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Rail Maintenance Solutions for Urban Networks

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Abstract

Urban rail maintenance presents unique operational challenges (especially for tramway networks), including high traffic frequency that limits available maintenance windows, tight track geometry, condensed clearance envelopes, and the need to share infrastructure with other transport modes. Available maintenance technologies like rail grinding with rotating stones or rail milling face technology specific challenges and restrictions when operating in these urban conditions. To overcome these limitations and demands of urban rail systems and especially tramway networks, a new grinding technology was developed with funding through European Union's Shift2Rail program. This paper describes the development, extensive testing and application experience of this purpose-built rail grinding solution based on block grinding technology.

Keywords: infrastructure maintenance, urban rail systems, rail damage, rail grinding, Railway noise mitigation, rail profiles.

1 Introduction

Urban railway networks generally fall into three broad categories: commuter rail (which links suburban areas to city centers), heavy rail metro systems (designed for high-capacity intra-city travel), and light rail or tramway systems. Commuter networks typically operate over mainline infrastructure and are maintained within that framework. Metro and tramway systems, by contrast, run on their own dedicated networks, characterized by significantly tighter curves than those found on mainline tracks. Tramway systems in particular tend to share their right-of-way with other road users — including cars, cyclists, and pedestrians — adding a further layer of operational complexity.

As part of the Shift2Rail initiative of the European Union [1] the Technical University of Vienna and Plasser & Theurer in Austria conducted a European tramway network survey to identify key characteristics/challenges of such systems:

- Tramway networks have small and often variable clearance envelopes with a mix of grooved (about 2/3) and vignol rails (about 1/3).
- Typical curve radii below 25m and a high number of special trackwork.
- Shared pathways with other motorised or non-motorised road vehicles and pedestrians – special safety requirements.
- The rails are often embedded in the road surface.
- The average travel speed of tramway systems is around 21km/h – main impact factor is distance between stops.
- Besides typical rail damage (wear, RCF), noise and vibration (e.g. caused by corrugation or singular rail surface defects) are of special concern in urban environments.
- Tramway systems have very dense train intervals and extended operational hours (sometimes close to 24/7) significantly reducing time for any maintenance.
- Tramway networks are often of small size and not connected to mainline networks.
- Maximum permitted axle loads are relatively low (e.g. 10 t).

2 Technology Development

Drawing on the findings of the network survey, Plasser & Theurer developed a track maintenance solution tailored to address the characteristic challenges of urban rail environments. This work was carried out under the Shift2Rail Initiative [1], with funding provided by the European Union's Horizon 2020 Research and Innovation Program.

Figure 1: Urban rail grinding trailer ATMO (Automated Track Machine Oscillator) towed by a high-rail vehicle.

Out of several potential rail maintenance technologies block grinding technology was chosen as the most suitable technology [2]. Block grinding allows two operational modes. In oscillating mode, the blocks oscillate back and forth with a dedicated frequency and amplitude while the vehicle is moving. In sliding mode, the stones are dragged along the rail (without oscillation). The grinding blocks continuously adapt to the general shape of the railhead treating the running surface of the railhead (no gauge face or gauge corner treatment). This process creates a typical longitudinal profile but cannot adjust or create any transversal profile. With this operational flexibility it is possible to cover a wide range of speed requirements from 0 km/h (oscillation mode only) to more than 30 km/h (no minimum speed required). Although available since the 1970s, the block grinding technology had to be completely redesigned for its intended urban application. Due to space restrictions the grinding unit had to be re-developed from scratch including the oscillation drive system. These new grinding units were incorporated in a prototype compact maintenance trailer vehicle (ATMO – Automated Track Machine Oscillator, Figure 1). The ATMO has its own diesel power supply (in future versions: electric power supply) for the grinding units (to be independent of the towing vehicle) and a water tank (2600l) to create a thin water film on the rail surface to enhance grinding output. The vertical grinding stone force (3100-7080N for each grinding unit) as well as oscillation amplitude (55mm max.) and frequency (0-6Hz) can be varied within the provided parameters. A guidance system had to be designed for the grinding stones not to deviate from the ideal path in tight curves and to compensate for gauge variations due to rail wear. The trailer is equipped with two grinding units on each side. The trailer can be pushed or pulled by any suitable rail bound or high-rail vehicle. Due to its variable speed capabilities, the trailer can be used during revenue tramway operations (in between trains) or during non-operational hours, complying with requirements for preventive maintenance in the intended meaning [3].

3 Yard Test Program

After some internal tests at the Technology Center of Plasser and Theurer in Purkersdorf/Austria, an extended testing program was conducted together with the operator of the tramway network in Vienna, Wiener Linien.

A rigorous testing program focused on understanding of general operational parameters and on achievable metal removal. For all tests at Wiener Linien the ATMO was towed by a UNIMOG high rail vehicle provided by Wiener Linien. Oscillation frequency, oscillation amplitude, vertical stone force and speed were varied to identify optimal parameters. Transversal profile was measured before and after each test using a MiniProf device. The obtained wear data showed quite some variability that was attributed to stone condition (worn-in vs. new), measurement/analysis procedure and to significantly varying track quality condition in the maintenance yard. Despite the data scatter an average metal removal of 0.01mm per pass was determined. The parameters of 4430N vertical force, 3.5 Hz oscillation frequency and an amplitude of 35mm were selected as standard parameters for any future tests. Additional tests also focused on different grinding stone types identifying the MH (medium-hard as per manufacturer specification) type stone as providing the most consistent results.

4 Corrugation Removal

The next test program focused on surface irregularities removal in revenue tramway track of Wiener Linien. A tangent track location on “Simmeringer Hauptstrasse” close to Vienna Central Cemetery that was known to consistently develop corrugation (Figure 2) [4] was selected for this purpose.

Figure 2: Example of corrugation severeness at selected track location

Longitudinal rail surface condition was measured before the first pass (initial condition) and after each 5th pass with a Railstraight Wave measurement device. The measurement was analysed according to EN 13231-2 (2020) [5] with special focus on the wavelength bands of 30-100mm and 100-300mm (typical corrugation wavelength at this location). In total 7 test were done at 7 test sections (section length approx. 100 m) along this stretch of tramway track next to the cemetery. All test sections consisted of R260 grade rails according to Wiener Linien. The tests were spread over four days in the months October, November, December of 2021 and April the following year. In total 7 tests were done with oscillation mode (40% pressure, 3.5 Hz, 35mm amplitude) and with sliding mode with a passing speed of 30 km/h. Additionally to the MH stone also softer stones type MS (medium soft) and Type S (soft) were tested.

Some of the tests had to be discarded due to hydraulic problems with the grinding trailer. Dependent on the initial severity, corrugation exceedance values fell consistently below the exceedance threshold of 10% (for track class 2 according to EN 13231-2:2020) after 5-10 passes (wavelength band 30-100mm) and respectively 15-20 passes (wavelength band 100-300mm) – exemplary results in Figure 3. Corrugation removal in oscillation mode was more efficient than in sliding mode. MS and S achieved higher corrugation improvement results compared to the MH stone, providing some operational flexibility with respect to removal capability, stone wear behaviour and resultant stone cost.

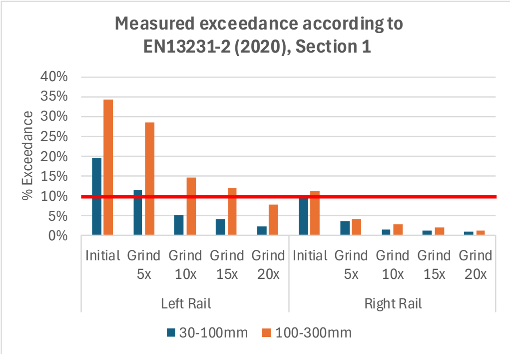

Figure 3a: Test in oscillation mode with 20 passes, MH stone. Final results dependent on initial corrugation level.

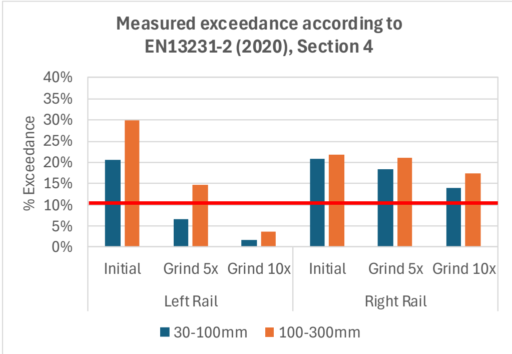

Figure 3b: Test in oscillation mode with 10 passes, MH stone. Oil leakage on right side resulting in reduced efficiency.

5 Noise and vibration mitigation

This test series focused on the impact of corrugation removal on noise and vibration mitigation. A previously not treated section along the long stretch of tangent track at Simmeringer Hauptstraße was chosen (Figure 4).

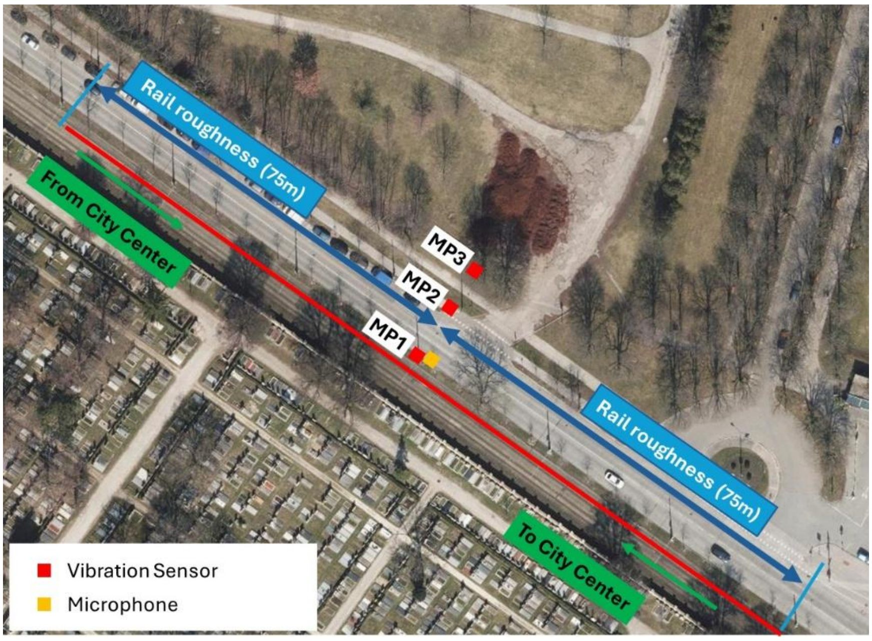

Figure 4: Measurement layout for tests concerning noise and vibration.

Three different types of measurements were conducted by the company VCE Vienna Consulting Engineers ZT GmbH (VCE):

- acoustic rail roughness according to EN 15610:2019 [6] during non-revenue hours with a Mueller BBM m|rail trolley device.

- noise emissions according to ISO 3095:2013 [7] with a G.R.A.S Type 26CA microphone. Microphone position had to be adjusted (compared to ISO 3095:2013 requirements) due to space constraints (street) – 4.7m from centerline of measurement track (track 1) and 0.7m above top of rail (TOR).
- ground vibration with vibration velocity sensors type Walesch MST-1031-V installed at 4m (MP1), 22m (MP2) and 30m (MP3) perpendicular distance from the centerline of the measurement track (track 1).

In addition, the speed of passing tramways was measured with a Stalker Sport 3 radar gun. Weather data (temperature, humidity and wind speed/direction) was collected from a weather station about 5.3 km away from the measurement location. The layout of the test site on track 1 is shown in Figure 4. Measurements were done on three different days – before grinding to capture the initial condition, directly after grinding with 15 grinding passes and three weeks after grinding to allow some wear-in period for the surface roughness.

Acoustic roughness data is provided for the left and right rail in Figure 5. Both rails show initial roughness levels well above the ISO limit (black line in Figure 5) with a roughness-peak at 50mm wavelength. The right rail also shows a distinctive peak at 125mm wavelength that is not as clearly visible on the left rail. The measurement directly after grinding (left and right rail) shows generally increased values that are most likely attributed to a contaminated rail surface. Therefore, these results should be discarded and are not further considered. After the wear-in period of 3 weeks, both rails show roughness values in the vicinity of the ISO limit with improvements of up to 15 dB compared to the premeasurement.

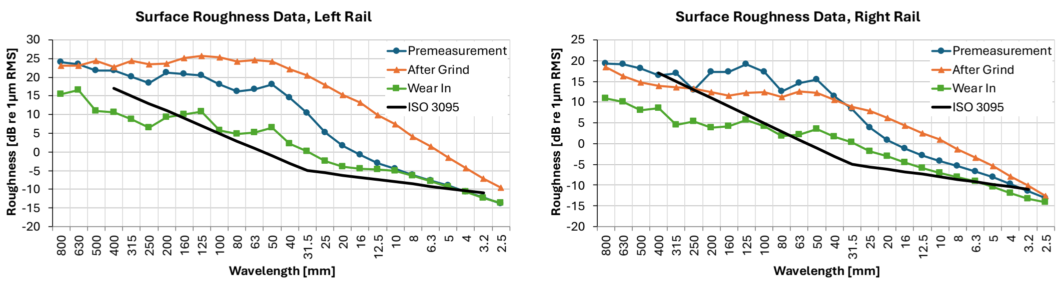

Figure 5: Rail roughness data according to EN 15610:2019 / ISO 3095:201., Before, directly after, and 3 weeks after grinding, left and right rail

Noise measurements including speed measurements were conducted for passing trains over several hours on each measurement day. The microphone was set up that it was shielded from street vehicle traffic. Only trains travelling on the measurement track (track 1) were used for the analysis. Three different tram types were travelling on this section, denoted as type A, B and C. The passing speed of measured trains was between 20 km/h and 50 km/h with an average speed of 38 km/h. Passing sound level difference of all three train types (averaged over each train type) is shown in Figure 6 as third octave plot. Reductions in passing sound levels (positive values in were found in the frequency range of 50 to 400 Hz over all train types, with train type A showing the biggest improvement (8dB).

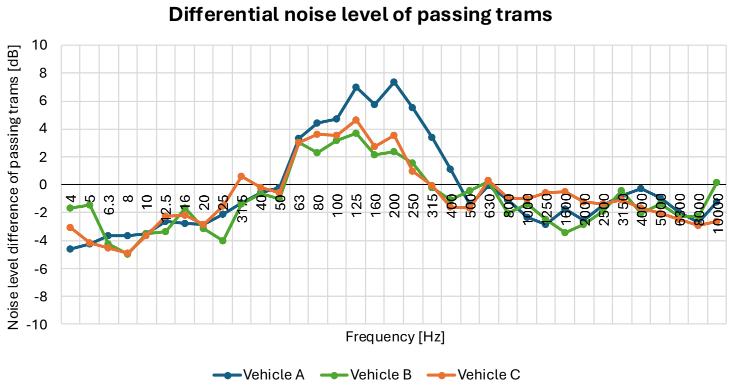

Figure 6: Differential noise level averaged over all trams per tram/vehicle type (A, B and C), third octave plot. Noise reductions indicated by positive values.

Analysis of vibration data was done according to ÖNORM S 9020 [8]. Table 1 shows the peak velocity ($v_{R,max}$) of vibration in mm/s at three defined distances (MP1, MP2, MP3) for all vehicle types (A, B, C).

	Premeasurement			After Grind			Wear-In		
Train	MP1	MP2	MP3	MP1	MP2	MP3	MP1	MP2	MP3
A	12,3	2,6	0,8	5,9	1,1	0,4	6,8	1,8	0,8
B	8,2	1,3	0,5	4,1	0,8	0,3	4,9	0,6	0,4
C	7,6	1,3	0,5	3,5	0,7	0,4	4,1	0,8	0,5

Table 1: Peak vibration velocities in mm/s at three different distances from centerline of track (MP1 – 4m, MP2 – 22m, MP3 – 30m)

The threshold of 2.5 m/s (according to the Austrian standard) was reached at a distance of 22m (MP2) and beyond. Table 1 shows a significant reduction of peak vibration values after grinding and after the wear in period. The highest reduction could be achieved for the vehicle Type C. On average a reduction (compared to pre-grind values) of 50% could be achieved at the 4m measurement position (MP1). With increasing distance from the center point of track the determined reduction is reduced to 30% at 22m (MP2) and 10% at 30m (MP3).

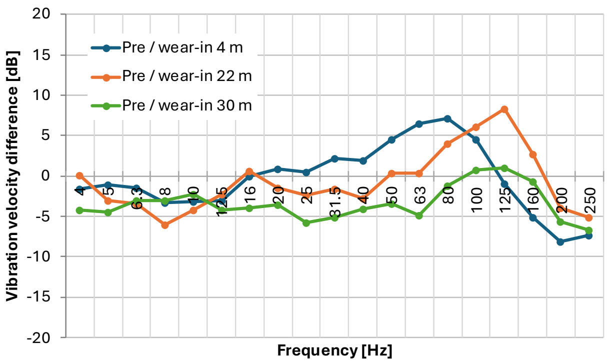

Figure 7: third octave plot of vibration velocity difference per-grind vs. wear-in at three measurement positions. Values were averaged over all measured trains.

Figure 7 shows a third octave plot of vibration velocity difference (pre-grind to wear-in) at all three measurement distances averaged over all tramway types. A reduction of vibration velocity (positive values) was found in the frequency range of 50-125 Hz at 4m and 22m. At 30m distance no reduction was measurable.

6 Customer application example Odensee

The tramway of Odensee (Odensee Letbane - OL) in Denmark was opened in 2022 and consists of a 14.5km double track line. Due to continuing noise problems and noise complaints, OL contracted an external consultant to conduct a study on this problem. The study unveiled rail surface irregularities as main cause. These irregularities were related to repeated wheel slip events, caused by excessive rail lubrication. This over-application of on-board wheel flange grease led to the formation of a continuous hard-pressed low-friction layer (mixed in with vegetation from grass track sections or debris from other street vehicles) on the surface on the rail. As it was very difficult and labour-intensive to remove this layer by conventional means, OL looked for alternative solutions. The ATMO was used during 5 night shifts to remove this layer from the rail surfaces in the whole network. Dependent on the severity of the conditions 1-2 ATMO passes were done in oscillating mode (with standard settings) at speeds between 5 and 15 km/h. The ATMO was equipped with the soft (S) stone type. Figure 8 shows some example pictures of pre and post grind conditions. The left photo clearly shows the surface layer on the rail surface. In the right photo taken at the same location, the layer was successfully removed from the rail surface.

Figure 8: Examples rail surfaces before and after treatment / cleaning.

An extensive photo documentation visually verified that the layer could be successfully removed in the whole network of OL (no other measurements were done). This was also confirmed by tramway drivers reporting a significantly improved (smoother, less noisy) driving experience after rail surface treatment. A regular tramway vehicle (Stadler Variobahn) was used to tow (push and pull) the trailer for the majority of the shift days.

7 Technology Demonstration in Graz

Graz is the second largest city of Austria and has a tramway network of about 70km system length. The tramway as well as bus lines are operated by Graz Linien. Due to very sharp curves, Graz Linien has several corrugation hotspots in their tramway network. Two of these hotspots (section 1 and section 2) were selected to be treated by the grinding trailer (rail grade 290GHT). In this case the ATMO was used as part of an integrated treatment process that included continuous pre- and post-measurements of corrugation according to EN 13231-2:2020 [5]. For the corrugation measurement a ROSPECT measurement vehicle by Robel Rail Automation was used. ROSPECT is a modular, battery operated measurement platform that allows measurements up to a speed of 30km/h. ROSPECT can be equipped with various measurement systems (transversal profile, long. profile, track geometry, geo-radar, 3D scanner, rail damage system…) as required. In the case of the Graz campaign, ROSPECT was equipped with a Vogel & Plötscher RMF1100 longitudinal profile measurement system.

Track section 1 (single track) in the "Smart City" neighbourhood only had initially low corrugation damage with very little threshold exceedance (EN 13231-2:2020 track class 1) in the wavelength-class of 100-300mm. After 4 passes in oscillating mode with 5-8 km/h (vertical stone force of 4200N) exceedance values were below the required threshold of 5%.

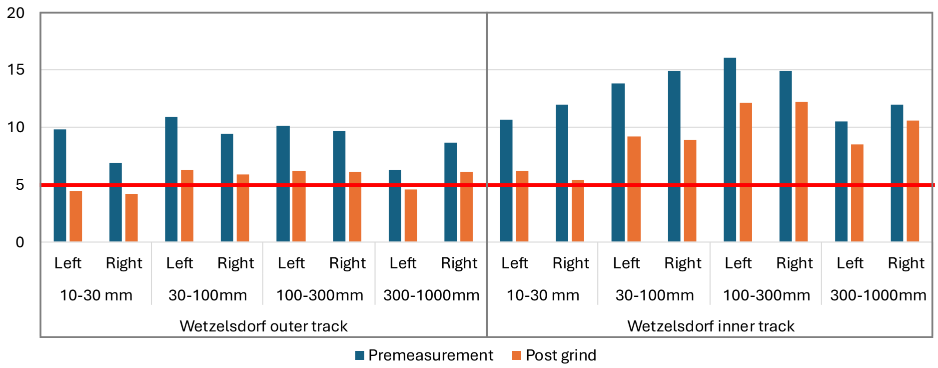

Figure 9: Corrugation reduction results at turning loop Wetzelsdorf

Track section 2 at the turning loop Wetzlesdorf (double track) had significant initial corrugation present. Three passes were done on both tracks (outer + inner track). The final results for the outer track were at or slightly above the threshold for all four wavelength classes (Figure 9 left). The inner track had initially more severe corrugation present. After three passes with the ATMO corrugation levels were reduced (Figure 9 right) but were still above the threshold. Additional grinding passes would have been required to reduce corrugation further below the threshold. Due to time constraints these additional passes could not be done. The results at Graz Linien generally coincide with the corrugation reduction results obtained during the extensive testing at Wiener Linien.

8 Milling Structure Removal

The surface structure directly after rail milling (honeycomb like milling grooves – see Figure 10 left) can cause unwanted tonal noise effects [9]. Although this structure will eventually wear out it might stay on the rail surface for several days or weeks dependent on the local traffic condition. To prevent this unwanted noise effect from happening, polishing systems are integrated into milling machines that flatten out this structure on TOR – see Figure 10 right.

Figure 10: Left - rail surface condition directly after milling (milling grooves visible) with no post processing. Right - rail surface condition after one ATMO pass.

Oscillating stone technology is currently used on mainline milling machines in Japan to achieve this polishing task. However, the Japanese systems significantly differ in size, stone configuration and drive system from the grinding system used on the ATMO. To better understand the applicability of the ATMO grinding system for smaller type transit milling machines, a series of tests were conducted at the museum railway of Chiemgauer Lokalbahn in Obing / Germany. A ROMILL Urban 3 E3 transit milling machine was used to mill the rails (with the integrated polishing system deactivated). The ATMO was then used (towed by the milling machine) to grind the rail surface. Longitudinal profile was measured using a Vogel & Plötscher RM1200 spot measurement device and analysed according to EN 13231-2:2020 [5].

Four test sections with lengths between 55m to 80m were analysed. To mimic milling conditions, the ATMO passes were done with a speed of 800m/h (0.8 km/h) and 4900 N vertical stone force. Three sections (sections 1,2, and 3) were done in oscillating mode (3.5 Hz, 35 mm amplitude). A test with sliding mode at 800m/h did not have any effect on the rail surface and was discarded. The initial measurements after milling on the left rail (section 1) showed expected exceptions above the threshold (EN 13231-2:2020 track class 1) in the 10-30 mm wavelength-class. After grinding (one pass), the exceptions were significantly reduced below the threshold of 5%. On the right rail in section 1, the exceptions after milling were already significantly below the threshold value. Consequently, grinding had only minor improvement effects on the already EN 13231-2:2020 compliant rail surface. The difference in rail surface condition between left and right rail is most likely attributed to the wear condition of the milling carbides (left vs. right). These findings indicate that the milling technology used for this test is capable of achieving surface conditions compliant with EN 13231-2:2020, even in the absence of a polishing process. This was further supported by the comparable results observed across Test Sections 2 and 3.

9 Defined surface roughness for test tracks

The Wegberg-Wildenrath Test and Validation Centre (German: Prüf- und Validationscenter Wegberg-Wildenrath) is a railway test centre owned by Siemens Mobility near the city of Wildenrath in North Rhine-Westphalia, Germany. The test center has 28 kilometres of standard and metre gauge tracks. The facility is used for technical acceptance tests (for Siemens and other manufacturers) and approvals of locomotives, EMUs/DMUs, trams and general rolling stock under operating conditions as well as personnel training. Especially when it comes to tests concerning noise, the rail surface hast to meet very stringent roughness specifications. Siemens requires to meet a -2.5dB threshold compared to ISO 3095:2013 [7]. Initial measurements at four different lateral positions on top of rail (31, 36, 41 and 46 mm) on both the inside and outside rail at the test ring indicated that for wavelengths below 40mm most of the measurements were above of the required ISO3095 -2.5dB threshold. Some of the values for specific wavelengths were also above the regular ISO limit (Figure 11).

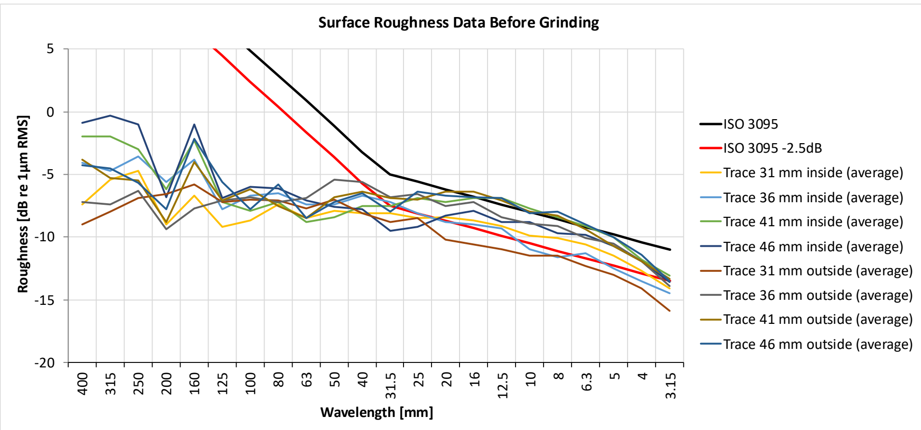

Figure 11: Surface roughness results at 4 different lateral positions on top of rail before grinding, Inside and outside rail.

After a total of 76 passes at various speeds (5km/h, 8 km/h and 15 km/h), with different vertical loads (70% and 10%), with a soft (S) stone type and standard oscillating parameters, (almost) all values fell below the target of ISO3095 -2.5dB. Only one individual value was above the limit that was attributed to a rail surface defect (Figure 12).

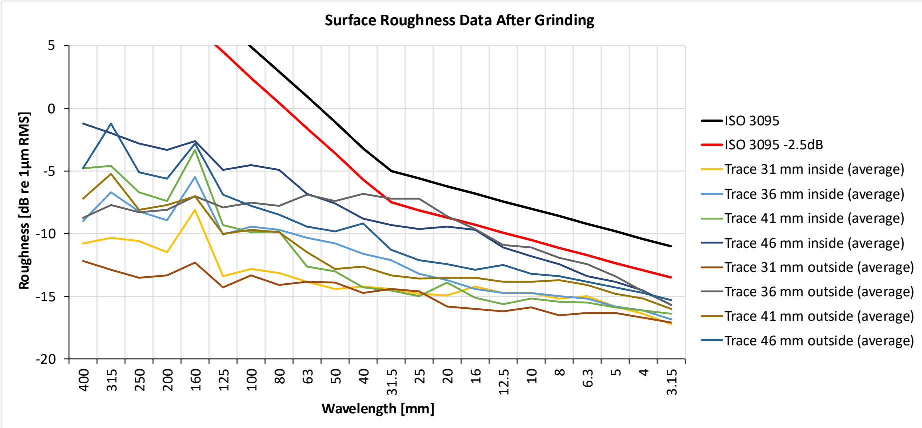

Figure 12: Surface roughness results at 4 different lateral positions on top of rail after grinding, Inside and outside rail. All values (except 1 outlier) below the ISO3095 -2.5dB limit (red line).

10 Conclusions

This paper presents an extensive test program for a newly developed rail grinding trailer employing block grinding technology in either oscillation or sliding mode. The trailer was specifically designed to address the challenges of urban and tramway systems.

An initial test campaign conducted at a tramway operator's yard identified optimized grinding parameters, including a vertical stone force of 4,430 N, an oscillation frequency of 3.5 Hz, and an oscillation amplitude of 35 mm. In addition, various stone qualities and hardness levels were evaluated, with a medium-hardness stone selected as offering the best balance between metal removal and stone life under these conditions. Using this configuration, an average metal removal of 0.01 mm was achieved, making it well suited for preventive maintenance applications.

A second test series focused on corrective corrugation removal capability. Corrugation could be reduced below thresholds of EN 13231-3:2021 within 10 to 20 passes (dependent on corrugation severity) in oscillating mode. Sliding mode achieved similar reduction trends but with reduced efficiency compared to oscillating mode. For this corrective task stones of the type MS and S were found to be most effective.

Additionally, noise and vibration tests were conducted that showed under revenue conditions that corrugation related noise and ground vibration could be significantly reduced. Acoustic rail roughness measurements according to EN 15610:2019 confirmed the findings with respect to noise and vibration mitigation.

Customer applications concerning surface structure removal (low-friction layer, corrugation, milling structure) and special low-noise rail surface requirements were presented that supported the findings of the extended test series.

The ATMO rail grinding trailer has demonstrated effective solutions for two key maintenance applications in urban environments. First, it is well-suited for routine preventive maintenance, providing cyclic rail conditioning before significant damage can develop. In addition, it proves equally effective for corrective interventions, addressing existing top-of-rail damage when it occurs. For both application scenarios it is possible to create a well-defined low noise rail surface condition that can meet most stringent roughness / noise requirements and standards. Together, these findings confirm the trailer's versatility as a comprehensive maintenance solution for urban rail systems with focus on tramways.

Acknowledgements

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