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Status and perspectives of the "Specially Monitored Track"

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Abstract

Deutsche Bahn AG has developed and continuously improved over the last decade a system called "Specially Monitored Track". It is based on the fact that the noise emission from railways can be reduced by rail grinding and has been confirmed officially in 1998 by the German Federal Railway Office (EBA) as a noise reduction system with an effectiveness of −3 dB(A). Meanwhile almost 1000 km of DB's network are specially monitored. In order to comply with this legislation, intensive grinding and monitoring is required. The latter is done by a dedicated monitoring car and supplemented by roughness measurements using a modified roughness-measuring device in connection with a newly developed algorithm for data analysis, enabling a prediction of the noise emission on the basis of roughness measurements.

Future developments will aim at increasing the performance of the system "Specially Monitored Track". This will particularly include grinding at high working speeds ("High Speed Grinding") with two targets: (1) reducing costs for rail grinding and (2) merging rail grinding for acoustic reasons with grinding for regular track maintenance.

1. Introduction

For train speeds up to about 250 km/h, rolling noise is the dominant contribution to the overall noise emission from railway traffic. It is well known that there is a close relationship between the surface conditions of both wheel and rail and noise emission [1]. Rolling noise is mainly caused by small irregularities (surface roughness) on the running surfaces of wheel and rail with amplitudes of the order of 10 μm and wavelengths in the range 10–100 mm. A very powerful tool to reduce the noise level directly at its origin is rail grinding, because it removes these irregularities on the rail [2].

Within the last decade, Deutsche Bahn AG has developed and continuously improved a system called "Specially Monitored Track" (in German: "Besonders Überwachtes Gleis—BÜG"), where a certain standard of rail roughness and a correspondingly low level of rolling noise is being guaranteed to the residents living close to a railway line. BÜG essentially consists of three components:

1. Surveillance of noise emission by a dedicated monitoring car twice per year.
2. "Acoustic" rail grinding when the monitoring car indicates the exceedence of a certain threshold value.
3. Surface roughness control.

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At present almost 1000 km of DB's network are defined as BÜG. DB benefits from the Specially Monitored Track in that a 3 dB(A) reduction has been acknowledged by the German legislation in the forecasting formula for the noise emission of railway lines to be newly built or facing major reconstruction. This can considerably reduce or even totally avoid additional measures such as, for example, noise barriers.

In the following, the general concept of BÜG is explained, thereafter following a description of the above-mentioned three central components of BÜG. The paper concludes with an outlook for future developments.

2. The general concept of the "Specially Monitored Track"

In the last few years, DB has implemented the acoustic concept of the "Specially Monitored Track", BÜG. The BÜG concept is based on the periodic acoustic monitoring of the relevant track section by means of a test coach specialized for measuring sound. Should noise exceed a certain limit, grinding the track section will reduce the roughness of the rolling surface of the rail and, hence, the rolling noise considerably. The German Federal Railway Office (EBA) officially confirmed BÜG in 1998 as a noise reduction system with an effectiveness of −3 dB(A) both for ballasted track and for slab track.

Fig. 1 illustrates in a simplified manner the typical time dependence of the noise emission from a BÜG track. It shows the monitoring and grinding procedures that are applied in order to ensure the 3 dB(A) reduction compared with ordinary tracks without special monitoring. For simplification it is assumed that the noise emission increases linearly in time (solid curve in Fig. 1). At least every 6 months the BÜG sections have to be monitored by the monitoring car SMW (see Section 4). As soon as the +3 dB(A) limit in Fig. 1 has been reached, the section has to be ground. This should lead to a reduction of the noise emission level by about 6 dB(A). In the past there was no direct way to check the quality of the grinding immediately after completion of the work. This gap has been filled meanwhile by the recent development of a roughness-measuring device (RMFBÜG—see Section 5).

The noise emission level in Fig. 1 oscillates between −3 dB(A) and +3 dB(A), thus giving a time average of 0 dB(A). This zero value corresponds to a basic value for BÜG sections of 48 dB(A) compared to a basic value of 51 dB(A) for ordinary tracks. This basic value is the time averaged sound pressure level measured 25 m away from a ballasted track with wooden sleepers, when 1 train/h passes at a speed of 100 km/h and when this train has only disc-braked wheels and is exactly 100 m long.

It has to be emphasised that the reduction from 51 dB(A) to 48 dB(A) is a value averaged over the different train types. Of course, the noise emission associated with trains like ICE is much more sensitive to the quality of the rail head than the noise emission from tread braked freight trains. In the former case, regular rail grinding can easily reduce the time-averaged noise emission by 4 dB(A) or even more, while the effect in the latter case is only of the order of 1–2 dB(A). This on the other hand means that BÜG will be even more effective as soon as a considerable part of the freight wagons are equipped with composite block brakes.

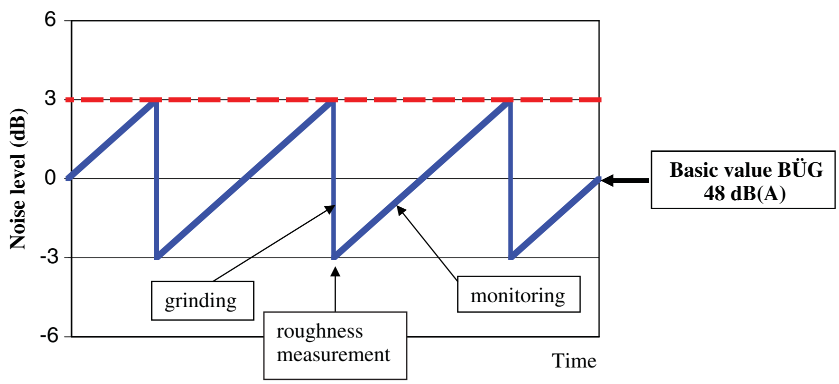

Fig. 1. Schematic representation of the variation of noise emission from a BÜG section with time. Typical intervals between the grinding are of the order of 8 years. The dashed line indicates the limit, when grinding is required.

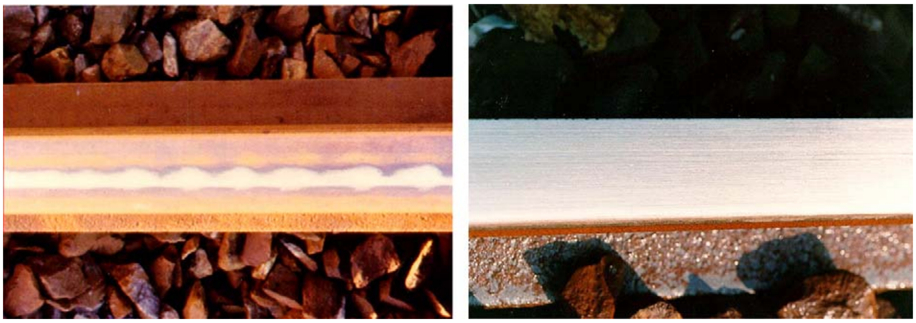

Fig. 2. Surface of the rail before (left) and after (right) acoustical grinding with oscillating stones.

When the BÜG-system was first implemented in 1998, it was assumed that grinding has to be performed every 4 years. Now with 7 years of experience with BÜG on DB's network a statistical analysis has yielded an average level increase of about 0.7 dB/year which means an average periodicity of about 8 years in Fig. 1. This is supported by the fact that only very few BÜG-sections had to be ground twice since 1998.

3. Grinding

According to the high requirements the grinding equipment that provides the smoothest rail surface is applied on BÜG track. The currently applied grinding of BÜG sections is a two stage process: (1) planing or milling and (2) acoustical grinding using oscillating stones. The driving speed of the second stage is approximately 1.2 km/h. The very best results are obtained, if step 2 is supplemented by a static one-way grinding using the same grinding vehicle. Fig. 2 shows as an example the surface of a rail before (left) and after (right) acoustical grinding.

At present, the grinding operations are initiated only on noise related criteria (i.e. noise levels increasing over the stated limit) separately from classical rail maintenance (mechanical or fatigue) criteria. Future developments, particularly in connection with "High-Speed Grinding" will aim at combining acoustic grinding with rail maintenance grinding (see Section 5).

4. The monitoring car SMW

At present, Germany is the only country in Europe having specific noise legislation regarding a "Specially Monitored Track". In order to comply with this legislation, intensive monitoring and grinding is required.

One of the conditions stated by the German Federal Railway Office for the use of BÜG is that periodic acoustic monitoring of each BÜG section has to be performed at least every 6 months. For this purpose DB uses a specially built monitoring car ("Schallmesswagen"—SMW) [3], which travels across the entire BÜG network at regular intervals. The basic idea behind SMW is to use its own rolling noise as a measure for the sound emission. SMW is a modified passenger coach with a microphone mounted above a hole located directly above one bogie (see Fig. 3).

It is vital for the reliability of the measurements that the wheels of the bogie below the microphone room have extremely smooth running surfaces. This means that the combined roughness of rail and wheel is essentially equal to the roughness of the rail alone so that the rolling noise of SMW is a measure for the rail roughness. To ensure the required high quality of the wheels, the test bogie has no brakes and wheel roughness measurements are carried out at short time intervals (typically once per year).

In a large series of measurements DB has proven that the rolling noise measured by SMW correlates very well with the average sound emission from a typical group of trains. These correlation measurements, which

Fig. 3. Semi-anechoic microphone room inside the noise monitoring car (''Schallmesswagen''—SMW) built by DB for monitoring the sound emission of BÜG track.

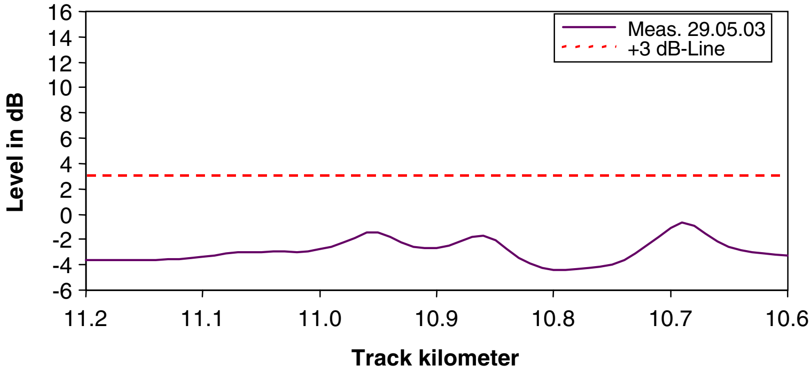

Fig. 4. Example of an SMW measurement. The dotted line indicates the upper limit above which grinding is required.

have to be repeated every second year, are performed in the following way:

1. On a BÜG-track with an emission level close to 0 dB (i.e. ''average'' BÜG-quality; cf. Fig. 1) measurements are performed separately for the four train categories ICE, IC, regional train, and freight train by a single microphone 25 m away from the track.
2. Corrections are performed accounting for different speeds, lengths, and brake types of the trains.
3. The pass-by levels calculated for 1 train/h from each of the four train categories are averaged.
4. A value of 48 dB is subtracted from the average level thus calculated. This level, which should be close to 0 dB gives the reading to which the SMW has to be adjusted.

This procedure means that SMW's calibration is as close as possible to the average value of 0 dB in Fig. 1. Since the rolling noise which SMW measures is somewhat more sensitive to increasing corrugation than the rolling noise of the group of trains (which is mainly due to the relatively rough wheels of the freight trains), the reading of SMW close to the threshold value of +3 dB in Fig. 1 is typically 1 dB higher than the value a microphone measurement would yield. This gives a ''safety margin'' for the residents living close to a BüG track ensuring that the noise emission in the most critical phase near the +3 dB limit is always less than that recorded by the measuring car.

Fig. 4 shows an example of an SMW measurement. The noise levels are scaled such that 0 dB corresponds to the time averaged level on a BÜG section (cf. Fig. 1). The dotted line in Fig. 4 indicates the limit, above which grinding is required.

5. The roughness measuring device RMF-BÜG

An important feature of the BÜG-system is that it guarantees the residents of a BÜG-track a certain *average* reduction of the noise emission. Assuming a linear increase of the emission (see Fig. 1), this average reduction can be guaranteed by ensuring that (a) the noise emission never exceeds the upper threshold of 51 dB(A) and (b) the level immediately after grinding is close to 45 dB(A).

The first condition is fulfilled by the regular monitoring of SMW. Until now there was no direct way to check condition (b). In order to fill this gap, a measuring device RMFBÜG has been developed, which enables a prediction of the noise emission based on roughness measurements (see Fig. 5). RMFBÜG has been developed with the purpose primarily to provide an easy-to-handle portable means of measuring relatively long sections of track within short times so that it can serve as an in-situ quality control for grinding.

Two measuring units enable the simultaneous recording of the longitudinal profiles of left and right rail. Each unit has a displacement transducer held by two skates, each of which roll on seven small wheels. The units are mechanically decoupled from the rim and have an overall length of about 0.3 m (including skates and transducer), thus giving an upper limit for the roughness wavelengths that can be taken into account.

In order to get from a roughness measurement a prediction for the sound emission from the track, a special algorithm for data analysis has been developed and implemented into the RMFBÜG software. This algorithm comprises the following steps:

(1) Measuring the longitudinal profile of the track (typically 100–1500 m).
(2) Filtering of raw data ($10\,\text{mm} < \lambda < 100\,\text{mm}$).
(3) Partitioning of the measurement into sections each 2 m long.
(4) Calculation of the power spectral density for each 2 m section.
(5) Calculation of one-third octave spectra for each 2 m section and consecutive filtering in order to account for the low-pass filtering of the wheel/rail contact patch [4].
(6) Calculation of the total level of the one-third octave spectra in terms of roughness.

Step (6) provides single levels for each 2 m section of the rail separately for left and right rail ($L_{v,2\,\text{m},\text{left}}$ and $L_{v,2\,\text{m},\text{right}}$). Energy summation of $L_{v,2\,\text{m},\text{left}}$ and $L_{v,2\,\text{m},\text{right}}$ gives a single value $L_{\text{v},2\,\text{m}}$, which provides a measure for the roughness of the respective section. If required, the levels $L_{\text{v},2\,\text{m}}$ may be averaged over longer sections, hence giving a single value for the roughness.

In an extensive measurement campaign a reasonable correlation was established between the roughness levels calculated as above and the sound emission from the track. This task was accomplished by using SMW measurements as reference for the noise emission (see Fig. 6).

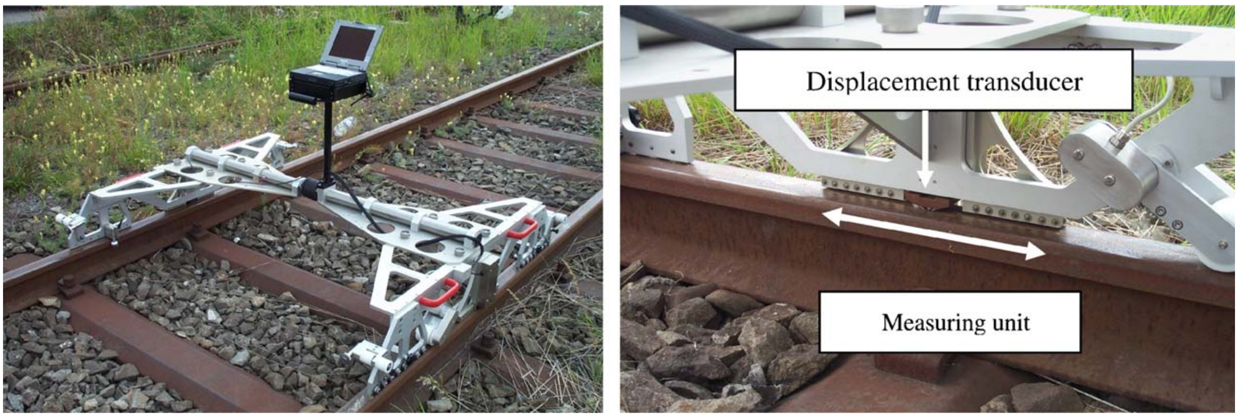

Fig. 5. Roughness measuring device RMFBÜG. It contains two displacement transducer units for simultaneously measuring the longitudinal profile of left and right rail. The right figure shows one unit in more detail.

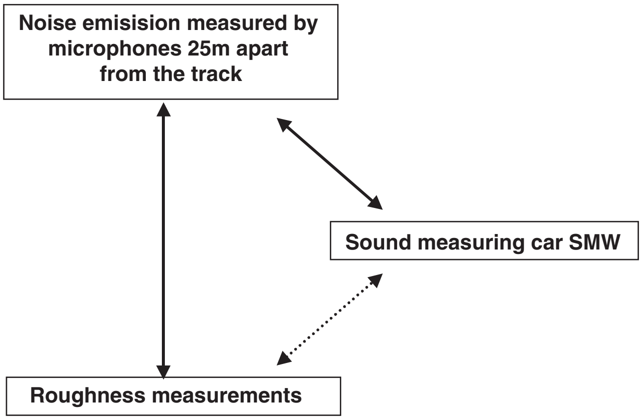

Fig. 6. General concept of the correlation of the roughness data with noise emission. The correlation between roughness measurements and SMW (dashed line) is demonstrated in Fig. 7. This means that also the correlation between roughness and noise emission as measured by single microphones is established.

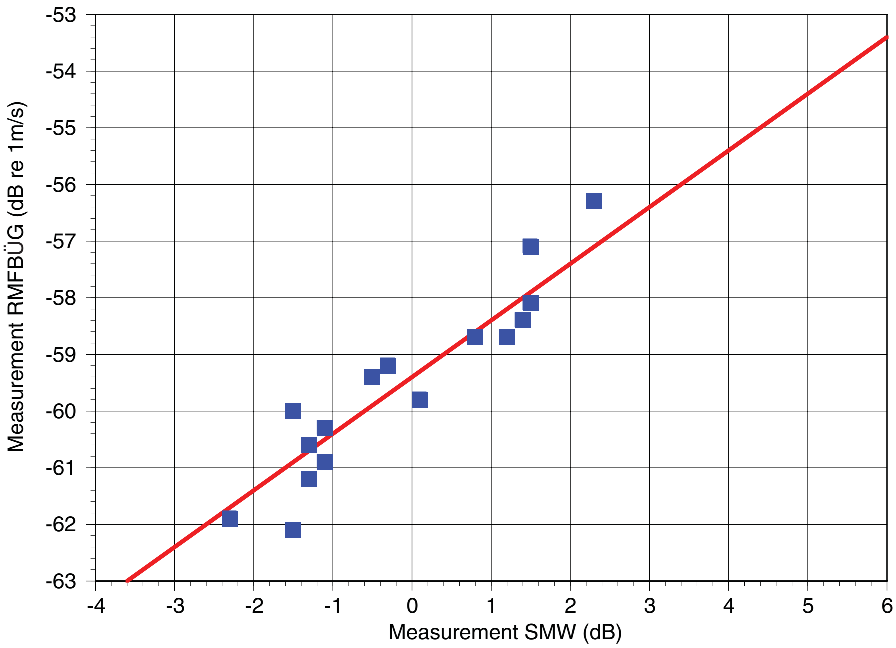

Fig. 7. Correlation between results from SMW and results from RMFBÜG. Each dot corresponds to a separate measurement. These 16 measurements were performed over a period of more than 2 years on many different tracks of DB's network. The straight line results from linear interpolation.

Fig. 7 displays the correlation between measurements of SMW and results from RMFBÜG based on sixteen comparative measurements on ballasted tracks of DB AG. Each point in Fig. 7 refers to a measurement, where the roughness of a track (typically 500–1000 m long) has been measured. After performing steps (1)–(6) the roughness level has been averaged over the full measured section of the track. Equivalent averaging has been done with the SMW-measurements of the same track. The roughness is plotted along the vertical axis while the corresponding SMW-result is plotted along the horizontal axis.

From Fig. 7 the results of a roughness measurement by RMFBÜG may be calibrated directly in terms of the scale of SMW. An example for an RMFBÜG measurement is shown in Fig. 8. It was performed over a section

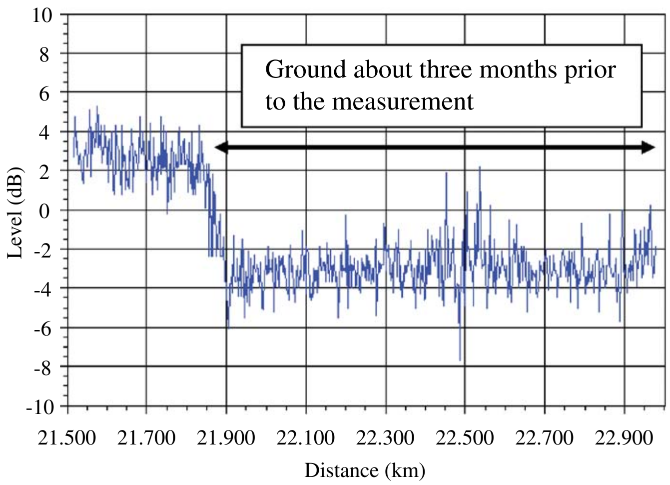

Fig. 8. Example of an RMFBÜG measurement. The track has been ground about 3 months prior to the measurement (GWM550, Fa. Schweerbau). It is clearly visible that the grinding has reduced the level by about 6 dB.

of track 1500 m long about 3 months after part of this section has been ground using GWM550 (Fa. Schweerbau). Clearly visible is the transition from the not-ground to the ground section. The grinding has led to a level reduction by about 6 dB and the ground section is still in a very good condition with levels corresponding to the lower limit shown in Fig. 1.

6. Recent and future developments

The noise generation by rail grinding depends on the difference in wheel and rail roughness: the smoother the wheel the larger the influence of rail roughness. Therefore grinding will be an even more powerful tool for noise reduction in the future when the ongoing replacement of cast-iron brakes by composite-block brakes for freight wagons has been completed.

Recent developments in grinding techniques indicate that the grinding as it is done at present with low working speed may be replaced by ''High-Speed Grinding'', i.e. by grinding with working speeds at least above 50 km/h. Grinding with such high speed has the following advantages:

(1) Grinding can be synchronised with the regular train-free intervals, which means that it may be carried out during normal service hours without the necessity to close the track.
(2) Long sections can be ground within one shift at low costs.
(3) Frequently repeated grinding with only thin layers of material removed from the rail head will result in a smaller width of the range, within which the emission level oscillates over time. At present it oscillates within a range of 6 dB(A) (see Fig. 1). This could be reduced to values as low as 1–2 dB(A).

In year 2002, DB in cooperation with the grinding companies Schweerbau and Stahlberg-Rönsch has undertaken tests on a track near Munich with two potential candidates for High-Speed Grinding:

(1) Static acoustical grinding using the locomotive-hauled grinding machine GWM 550 of Schweerbau at 40 km/h.
(2) Multiple pass-bys of the prototype of a new grinding system under development by Stahlberg-Rönsch (see Fig. 9).

Both tests gave promising first results and demonstrated the potential for an even further noise reduction than the current 3 dB(A) of the BÜG system.

Fig. 9. Grinding stones of the prototype developed by Stahlberg-Rönsch.

The development of grinding techniques towards higher working speeds shall be accompanied by the development of a mobile measuring device for rail roughness, which can be adopted to the same speed as the grinding machines and may serve as an in-situ quality control.

Acknowledgements

The measuring device RMFBÜG is based on the Vogel & Plötscher system RMF and has been developed by DB Systemtechnik in collaboration with Vogel & Plötscher, Breisach.

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