CASE STUDIES ON THE APPLICATION OF PSYCHOACOUSTIC METHODS FOR TRAFFIC NOISE

Christine Huth **Ulrich Möhler** **Manfred Liepert**
Möhler + Partner Ingenieure AG, Prinzstr. 49, 86153 Augsburg, Germany
info@mopa.de

ABSTRACT

Psychoacoustic methods can make an important contribution to various acoustic problems. In many cases the A-weighted level commonly used for traffic noise can't describe sufficiently the impact and may lead to misinterpretation. The Möhler + Partner Ingenieure AG apply in various projects psychoacoustic analysis of basic sensation magnitudes on the one hand and subjective evaluations of e.g. the annoyance on the other hand. Examples of the field of road traffic noise, especially emissions from motorcycles and railway noise, as e.g. emissions from rail grinding, will be given. A perspective on the other fields of application, as e.g. infrasound, will be discussed.

1. INTRODUCTION

In the practice of sound consultancy the workflows usually consist of the consideration and estimation of classical acoustic level magnitudes with A-weighting (as e.g. L_{Aeq} or L_{Amax}). Based on these level magnitudes noise indices for particular time intervals are defined (as e. L_{day} or L_{night}). The application of psychoacoustic magnitudes and techniques however are almost not used to describe environmental noise, whereas for the optimization of products the psychoacoustic approach is well known and frequently in use.
The following two different case studies in the field of traffic noise will describe and illustrate the possibilities of psychoacoustics in the area of sound consultancy.
In the first example of the area "road traffic noise", the analysis of traffic noise by psychoacoustic magnitudes takes center stage. In the second example of the area "railway noise", the psychoacoustic approach is realized by subjective evaluations of traffic noise in listening sessions.

2. APPLICATION OF PSYCHOACOUSTIC ANALYSIS FOR ROAD TRAFFIC NOISE

2.1 Background

In the context of the research project ""Noise Emission of Motorcycles under Real-life Driving Conditions" funded by the German Environment Agency (Umweltbundesamt) the pass-by noise of various motorcycles was analyzed in detail. Next to passings according to the current regulation ECE R41.04 [1] also passings under typical "real-live driving condition" with a maximum annoying potential for residents were measured and analyzed. To realize these so-called "worst-case" pass-by scenarios the driver of the vehicle should provoke maximum noise emission and influence the pass-by noise level especially by undesirable driving behavior. Typical driving manoeuvers creating high noise levels were for example pass-by at high speeds, or shifting down from a high gear to a lower gear whilst running at high revs.
For the analysis of the pass-by signals not only A-weighted levels were consulted but in particular psychoacoustic magnitudes were evaluated.

2.2 Test vehicles

For the study three representative motorcycles were selected from three different segments. The first segment stands for motorcycles with a high cubic capacity and maximum power at low engine speed. The motorcycle representing this segment was a Harley-Davidson Softail Heritage Classic with a displacement of 1745 ccm, a power of 64 kW at 5020 rev/min and a torque of 145 Nm at 3000 rev/min..
The second category of motorcycle covers a standard-design motorcycle and was represented by a BMW R NineT Urban G/S with a displacement of 1170 ccm, a power of 81 kW at 7550 rev/min and a torque of 116 Nm at 6.000 rev/min..
The third and last segment stands for motorcycles with the maximum power at high engine speeds and is represented by a Kawasaki Ninja ZX-10R KRT. This engine disposes of a displacement of 998 ccm, a power of 147.1 kW at 13000 rev/min and a torque of 115 Nm at 11000 rev/min..
Figure 1 shows these three test vehicles.

Figure 1. Test vehicles: Harley-Davidson Softail Heritage Classic (left), BMW R NineT Urban G/S (middle), Kawasaki Ninja ZX-10R KRT (right).

2.3 Results

The pass-by noise levels of all three motorcycles resulted below the legal limit value of 77 dB(A). Table 1 shows the test values of L_{urban} measured according to ECE R41.04 for all motorcycles.

Test vehicle	L_{urban}
Harley-Davidson Softail Heritage Classic	75,4 dB(A)
BMW R NineT Urban G/S	73,9 dB(A)
Kawasaki Ninja ZX-10R KRT	75,9 dB(A)

Table 1. Measured L_{urban} according to ECE R41.04.

To compare the passing according to the regulation and that of the worst-case manoeuver, the maximum resulting level during the pass-by will be compared in the following. For this purpose the passing according to the regulation with the maximum level was selected and faced to the worst-case passing. Figure 2 shows the maximum level obtained for these passings for all of the three tested motorcycles.
For the Harley Davidson Softail Heritage Classic, a difference of 14 dB(A) was found between regulation and worst-case pass-by. For the BMW R NineT Urban G/S even a difference of 18 dB(A) was resulting and for the Kawasaki Ninja ZX-10R KRT a difference in sound pressure level of 20 dB(A) was obtained.

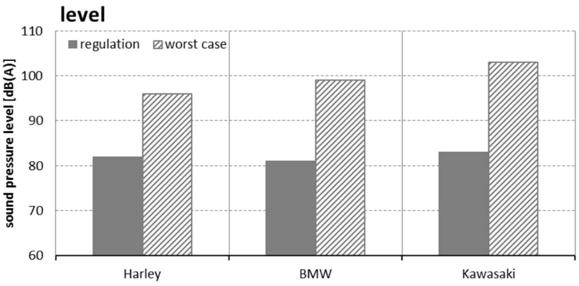

Figure 2. Maximum measured level for the passing according to the regulation measurement and the worst-case manoeuver.

In a next step, the signals were also analyzed regarding to their loudness, roughness and sharpness. Figure 3 shows for all three motorcycles the resulting values while passing according to the regulation cycle and passing with a worst-case manoeuver.
In loudness, this means a difference between regulation and worst-case of factor 2.3 for the Harley-Davidson, 2.8 for the BMW and 2.9 for the Kawasaki. The roughness however was for the Harley-Davidson with a factor of 0.5 and the BMW with the factor of 0.7 even for the worst-case manoeuvers less, only the Kawasaki obtained during the worst-case pass-by with the factor 1.7 higher values in roughness. Regarding the sharpness the worst-case manoeuvers show for all motorcycles with an increase between factor 1.4 (Harley-Davidson) and 2.3 (Kawasaki) clearly higher values.

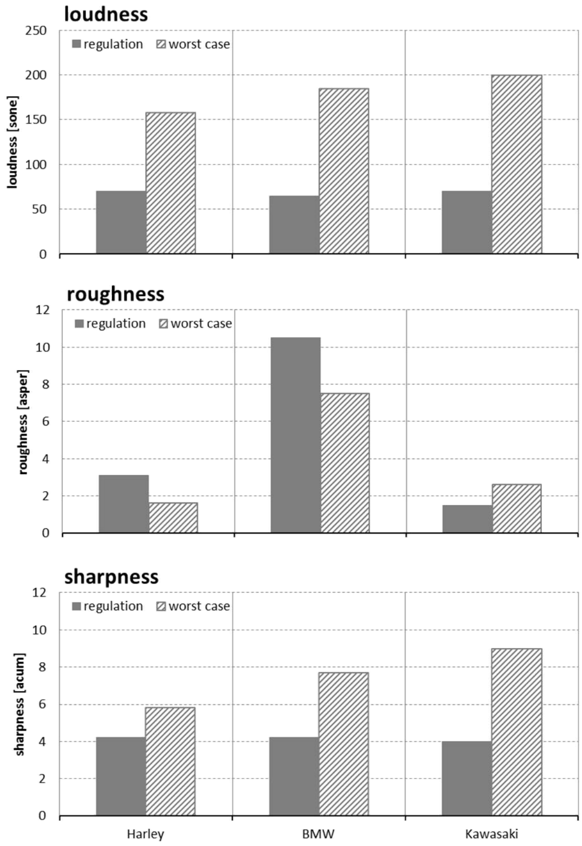

Figure 3. The psychoacoustic magnitudes loudness, roughness and sharpness for the passing according to the regulation and during the worst-case manoeuver.

Finally, based on these sensation magnitudes, the psychoacoustic annoyance was estimated [2] to suggest the impact on residents from these vehicles under real-life driving conditions. Figure 4 shows the relative annoyance standardized to the value 100 for the pass-by of the Harley-Davidson during the regulation measurement.

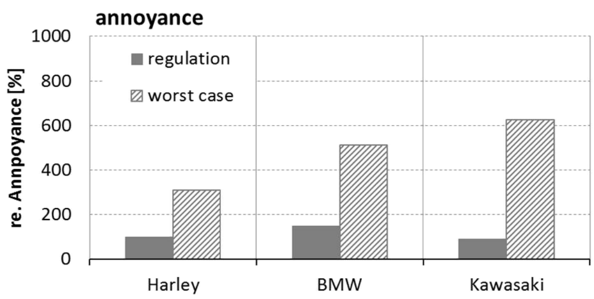

Figure 4. The relative psychoacoustic annoyance calculated on the basis of loudness, roughness and sharpness for the passing according to the regulation and during the worst-case manoeuver.

It can be found an increase in annoyance between the pass-by during the regulation measurement and the worst-case manoeuver of a factor 3.1 for the Harley-Davidson.

For the BMW even an increase in annoyance of factor 3.4 is obtained and the maximum increase was found for the Kawasaki with a factor 7.0.

2.4 Benefits of psychoacoustic application

By means of psychoacoustic methods the distinct increase of annoyance due to critical driving manoeuvers can be illustrated much better.

Even though all motorcycles meet the limits, very different annoying worst case scenarios resulted which could not be described just by the A-weighted sound pressure level.

Based on this knowledge, it appears necessary to improve the current type test to protect the residents' concerns. From the residents' point of view it would be reasonable to implement also worst-case scenarios into the current type test. Therefore, different possibilities for an improvement of the current type test were suggested in the research project.

3. APPLICATION OF SUBJECTIVE EVALUATIONS FOR RAILWAY NOISE

3.1 Background

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. [3, 4]

3.2 Method

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 and was assigned to the fixed value "100". The second passing was the same train passing on the measuring point grinded by one of five participating grinding companies (1A, 1B, 1C, 2A and 2B). In this way, subjects had to evaluate the annoyance of three different kind of trains: one high speed train IC at 200 km/h and two regional trains ET440 at 140 km/h and double-deck train (DoSto) at 120 km/h. All train passings have been recorded at 3 different time intervals after the grinding process (t1: after 0 loading tons, t2: 700k loading tons, t3: 2 mio loading tons) and in a distance of 7.5 m to the rail track. To present a realistic impression of the train passing for the subjects in the listening sessions, the signals have been filtered for different receivers, as e.g. outside in the garden in front of a house (R1) or inside the living room with closed windows (R2).

All subjective evaluations were carried out before the optimization of the grinding process (listening session "state-of-the-art" (S)) and afterwards the optimization of the grinding process (listening session "verification" (V)).

3.3 Results

Figure 5 shows representatively for the receivers' position R1 (outside in the garden) the results of one measuring point (2B). For all different trains the annoyance reduces significantly with the time interval after the grinding process both for the listening session "state-of-the-art" and "verification".

A reduction of annoyance between the first ("state-of-the-art") and the second ("verification") listening session can be found in particular for the high speed train IC. For the optimized grinding process ("verification") the annoyance is judged for all trains similar to the reference track ("100") after passing 2 mio loading tons (time interval t3).

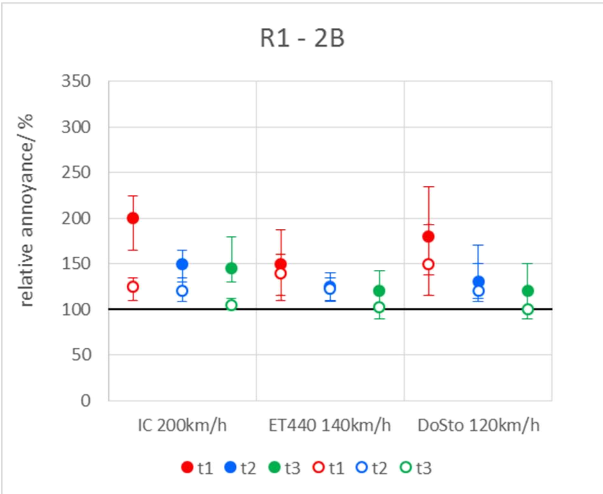

Figure 5. Representative results for the measuring point 2B of the listening sessions „verification" (empty symbols) in comparison to the „state-of-the-art" (filled symbols) for the different time intervals after the grinding process (t1, t2 and t3) and for the receivers' position R1 "garden".

To illustrate the differences between the participating grinding companies, a ranking was done for each train category and each time interval for every rail grinding company. The median of these rankings is figured for both receivers' positions (R1 and R3) and for both listening sessions ("state-of-the-art" and "verification") in the following diagram.

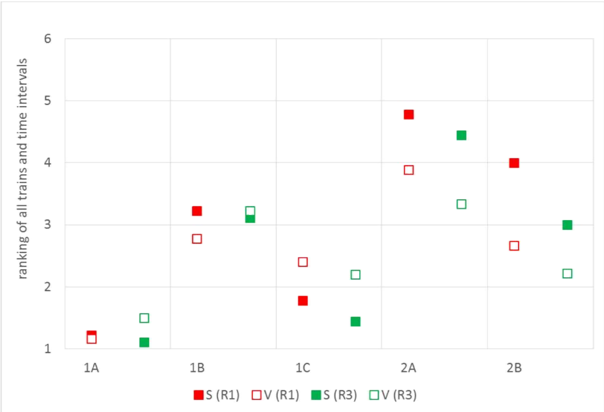

Figure 6. Ranking of the annoyances for each rail grinding company for the listening sessions „state-of-the-art"(filled symbols) versus „verification" (empty symbols). Red symbols: receiver "garden", green symbols: receiver "living room with closed windows".

Overall a significant improvement in the ranking between "state-of-the-art" (filled symbols) and "verification" (empty symbols) can be seen for nearly every rail grinding company. Deteriorations can be found for the two rail grinding companies showing the best results in the first listening session (1A and 1C).

To shed light on the overall improvement between the listening session before the optimization of the grinding process and afterwards, the median was calculated for each train category through every rail grinding company. Figure 6 shows the annoyance of the first listening sessions ("state-of-the-art") versus that of the second listening sessions ("verification"). Overall by means of the optimization process a reduction in annoyance up to 20 % can be achieved.

3.4 Benefits of psychoacoustic application

By means of subjective evaluations the annoyance of train passings has been determined. An optimization of the rail grinding process was realized based on the subjective evaluations. Thereby, the resulting improvement means an effective reduction in annoyance for the residents.

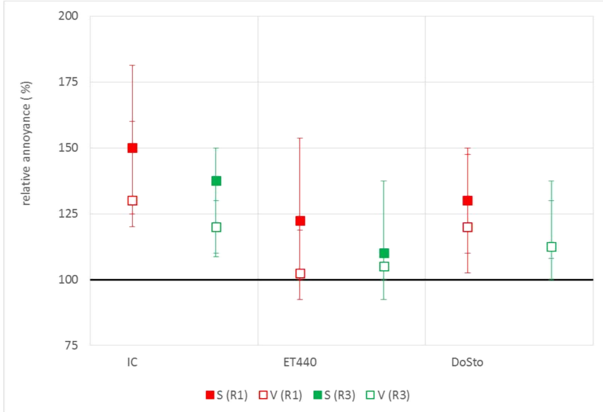

Figure 7. Median of all annoyances for each train category throughout every measuring points for the listening sessions „state-of-the-art" (filled symbols) versus „verification" (empty symbols). Red symbols: receiver "garden", green symbols: receiver "living room with closed windows".

4. CONCLUSION

Both case studies show different possibilities for the application of psychoacoustic methods. However, for both examples the target is a reduction in annoyance for the residents. In this context, the psychoacoustics is able to provide various tools for an adequate analysis and evaluation of environmental noise.

5. REFERENCES

[1] Europäische Union (2012): Regelung Nr. 41 der Wirtschaftskommission der Vereinten Nationen für Europa (UN/ECE) — Einheitliche Bedingungen für die Genehmigung der Krafträder hinsichtlich ihrer Geräuschentwicklung. Änderungsserie 04 — Tag des Inkrafttretens: 13. April 2012.

[2] Fastl, H., Zwicker E.: *Psychoacoustics – facts and models*. 3. Auflage, Springer-Verlag, 2007.

[3] Ch. Huth, G. Eberlei, M. Liepert and Th. Kempinger: Psychoacoustic approach for noise optimized rail grinding, *IWRN*, 2019.

[4] Ch. Huth, G. Eberlei, M. Liepert, Th. Kempinger: Psychoacoustic study on the acceptance of train passings after rail grinding. *Euronoise* 2018.