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DEVELOPMENT AND ROLL-OUT A TRACK DYNAMICS LOGGER (TDL) IN ORDER TO MONITOR RAILWAY TRACK-ASSESTS BY INSTRUMENT TRAINS

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ABSTRACT

In Europe today, several measurement trains are already equipped with Track-Dynamic-Loggers. The SD&M - TDL system consists of 12 accelerometers, 4 microphones and a DGPS system. By introducing real-time RTX corrections, the GPS position of dedicated reference points on the rails can be reproduced within 10 cm. The fully automated system design, definition of components, signal data processing, programming and development is optimized by SD&M. The sensor data, sampled with a 16-channel 24bit A/D converter at 20kHz, is combined with real time corrected positions (10cm accuracy) at a rate of 20 positions per second. It is a challenge to link time, frequency, and space domain in a consistent way. Apart from the detection of rail flaws in the wheel-rail contact surface, it is also easy to identify, parametrize and visualize "acoustical" parameter as rail grinding quality, unacceptable wavelengths but also TDR differences in a GIS environment. To keep the sensors working in harsh (weather) conditions e.g., air flow turbulences, rain, condensing environment, snow, etc., custom designed microphones and 3 axis-accelerometers are installed. The running band of the measurement train wheels must be very smooth and free of wheel flats. Several proofs of concept have shown the reliability of the TDL.

Keywords: *track dynamics logger, track assets, train instrumentation.*

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1. INTRODUCTION

The goal of the TDL is to provide a tool to acoustical and track maintenance engineers that can be used to study track issues over a complete network and analyze them over the long term. The system is installed in 5 measurement trains in 2 countries. In some cases, the positioning - and derived roughness data is of better quality than what the actual measurements trains systems generate. If systematic measurements are available, e.g., 5 measurements a year, trend analysis can be performed, in order to be able to predict in advance threshold passing. Many Infra managers have measurement trains available to inspect their network. Often these trains run daily. The TDL can easily be installed on these trains. In the past, installation on a measurement train was done in only 3 days. It is essential to mention that these trains need to have either disk brakes or composite brake blocks. Once sensors are installed on the bogies and the DGPS antenna on the roof of the train, and cabling is installed towards the monitoring box, the systems can be used.

Acoustical parameters that are already studied are: roughness / corrugation, and TDR (Track Decay Rate) [1]. Track maintenance parameters can be: presence of hanging sleepers, ballast quality, quality of electrical isolation joints, quality of turnouts (frog, guiding rails, point machine) and rail grinding location and quality. By combining data captured by the 4 microphones and the 12 accelerometers, parametrization can be done towards one of the above-mentioned parameters.

The TDL generated parameters may also be very useful for noise mapping (CNOSSOS) to get input and to link them with the noise mapping. They can also be used for defining a "track acoustical quality" parameter, a parameter that includes both TDR and rail roughness, the 2 most important parameters that have a major influence on the track noise contribution of the track. And finally, the parameters can be useful for the analysis of complaint: they can help to identify vibration sources in the track, to understand and to solve Noise and Vibration hot spots and to get a quick answer on the cause of noise and vibration complaints, without going outside for a visual inspection.

2. METHODOLOGY

The selected DGPS (Differential Global Positioning System) is able to generate real time, RTX-corrected, (Real Time eXtended) 10cm accuracy positions at a high sample rate. This leads to position discretization from some centimeters up to 1.5m, depending on the train speed. Also, the sensor data, sampled with a 24bit A/D at 20kHz, is a time-based parameter. By using a network fix 10m line position database (line, track, line km, line dam) the measured parameters for each TDL-run can be assigned to a 1m interpolated database. With this data we can go from time to a spatial domain. This is one way of detecting the exact position of the assets: e.g. electrical joints, expansion joints, switches, switch components. It is also possible to detect rail flaws in the wheel-rail contact surface, rail corrugation, rail grinding quality, badly tamped track (hanging sleepers), unacceptable wavelengths in track and much more.

A first challenge is to link time, frequency and space domain in a consistent way. First, all data is captured with a time reference up to 0.01second. After this synchronization, the calculated frequency components (e.g. 1/3 octave band analysis, XFR/phase information,) can be linked to the space domain (position points on a specific line).

A second challenge is to keep all sensors working in harsh conditions such as wind speed, turbulence, rain, condensing environment, snow, ice, objects in the track, etc. For this purpose, sensors designed for and used in the airplane and car industry are chosen and improved.

A third major challenge is how to deal with the varying train speed, which affects many measured and calculated parameters. This can be solved by using dedicated test tracks with known parameters that are measured in a direct way, e.g. acoustical rail roughness (MBBM m|track), Track Decay Rate (TDR [3]), type of railpad, rail surface quality, presence of rail flaws, expansion joints, switches. This dedicated test track is then measured with the TDL at different speed and measurement directions, as most measurement trains have 2 running directions. This allows us to define calibration matrices and speed correction for all parameters.

And finally, the wheel running band has to be very smooth and free of wheel flats. A wheel flat detection algoritm can be applied to send alerts and stop recording. The acoustical wheel roughness should be checked periodically and, if necessary, the wheel should be reprofiled as soon as possible.

The system is fully automated. It boots up automatically when the train driver starts his train and activates his driving post. Once a defined minimum speed is reached, the data acquisition starts, and stops when the speed goes out of a specified speed window. Once the steering post is deactivated, the system automatically starts post-processing all available measurement files and can then copy and send data to a specific server location, inside or outside the measurement train. The system owner can be informed about the status of the system: about booting, acquisition, processing, shutting down, etc.. Via text messages, he can also request info to be sent to him by SMS, or he can manually start the system by sending text messages to the system.

3. SENSORS AND EQUIPMENT

The microphones (10mV/pa) and their suspension and protection are designed to withstand the harsh conditions under the train. They are tested in a wind tunnel from 40 to 100km/h, to know the contribution of the turbulences in the overall response, and to define the active operating range as a function of speed. A specially designed microphone membrane protection is used to prevent damage from stones or other objects. This mechanical coupling also has the advantage of amplifying the sensitivity perpendicular to the membrane surface by 6 dB compared to waves parallel to the membrane. Special care is taken to prevent problems with water using waterproof wind protection. It is clear that daily inspection is necessary, and that periodic calibration of the microphones must be planned.

The accelerometers (10mV/g) are specially designed with double electromagnetic screening, both for the sensor itself and for the cable. The cable is attached directly to the accelerometer housing to avoid problems with connectors and humidity, and it goes directly to the data acquisition unit without additional connectors. The body of the accelerometer can be designed both for single and for 3-axis measurements.

Positions are generated by a DGPS system in combination with inertial sensors, and RTX position corrections. This results in a position accuracy of approximately 10 cm, depending on satellite and 4G connectivity during the test runs. The positions are generated and captured at a rate of 20Hz. During post- processing, they are synchronized with the sensor data sampled at 20kHz.

4. RESULTS

This paper explains below only 2 examples of already running applications and analysis. In this analysis, both the vertical axle box acceleration of the train, installed on the 4 axle boxes of one bogie (ideally non-driven), and the 4 microphones, which are installed both at the train nose at 2.5 m from the wheel rail contact and at 15 cm from the wheel-rail contact for the 2 rails, were used.

4.1. Rail Roughness measurement

The combined wheel roughness is calculated from the acceleration of the vertical axle box, in combination with microphone data for specific wavelengths. Due to the contact length of about 10 to 14mm between wheel and rail, microphones are used for analyzing wavelengths smaller than 2cm. Specific transfer functions between rail and axle box accelerations and microphones are used to calibrate amplitudes.

Figures 1 till 5 show some analysis of the rail roughness assuming that wheel roughness is under control and negligible compared to rail roughness. If necessary, the wheel roughness can be subtracted from the combined calculated wheel-rail roughness. For every figure there are 6 plots.

- The plot at the top left shows the measurement speed as a function of the analyzed distance.
- The plot at the top right shows in the x-y plane the position of the track to be able to identify straight lines or curves. Point (0,0) is the starting point of the analysis. The maximum wheel/rail noise emission level in dB(A) per 50 ms is indicated in color.
- The 2 middle plots show the roughness amplitudes in dB re.1µm as a function of wavelengths: 0.01m – 0.5m.
    - The blue curves show the average calculated roughness over the distance d [m], as indicated in the title of the plot.
    - The red curves show the averaged roughness over the selected distance calculated from the vertical accelerometers.
    - The green curves show the averaged roughness over the selected distance calculated from the microphones.
- The 2 lower plots show the roughness amplitudes as a function of wavelengths: 0.01m – 0.5m but in spectrogram format as a function of the distance. This is to understand the variation of roughness as function of distance. The color scale ranges from -20 dB (blue) to +40 dB (red).

In Figure 1, extremely high amplitudes of about 40 dB or 0.1mm RMS are calculated especially on the inner rail (RAIL1) at a wavelength of about 15 cm. This can also be seen in the photo. The amplitudes on the outer rail are overestimated, probably by the transmission of vibrations from the inner wheel to the outer wheel.

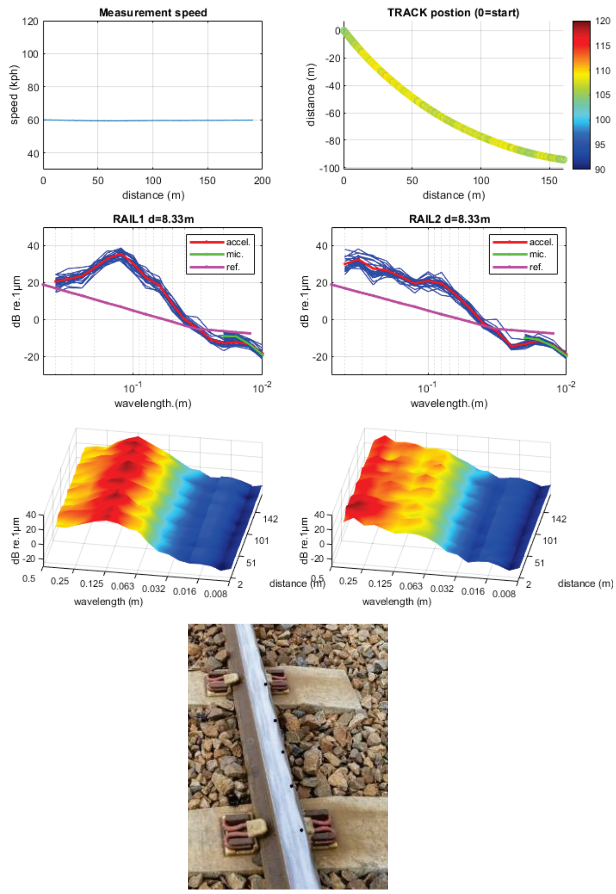

Figure 1. Rail roughness processing as a function of distance in a curve with corrugation. RAIL1 is the inner rail in the curve.

Figure 2 analyses a different curve. RAIL2 is now the inner rail. Only the middle section of 150 meters in the selected distance is strongly corrugated. 100m before and after the corrugated section, the roughness levels are much lower. Here the dominant wavelengths are about 8 cm. This clearly demonstrates that the presence and exact location of the corrugation can be identified.

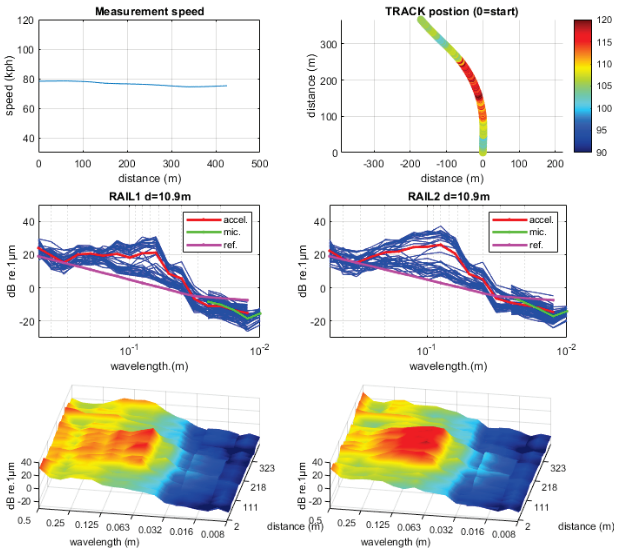

Figure 2. Rail roughness processing as a function of distance in a curve with corrugation. RAIL2 is the inner rail in the curve.

Figures 3, 4, and 5 focus on grinding activities, performed some days before the measurement campaign. Based on the combination of the speed of the grinding train and the rotation speed of the grinding stones, a specific periodic roughness can be applied to the rail surface, and thus identified by the TDL system.
Figures 3 and 4 show the beginning and end of grinding activities, respectively, carried out about 1 week before the measurement campaign. The wavelengths are now 2 to 3 cm and they are clearly determined by both the accelerometers and the microphones.

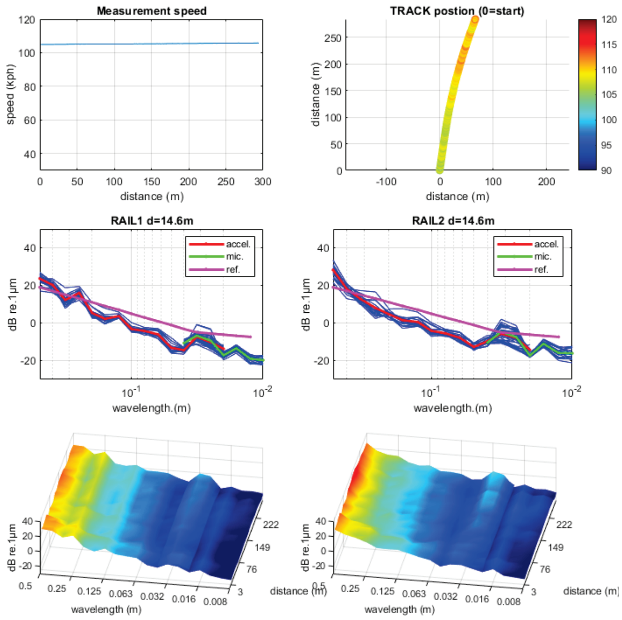

Figure 3. Rail roughness processing as a function of distance on a section where the grinding of the rail is started.

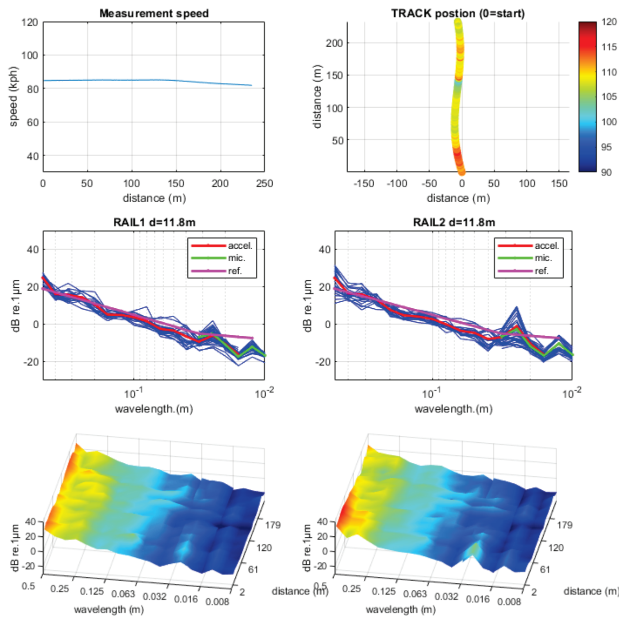

Figure 4. Rail roughness processing as a function of distance on a section where the grinding of the rail ended.

Finally, Figure 5 shows a longer section of the line of about 2.8km. Roughness amplitudes are averaged over a distance of about 67m.

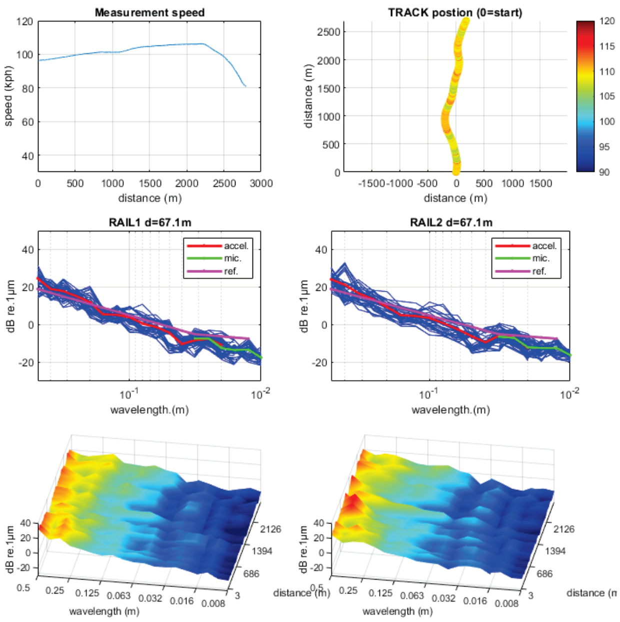

Figure 5. Rail roughness processing as a function of distance on a 2.7 km section where the grinding marks on the rail are still visual.

Figure 6 shows a visualization of the identified corrugation for a longer part of the line and can be used for maintenance and grinding planning.

Figure 6. Rail roughness visualisation with rail roughness amplitudes visualised in color.

4.2 Rail pad detection

Two examples are given to demonstrate how railpads with different stiffness and damping properties can be detected. When the TDR [3] of railpads is different, their noise emission during the train pass by will also change. In the example given, the measured pass-by noise difference at 7.5m from the track is about 3 dB. [2]. These changes can also be captured by the microphones mounted under the train.

In the first example, there are two adjacent 100m sections that are covered in the 7 seconds recording as shown in Figure 7. First, the train runs on the section equipped with an optimized railpad, then on the section equipped with soft railpads. The noise emission difference between the 2 sections at the nose of the train is about 5 dB, while the difference close to the wheel, the excitation point on the rail, is only about 2 dB. The difference of the measured noise emission between these 2 points (close to the excitation, and at 2.5m from the excitation) can be used to estimate the spectral difference in TDR. Figure 7 shows the overall levels, calculated with a time constant of 1 s.

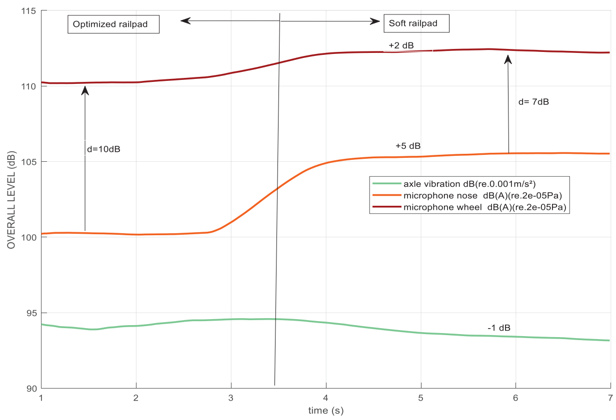

Figure 7. Captured noise and axle box vibrations during a pass by over two 100m sections, first an optimized railpad with high TDR, then a soft railpad with low TDR.

More details can be seen in Figures 8, 9 and 10, where spectrograms are shown. They indicated that the changes in emission are different depending on the frequency. For the axle vibration, reduction can be seen in the 800Hz band for the optimized pad, compared to the soft railpad. There are slightly higher levels on the 1.25kHz band. For the microphones, the reductions can be seen in the 800Hz, 1kHz and 1.25kHz bands, but we note slightly higher levels at 250Hz and 315 Hz bands. This can be explained by the higher vibration transmission to the sleepers, due to the stiffer railpads. This results in higher vibration levels and thus in a higher contribution of the sleepers, especially since the first and second bending modes of the sleeper are in this frequency range. This shows that the installed microphones are capable of capturing noise emitted by the sleepers.

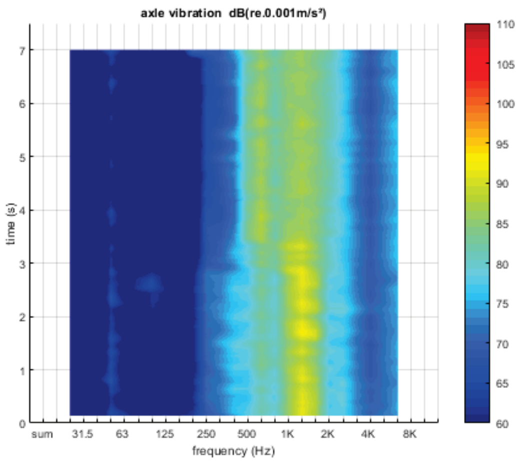

Figure 8. Spectrogram of the axle box vibrations for two adjacent 100m sections, first on the section equipped with optimized railpad with high TDR, secondly on the section equipped with soft railpads with low TDR.

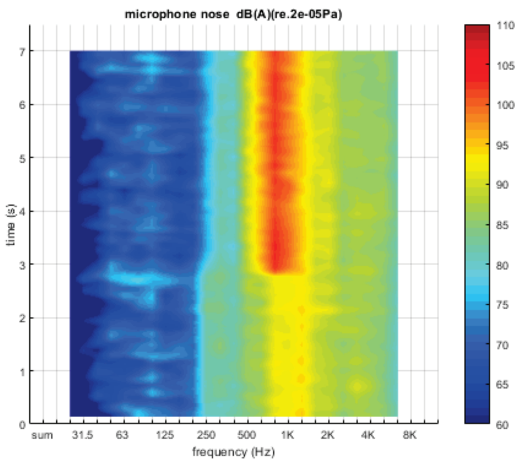

Figure 9. spectrogram for Sound pressure at the nose of the train for two adjacent 100m sections, first on the section equipped with optimized railpad with high TDR, secondly on the section equipped with soft railpads with low TDR.

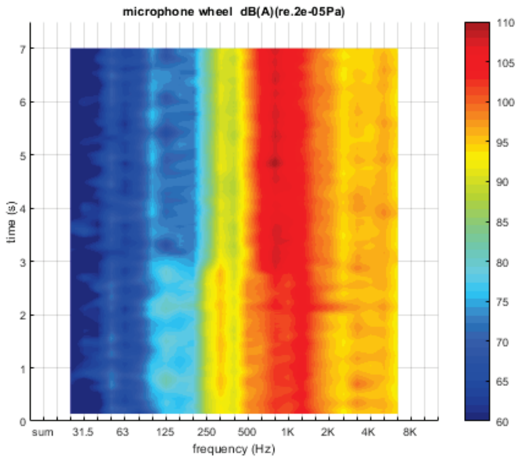

Figure 10. Spectrogram for Sound pressure at the wheel rail contact for two adjacent 100m sections, first on the section equipped with optimized railpad with high TDR, secondly on the section equipped with soft railpads with low TDR.

In the second example there are five adjacent 100m sections that are covered in the 15 second recordings as shown in Figure 11, where the type of pads is also indicated. There are no optimized railpads in this section, just railpads with different properties. The medium soft railpads have a static stiffness of about 130kN/mm, the soft pads about 90kN/mm and the stiff pads (EVA) more than 1000kN/mm. From the middle of the fourth section to the middle of the fifth section, the rail is equipped with additional rail screening.

The noise emission differs clearly between all the sections. Here, the overall levels are displayed, for 2 microphones at the nose of the train and close to the wheel, processed with a time constant of 1/8 s. (fast).

At the train nose, the differences between the medium soft pads and the soft pads are about 3 dB, and they go up to about 4 dB compared to the stiff (EVA) pad. The effect of the rail screening can also be seen: compared to the soft pad there is a reduction of about 2.5 dB, and about 1.5 dB compared to the stiff railpad. Close to the wheel, the differences are smaller. Again, by combining the spectral differences for the microphone positions (close to the excitation, and at 2.5m from the excitation) a correlation with the TDR of the railpad can be estimated.

More details can be seen in Figure 12, where a spectrogram is shown for one microphone at the nose of the train. The results are very similar to the previous example.

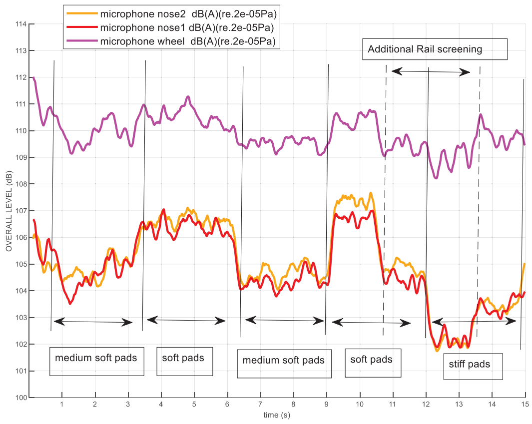

Figure 11. Sound pressure measured at the train nose for the 2 rails and at 15cm of the wheel rail contact during a run over the 5 different railpads at 120km/h.

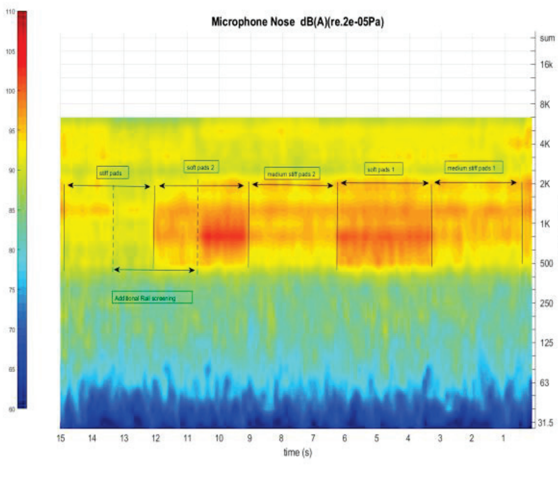

Figure 12. Spectogram for Sound pressure at the train nose during a run over five adjacent 100m sections, equipped with different railpads, half of the fourth and fifth section equipped with additional rail screening.

5. CONCLUSION

In this paper, we showed that the TDL system can capture both noise emissions and axlebox vibrations during the runs of the equipped measurement train. The system stores the train position on the line with the emissions captured by 16 sensors, in an automated way, without user interface, and synchronizes them. Two examples were given of how the captured data can be processed to the combined wheel/rail roughness and railpad detection. Many other parameters can be extracted from the measurement data. Automated calculation of these can be included in the auto-post-processing routines, that run on board the train. In the future, this will lead to a database of information, which can be used by both acoustical and track/maintenance engineers. This database can be used as input for, for example, noise mapping, track maintenance planning and trend analysis. Comparison and sharing data with other on-board systems is ongoing.

6. ACKNOWLEDGMENTS

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7. REFERENCES

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