Psychoacoustic approach for noise optimized rail grinding

Christine Huth[1], Geske Eberlei[1], Manfred Liepert[1] and Thomas Kempinger[2]

[1] Möhler + Partner Ingenieure AG, Germany
[2] DB Netz AG, Germany

Abstract. Deutsche Bahn AG has initialized the research project "Noise Optimized Rail Grinding" to optimize the grinding process of maintaining rail grinding acoustically. Residents previously often complained about annoying whistling sounds caused by trains passing after the grinding process. The aim of the project is to minimize these annoying sounds by optimizing the grinding process. In the entire project of DB Netz AG different project partners took part, which consisted of six different grinding companies, DB Systemtechnik and Möhler + Partner Ingenieure AG. Möhler + Partner Ingenieure were responsible for the psychoacoustic project part.
In a first step, the „State-Of-The-Art" of the annoyance caused by three different kind of trains passing after three different time intervals after the maintaining rail grinding of all participating grinding companies was evaluated by psychoacoustic experiments. In a second step, a threshold of acceptance was determined for the various whistling sounds of the train passings. Based upon the received psychoacoustic data, a threshold for the rail roughness was extracted by DB Systemtechnik and distributed to the participating grinding companies for an optimization process. In a last step, the actually achieved improvement in annoyance was evaluated again in listening sessions.

Keywords: Rail Grinding, Psychoacoustics, Annoyance.

1 Introduction

To prevent cracks and roughness on the surface of rails, the DB Netz AG, infrastructure company of Deutsche Bahn AG, is grinding regularly the rails of its track network using the so called "Two-Pass-Grinding". During this process the railhead is profiled completely new. However, the profiling is leading to corrugations in lateral direction. Therefore, the residents quite often complaint about whistling noise during train passings after the grinding process. This whistling noise is clearly visible in the spectrum as a tonal component and correlates with the roughness spectrum.

In the context of the project "Noise Optimized Rail Grinding"of the DB Netz AG, psychoacoustic experiments were designed to minimize the annoyance of the described tonal whistling noise. As a result, the grinding process was optimized to the benefit of the residents.

2 Overall Concept

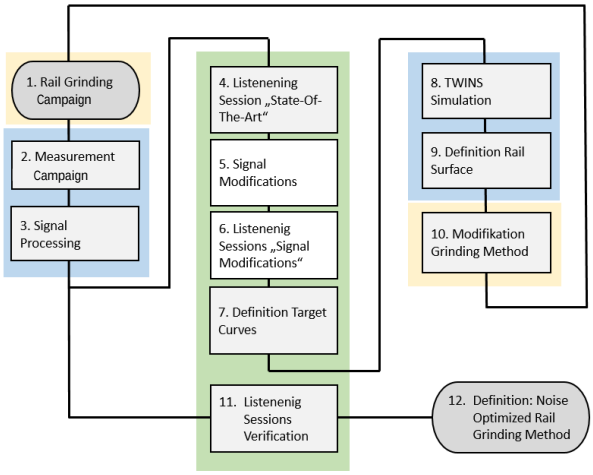


Fig. 1. Flow chart of the overall concept for the project “noise optimized rail grinding” [1].

Figure 1 shows a flow chart of the whole project of DB Netz AG comprising as project partners the participating grinding companies (yellow), DB Systemtechnik (blue) and Möhler + Partner Ingenieure AG (green). Möhler + Partner Ingenieure AG was focusing on the psychoacoustic investigations of the whistling noise caused by rail grinding. For these investigations DB Systemtechnik provided Möhler + Partner Ingenieure AG with signals of recorded train passings in a digital format (.wav format).

With these signals listening sessions were executed to determine the annoyance of the „State-Of-The-Art“ rail grinding. From this investigation sections with the most annoying tonal components were chosen to modify the tonal components of the signals step by step. In a following listening session the modifications were evaluated according to their annoyance. Additionally, the test subjects were asked to determine their threshold of acceptance, where the signals seem not acceptable to them anymore. Target curves for the subjective acceptance of train passings after rail grinding were defined based on the spectra of the signals, which were barely acceptable [1]. The results were delivered to DB Systemtechnik to calculate new parameters for the necessary roughness of the rail surface by using TWINS-Simulation. The parameters were submitted to the participating rail grinding companies. The rail grinding companies changed their rail grinding process according to the new parameters and new rail grinding campaigns were performed. The measured signals were submitted to Möhler + Partner Ingenieure AG to evaluate in a last listening session „Verification“ the annoyance of the signals. In the present study, results of the listening session „State-Of-The-Art“ will be compared to the results of the listening sessions „Verification“ to clarify to what extent the modified rail grinding process could reduce the annoyance compared to the results of the „State-Of-The-Art“. For this comparison the train passings

- at 7 different track sections (whereas 5 of them were grinded by different grinding companies; two reference sections were not grinded at all)
- at 3 different time intervals (after 0 loading tons, 700k loading tons, 2 mio loading tons)
- of three different trains (one high speed train IC at 200 km/h and two regional trains ET440 at 140 km/h and double-deck train at 120 km/h)
- at two different receivers (R1: in the garden in front of the house, R3: in the living room with closed window)

were evaluated.

3 Methodology

The terms of the listening sessions „State-Of-The-Art“ and „Verification“ were identically. The listening sessions were conducted via headphones in a quiet and neutral environment. In total 20 test subjects participated at the listening sessions.

To determine the subjective annoyance caused by trains passing after the grinding process the psychometric method of magnitude estimation with anchor sound was chosen. Sound pairs, consisting of two train passings, were presented to the subjects. The first signal was the implied anchor and consisted always of the passing at a reference track which was not grinded at all, the second one was the train passing of the same train at a grinded measuring point. The fixed value “100” of annoyance was assigned to the first train passing (anchor). The task was to assign a numerical value to the second train passing, which describes the relative annoyance compared to the anchor sound. If the second train passing is experienced half as annoying as the first one, the numerical value 50 should be assigned, if the second train passing is experienced twice as annoying as the first one the numerical value 200 should be assigned. Each pair was repeated three times and represented in random order to verify the accuracy of the test subjects in the evaluation of the signals.

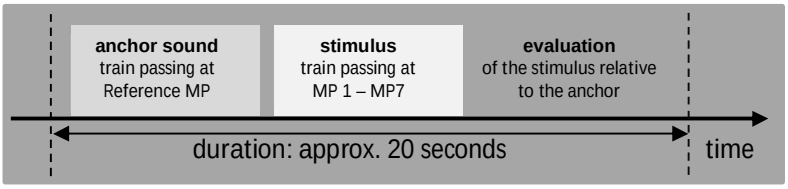


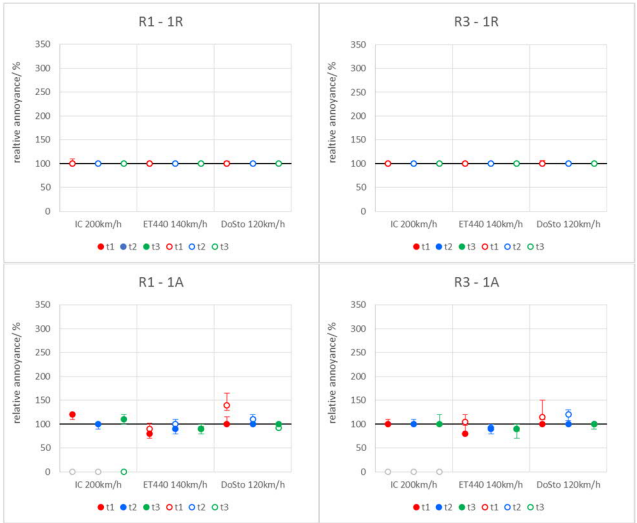
Fig. 2. Termination of sequence of the listening sessions “State-Of-The-Art” and “„Verification““ (Magnitude estimation with anchor sound)

4 Results

4.1 “State of the Art” versus “Verification” in detail

Figure 3 shows the results of the „Verification“ for the different measuring points (reference sections: 1R, 2R; grinding sections: 1A, 1B, 1C and 2A, 2B) in comparison to the initial results of the „State-Of-The-Art“. The results of the „Verification“ are represented by empty symbols, whereas the results of the „State-Of-The-Art“ are represented by filled symbols in Figure 3. The median and the interquartile range is represented for the median of the three repeated sound pairs of the 20 test subjects.

The left graphs show the data for receiver 1, R1 “Garden”, on the right the data for receiver 3, R3 “Living room, closed window” can be seen.



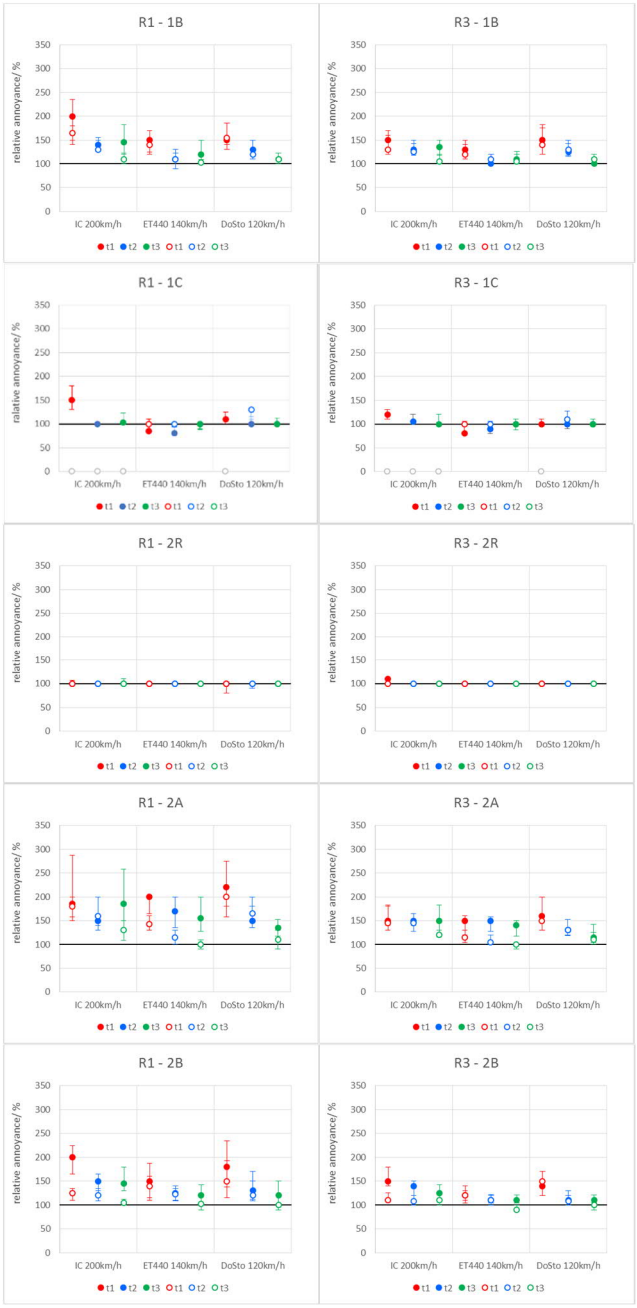


Fig. 3. Results of the listening sessions evaluating the annoyance of the „Verification“ (empty symbols) in comparison to the results of the „State-Of-The-Art“ (filled symbols) for the different measuring points. Left: receiver position R1 “Garden”, right: receiver position R3 “Living room, closed window”.

It can be seen, that the reference measuring points 1R and 2R for the „Verification“ as well as for the „State-Of-The-Art“ were reliably recognized by each test subject.

Measuring point 1A showed the best results already for the first listening test „State-Of-The-Art“, this is also the case for the „Verification“. However, a slight deterioration can be seen compared to the „State-Of-The-Art“.

Measuring point 1B showed for the first listening test average results, whereas for the „Verification“ a clear improvement of the results can be seen.

For measuring point 1C good results were achieved in the „Verification“. This measuring point was also one of the best in the first listening session. Although compared to the results of the „State-Of-The-Art“ a slight deterioration can be seen likewise to measuring point 1A.

Measuring points 2A and 2B showed in comparison to the first listening test a clear improvement in their results. Especially the train passing of the ET440 at measurement point 2A of the „Verification“ were experienced much less annoying. At measuring point 2B especially the train passing of the IC showed less annoyance compared to the „State-Of-The-Art“.

4.2 Overall view on the results

A ranking was done for each train category and each time interval for every rail grinding company, which took part both in the listening session „State-Of-The-Art“ and „Verification“. A median of these rankings was build and can be seen in the following figure.

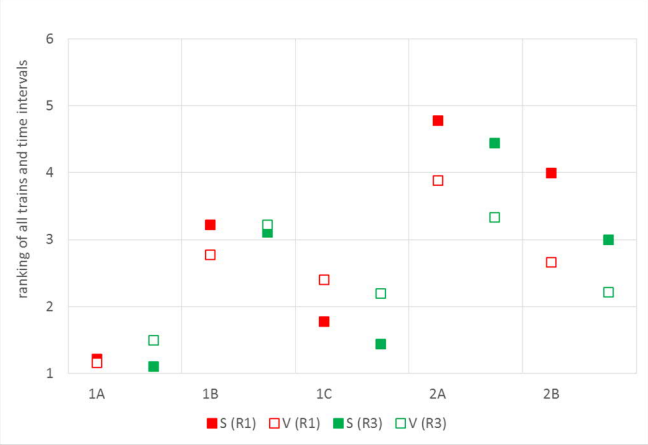


Fig. 4. Ranking of the annoyances for every rail grinding company (without reference) for the listening sessions „State-Of-The-Art“(filled symbols) and „Verification“ (empty symbols). The results are plotted for the receiver point R1 “Garden” (red) and R3 “Living room, closed window” (green).

Overall a significant improvement in the ranking can be seen for nearly every rail grinding company. Despite a small deterioration of rail grinding company 1A (about 0,4

ranks) towards the „State-Of-The-Art“ at receiver point R3, this measuring point still shows the best results.

Measuring point 1C deteriorates about 0,6 (R1) or 0,8 (R3) in the ranking. Still, this measuring point shows good results in comparison to the other measuring points. Significant improvements between „State-Of-The-Art“ and „Verification“ (up to 1,3 in the ranking) could be achieved to some extent for the other measuring points (1B, 2A and 2B).

The ranking of the „Verification“ between the measuring points 1B, 1C, 2A and 2B is closer for the „Verification“ (rankings between 2,2 and 3,9) as for the „State-Of-The-Art“ (rankings between 1,4 and 4,8). This implies a reduction of the range of annoyances between rail grinding companies of the „State-Of-The-Art“ towards „Verification“.

A detailed look of the improvement between „State-Of-The-Art“ and „Verification“ is given in the following. Therefore, a median was calculated for each train category through every rail grinding company. Figure 5 shows the median of the annoyance for „State-Of-The-Art“ (filled symbols) towards the median for the „Verification“ (empty symbols).

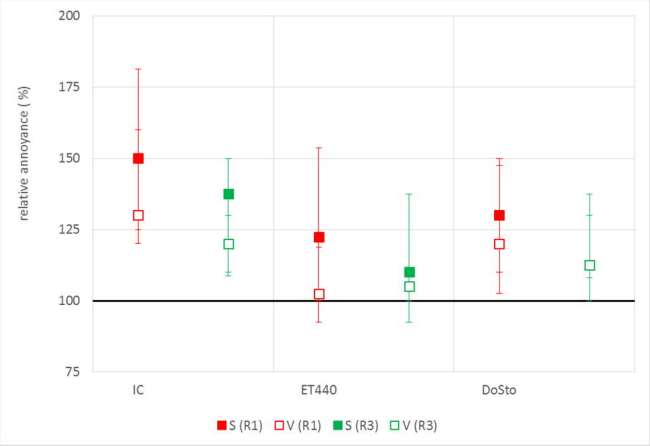


Fig. 5. Median of all annoyances for each train category throughout every measuring points (without reference). Comparison between the results of the listening sessions „State-Of-The-Art“ (filled symbols) and „Verification“ (empty symbols). The results are plotted for the receiver point IO1 “Garden” (red) and R3 “Living room, closed window” (green).

By comparing the annoyance of the „Verification“ to the „State-Of-The-Art“ a reduction in annoyance up to 20 % can be achieved for the „Verification“. The results of ET 440 matches nearly the reference. Every data point is representing the median of the different rail grinding companies, therefore the differences between the rail grinding companies are represented by the interindividual differences. Accordingly, when comparing the „State-Of-The-Art“ with the „Verification“ a reduction of these interindividual differences and therefore a difference between the rail grinding companies can be recognized.

Additionally, the results of R1 and R3 seem to be more similar for the listening session “Verification” than for the listening session “State-Of-The-Art”. This may be due to the reduction in annoyance of the train passings at reference point R1 (“Garden”) for the “Verification” experiments.

5 Conclusion

Overall a significant improvement of the annoyance compared to the „State-Of-The-Art“ was achieved after the modification of the rail grinding process.

Despite small deteriorations compared to the „State-Of-The-Art“ of rail grinding company 1A and 1C both measuring points still showed the best results in comparison to the other measuring points.

Measuring points 2A and 2B showed in comparison to the first listening test a clear improvement in their results. For measuring point 2A of the „Verification“ especially the train passing of the ET440 were experienced much less annoying. This was also the case at measuring point 2B, where the train passing of the IC showed less annoyance compared to the „State-Of-The-Art“.

During the first listening session „State-Of-The-Art“ most test subjects evaluated the annoyance as extreme, which was no more the case for the „Verification“. This emphasizes the significant improvement of the annoyance after the modification of the rail grinding process.

References

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