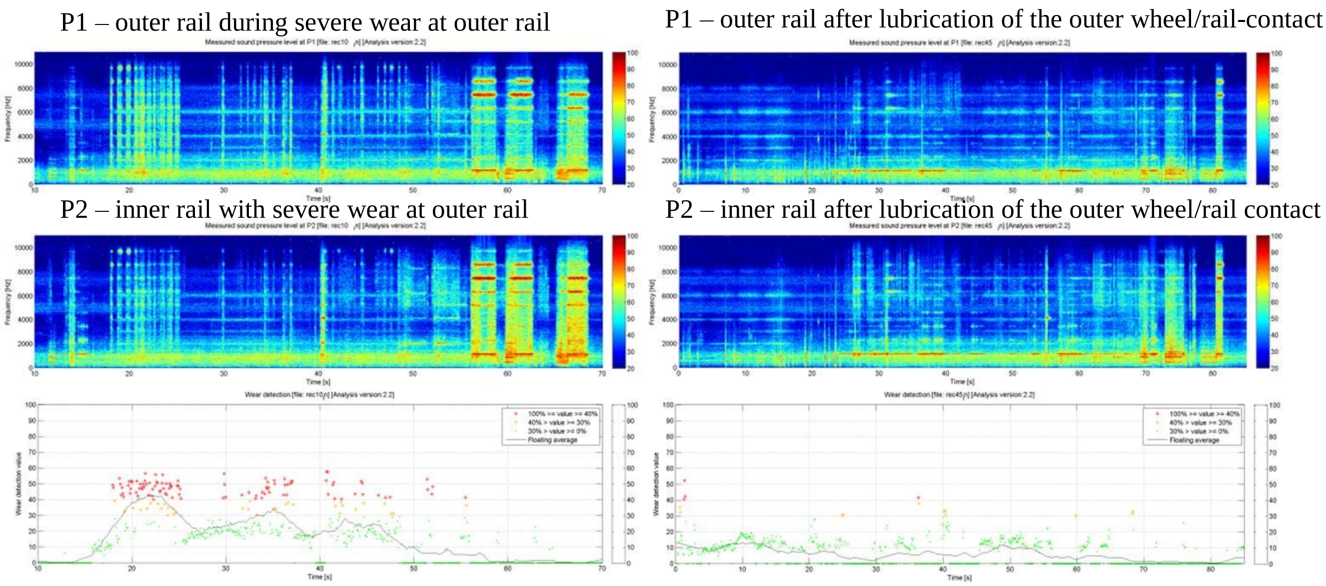

Figure 9. A-weighted sound pressure level close to outer (P1) and inner (P2) wheel/rail contact, one passage with severe wear (left) and one passage after lubrication (right). The bottom figures represent the wear detection parameter that is developed and calibrated within the Quiet Track project.

4. Discussion

The full scale test at the Högdalen site presents similar results as the previously presented pin on disc test results [6]: the transition from mild to severe wear is followed by an increase in the sound pressure and a broader sound pressure amplitude spectrum. That said, the influence of other sound sources does complicate the evaluation in the full scale test. In the evaluation of the noise signals, high frequencies (>5kHz) are of importance. These high frequencies are directive and the location of the microphones is also of importance. At the moment the monitoring system make use of only one microphone above each rail. If the monitoring microphone is “in front of the wheel” or “behind the wheel” when the train is rolling, it will affect the evaluation algorithm due to the screening of the noise by the wheel. The tests in Högdalen indicate that this problem can be handled, but further evaluation in real situations are needed to show whether the monitoring system must be supplemented with two additional microphones.

5. Conclusion

The tests performed in Högdalen, Sweden, have shown that the monitoring system has good potential for detecting severe or severe wear from railway traffic by analysing the noise emitted from contact between the wheel and the rail. In the next phase of the project, the developed wear detection value will be evaluated in real situations in the subway system. It is likely that the evaluation needs to be adjusted in some way due to differences such as the vehicle speed and curve radius on the track.

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REFERENCES

1 Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 2002 relating to the assessment and management of environmental noise.

2 Höjer, M., Almgren, M., Monitoring systems for track roughness, *Proceedings of Euronoise 2015*, Maastricht, 1-3 June, (2015).

3 Hardy A. E. J., Jones R. R. K., Turner S., The influence of real-world rail head roughness on railway noise prediction, *Journal of Sound and Vibration* **293**, 965-974, (2006)

4 Diest, K., Püschel, A., High Speed Grinding – railway noise reduction through regular rail grinding without traffic interruptions, *Inter-Noise 2013, the 42nd International Congress and Exposition on Noise Control Engineering*, Innsbruck, Austria, 15-18 September, (2013)

5 Kuijpers, A. H. W. M., Rail Roughness Monitoring in the Netherlands, *Notes on Numerical Fluid Mechanics and Multidisciplinary Design*, **99**, 348-354, (2008).

6 Jiang, S., Meehan, P. A., Bellette, P. A., Thompson, D. J., Jones, C. J. C., Validation of a prediction model for tangent rail roughness and noise growth, *Wear* 314 (2014) 261-272.

7 Jiang, J., Dwight, R., Determining wheel-rail wear conditions using wheel-rail noise, *7th International Conference on Contact Mechanics and Wear of Rail/Wheel System*, Brisbane, Australia, 24-27 September, (2006).

8 Lyu, Y., Bergseth, E., Björklund, S., Olofsson, U., Lindgren, A., Höjer, M., On the Relationships between Wheel and Rail Surface Topography, Interface Noise and Tribological Transitions, *Proceedings of the 18th Nordic Seminar on railway Technology*, Bergen, Norway, 14-15 October, (2014).

9 Bolton, P.J., Clayton, P., Rolling sliding wear damage in rail and tyre steels, *Wear*, 93 145-165, (1984).

10 Lewis, R., Olofsson, U., Mapping rail wear regimes and transitions, *Wear*, **257**, 721-729, (2004).

11 Lewis, S., Lewis, S., Olofsson, U., An alternative method for the assessment of railhead traction, *Wear*, **271,** 62-70, (2011).