Sound Improvements of Transrapid Girders

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ABSTRACT: Every operation of a high-speed train will inevitably lead to sound emissions. The noise produced by Maglev vehicles running at high speeds is mainly dominated by aerodynamic sources. Surveys at the Test Facility Emsland, Germany, and the Transrapid line in Shanghai, China, have shown that these aeroacoustic effects are strongly influenced by the construction of the girder. A new analysis is presented that allows to examine the effect of the girder's surface finish and geometry on its sound emission. According to the obtained results, a two-dimensional model was developed which allows to model the frequency-dependent radiation and reflection behavior of a guideway in dependence of the geometry and surface finish of its girder.

1 INTRODUCTION

The Transrapid system is the first and only commercially realized Maglev technology system of the world. It took 75 years of imagination, designing, technical development, testing, revisions and dedication until the inaugural ride of the first commercial Transrapid train took place on December, 31st 2002 in Shanghai. However, the greatest challenge the Maglev technology has been facing over the last decades was not found in technical problems but in public acceptance. This can be mainly attributed to the limited public knowledge regarding the technology, safety and ecological compatibility of the Maglev system. One of the main reasons for the rejection of planned commercial Transrapid Maglev lines amongst residents is for example their fear of extreme noise exposure due to the high speeds of the trains.

Numerous investigations were carried out in order to determine the annoyance caused by the sound emissions of Maglev trains (Vos 2004, Schuemer 2003). Since the Transrapid has been running only on the test facility Emsland for a long time, most of these studies rely simply on theoretical assumptions (Möhler & Liepert 1996, Guski 1996) and laboratory-tests (Fastl & Gottschling 1996, Neugebauer & Ortscheid 1997, Vos 2004). Besides a survey among visitors of the Test Facility Emsland by Möhler et al. (1996), the recent study of Chen et al. (2007) on the noise impact of the Shanghai Transrapid line on residents is the only survey based upon sound measurements and personal interviews with residents that are daily subjected to the sound emissions of the Transrapid. Although all studies found that the Transrapid system is indeed quieter than conventional high speed trains for similar distances from the track (Chen et al. 2007, Barsikow et al. 2002), many interview respondents expressed startling feelings at the train's sudden approach.

The aim of future modifications of both the train and guideway is therefore a further minimization of the sound emissions in order to improve public approval and confidence in the Transrapid Maglev system. A comparison of sound emission data from the Test Facility Emsland and the Shanghai Transrapid line recorded by ThyssenKrupp Transrapid GmbH showed that the latter emits a slightly higher sound level pressure and a different distributed sound propagation than measured at the Test Facility (Antlauf & Schöll 2006).

This contribution shows how these differences can be attributed to the construction of the guideway girder and which measures can be taken to improve the noise reduction of the girders.

2 MEASUREMENT AND EVALUATION OF PASS-BY NOISE FOR TRANSRAPID

The aerodynamic noise of Maglev trains can be separated into noise generated by turbulent airflow, e.g. the flow separation at the front and rear ends, the unsteady wake generated at the trailing end and turbulent boundary layers at the surfaces, as well as into sound emissions caused by flow over structural elements, e.g. vortex shedding from the equipment, flow interactions due to inter-space coaching and louvres (Talotte 2000). In addition, the aerodynamics and hence the pass-by noise of a Transrapid train is strongly influenced by the interaction between train and guideway. Therefore, an intelligent design of the girder construction and girder finish helps to absorb the sound emissions mainly in direct vicinity of the noise sources at the stator and guidance sections.

The noise impact on humans (sound imission) is generally described with the help of the sound pressure level

$$L_P = 10\,\lg\cdot\left(\frac{p^2}{p_0^2}\right)dB = 20\,\lg\cdot\left(\frac{p}{p_0}\right)dB \quad (1)$$

measured in decibels (dB).

$$p = \sqrt{\frac{1}{T}\cdot\int_0^T p_0^2(t)dt} \quad (2)$$

denotes the sound pressure, which can be understood as the local deviation from the surrounding pressure caused by a sound wave of the frequency

$$f = \frac{1}{T}\,. \quad (3)$$

The following investigations focus on measurements taken at the hybrid guideway generation H2 of the Shanghai Transrapid line and several modifications. Pass-by noise was measured and sound radiation characteristics were determined by microphone array measurements. For each microphone, all measurement data were evaluated with regard to the A-weighted maximum sound pressure level, the A-weighted mean sound pressure level and the A-weighted sound pressure level at a certain point of time (in the middle between initial and last maximum peak).

The results depicted in Figures 1 and 2 show the A-weighted maximum sound pressure level at 100 km/h (62 mph) and at 430 km/h (267 mph) for different girder realizations. The lowest sound emission in comparison with the reference guideway is observed for the girder laminated with sound absorbing material (cf. orange line: 17.07.2003). At lower speeds, the noise emitted by the passing train is reduced by 10 dB(A) while the difference decreases to 5 dB(A) for a speed of 430 km/h (267 mph). This effect can be attributed to the aerodynamical noise components of the train itself which increase with speed and superimpose the influence of the girder-train interaction.

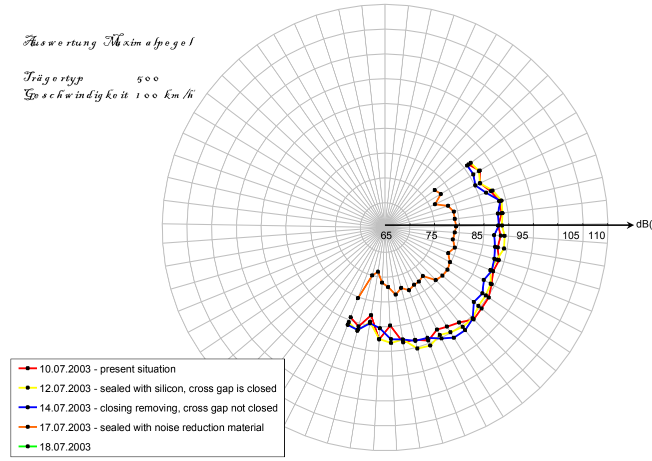

Figure 1. A-weighted maximum sound pressure level at 100 km/h (62 mph) for different girder realizations.

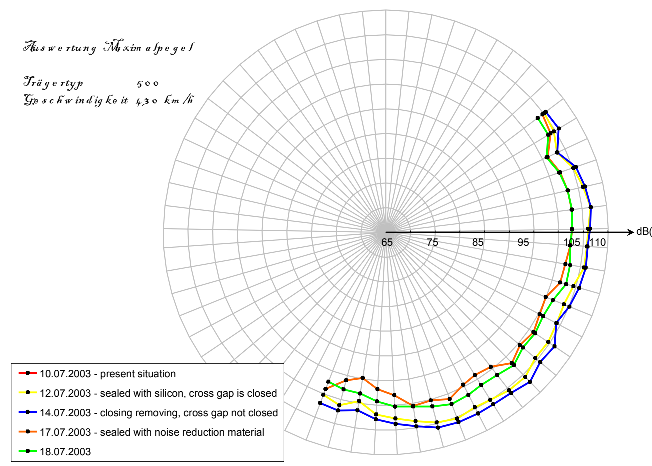

Figure 2. A-weighted maximum sound pressure level at 430 km/h (267 mph) for different girder realizations.

3 INFLUENCE OF THE SURFACE FINISH

Since the sound emissions determined for different girder types and modifications showed some significant differences in the emitted sound pressure level up to 10 dB(A) under comparable test conditions concerning the speed and length of the magnetically levitated trains as well as the distance from the track, further investigations of the reflection and absorption behavior of the girders were essential.

The acoustic intensity I of a free-hanging sound source decreases proportionally with quadratic distance from the source of sound

$$I(r) \sim 1/r^2\,. \quad (4)$$

This quadratic distance law does only hold without any limitations if no part of the sound pressure is absorbed by the surrounding material. But since all technical materials show at least some absorption, a part of the sound energy is always dissipated. The degree of absorption is mainly influenced by the properties, the surface texture and the thickness of the absorbing material as well as by the frequency of the emitted sound waves.

The waves can be also reflected by different obstacles. In dependence of the characteristics and the surface texture of the reflecting material, the sound wave might also experience some additional damping which leads to a further reduction of sound energy.

The emitted sound wave p_e is consequently split into a reflected and a transmitted part, p_r and p_d. The reflection coefficient is given as

$$R = \frac{p_r}{p_e} \quad (5)$$

and the absorption coefficient as

$$\alpha = 1 - |R|^2 . \quad (6)$$

By purposefully exploiting the absorption and reflection effects, i.e. by setting $\alpha \rightarrow 1$ or $R \rightarrow 0$, noise emissions can be reduced systematically.

Figure 3. Specimen prepared with form liner.

Figure 4. Specimen prepared with sound absorbing silica sand coating.

In order to analyze the influence of the girder's surface finish on the sound emission, several test specimens consisting of pure concrete with varying surface textures as well as concrete specimens with different sound absorbing coatings were tested in two Kundt's tubes of different sizes covering a frequency range of 0.05 to 1.60 kHz and 0.50 to 6.40 kHz. Figure 3 shows for example a test specimen prepared with a form liner (Neoplast Belgrad) leading to a rough surface. Figure 4 depicts a specimen with a sound absorbing silica sand coating.

The experimental investigation of the various specimens revealed a significant reduction of the pass-by noise for girder surfaces laminated with sound absorbing material in comparison to blank guideways but no strong influence of the surface texture (Fig. 5).

Additional studies of the absorbing materials found a considerable influence of the coating thickness on the absorption coefficient. It could be assessed that the absorption capability increases, depending on the frequency, with the layer thickness until a threshold value is met. Further expansion beyond this critical thickness will lead to a decline of the absorption coefficient.

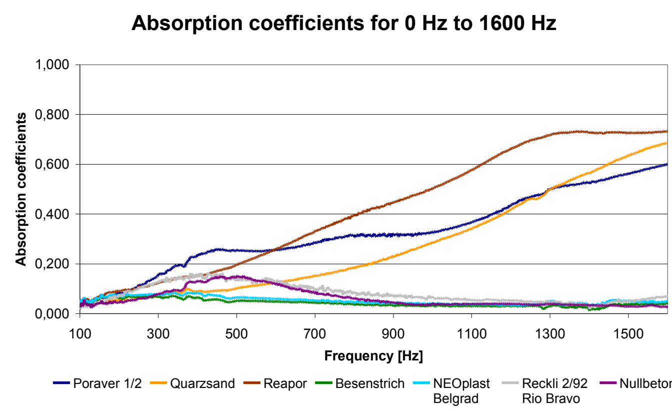

Figure 5. Absorption coefficients for girders laminated with sound absorbing material and girders with modified surface texture.

4 INFLUENCE OF GIRDER GEOMETRY

The sound emission characteristics of a girder are not only influenced by its surface finish but also by the geometry of its cross-section. In order to simulate the sound emitting behavior of girders with various cross-section geometries, a ray model was developed. This model accounts for arbitrary geometry and surface finishes of the girder as well as for the surrounding terrain. An extension to a logarithmic evaluation allows furthermore the computation of the time-equivalent sound pressure level at variable distances for different input signals. The proposed model was verified and validated with the help of sound radiation characteristics measured by microphone arrays along the Shanghai Transrapid line.

The damping coefficient is set to 8.3 which corresponds to a temperature of 15 °C (59 F) and a relative humidity of 50 % at a mean bandwidth frequency of 1600 Hz according to the German regulation DIN ISO 9613-2: 1999-10. The absorption coefficients were taken from the investigations carried out on the test specimens described in Chapter 3. Consistent with the results presented there, the simulated sound pressure level changes in dependence of the surface finish of the girder.

Furthermore, three different girder geometries were analyzed. The hybrid girder of generation H2 used for the Shanghai Transrapid project was the first to be analyzed. Due to the available test data from the commercial Shanghai Transrapid line, this cross-section was used as validation reference. The good agreement of the in-situ test data and the simulation results at the girder in both horizontal and vertical direction warrants the application of this model to other girder designs. In order to comply with German Magnetic Levitation noise standards, which regulate the so-called hourly-equivalent sound pressure level at a distance of 25 m (82 ft) from the track, another evaluation for the required distance was carried out in 20 vertical areas, each with a length of 1 m (3.28 ft).

The simulated hourly-equivalent sound pressure level at 25 m (82 ft) averages 40.2 dB(A) at a speed of 100 km/h (62 mph). Higher speeds of 250 km/h (155 mph) and 350 km/h (218 mph) lead to higher hourly-equivalent sound pressure level of 43.3 dB(A) and 45.5 dB(A), respectively. According to German noise emission regulations (16. BlmSchuV), the train and guideway design of the Shanghai Transrapid line is totally conform to current laws and can be even employed in residential areas.

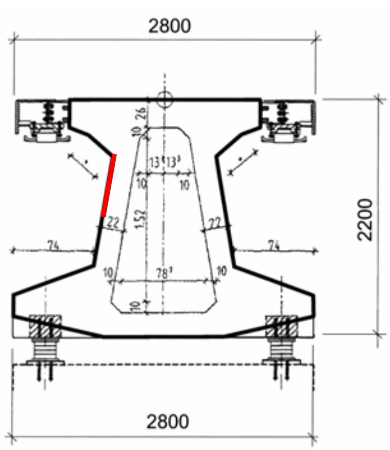

Figure 6. Girder generation H2 with partial coating (red line).

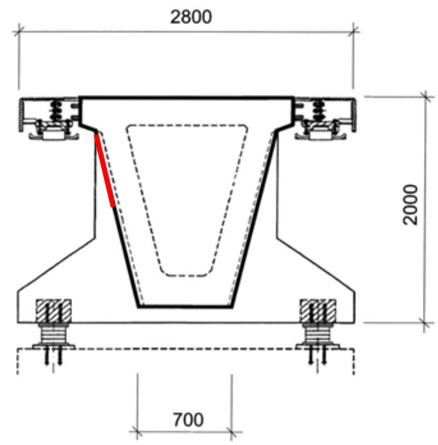

Figure 7. Girder generation H1 with partial coating (red line).

In order to investigate if the noise could be reduced even further for this girder type, additional studies with regard to the application of the sound absorbing materials described in Chapter 3 were performed. Lamination of the whole girder with a sound absorbing coating succeeded in a 60 %-reduction of the sound pressure level. The optimal position of a more cost-effective partial coating of the girder at the area of the strongest sound reflection and absorption (cf. Fig. 6) was also identified by simulation. In dependence of the absorbing material, a reduction of the sound pressure level up to 28 % could be realized for this modification. The simulation showed furthermore that this girder geometry leads to a great number of rays in the observed areas. In contrast to the H1 girders used at the Test Facility Emsland (cf. Fig. 7), the rays are not deflected into the direction of the surrounding terrain. It is therefore concluded, that the slightly higher sound emissions of the generation H2 girders in comparison with the generation H1 girders can be attributed to the different girder geometry.

Additional examinations with full and partial coating of the H1 girders revealed that a total lamination of the cross-section produced only 1 % better noise reduction than a partial lamination. This emphasizes the assumption that the geometry as well as the lamination of the girder are of significant importance regarding the sound emission behavior of Transrapid girders.

5 CONCLUSIONS

The investigations and simulations presented in this contribution show a significant effect of the girder geometry and surface finish on the sound emission properties of the Transrapid guideway. It could be assessed that the examined sound absorbing materials differ considerably with respect to their absorption coefficients while the influence of concrete girder surface textures (smooth, coarse or structured concrete surface) is negligible.

Based on the measured sound radiation characteristics it was shown how the angle of reflection varies with different geometries of the guideway girder.

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