An advanced measurement technique for an appropriate determination of TDR at less maintained railway tracks

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Summary
EN 15461 specifies a method for determining the dynamic behavior of the rails of a railway track. Although this method was originally intended to assess the quality of sections where rail vehicle acceptance tests are to be carried out as part of regulatory approval tests, this method is often used today to emphasize differences in overall noise radiation with different track superstructures.
Reference tracks for approval tests are generally very well maintained whereas rails in main traffic lines are processed with a lower maintenance quality. This often results in a rapid and noticeable change in railhead impedance along the track, resulting in undesirable deviations in the calculation of the TDR. Using examples, the possible differences are shown.
Based on the method described in EN 15461, an advanced measurement method is presented, which overcomes problems in determining TDR on poorly maintained tracks by using an additional vibration sensor.

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1. Introduction

Within the European Union, efforts are being made to reduce the noise emission from railway tracks substantially. In order to be successful here, in addition to a continuous and permanent improvement of the contact roughness of rail and wheel, further aspects of railway operation have to be considered for the overall optimization potential. This includes the Track Decay Rate (TDR), which describes the decay behavior of vibrations along the rail. A larger TDR will radiate less noise from the rail.

EN 15461 [1] describes the procedure for measurement of TDR and the calculation based on the measurement results. The aim of this EN 15461, however, was to start using this methodology for reference tracks on which measurements should be made for the soundproofing of new rolling stock. In recent years the TDR was also applied to describe the dynamics of railway tracks in daily use, in order to explain the partly increased sound emissions, or to compare two sections in their sound radiation with respect to the track condition.

The main difference between a reference track for acceptance measurements and a railway line in general use is that at reference tracks require a much higher effort to maintain the track quality. It follows, as will be shown later, that the EN 15461 methodology on general routes in the rail network will pose many problems.

2. Differences between Reference Tracks and Standard Railway Tracks

In order to be able to measure the noise emissions of new rolling stock in standardized form, requirements with regard to the TDR and the roughness of the running surfaces on the rail head are required on the reference tracks on which such measurements are to be carried out (EN 15610 [2]). This ensures that the noise emission from the track does not contribute a distortedly high proportion of the total noise emission of the vehicle to be examined.

Increased conservation measures are required for the reference track infrastructure to comply with these conditions, which are not implemented on normal railway lines, since the safety of the moving traffic must be ensured here and because of the cost pressure, only in selected sections of the route the increased maintenance costs as well as reference routes will be applied.

With regard to the dynamic behavior of the rails, these less frequent maintenance measures can be recognized by the fact that the elastic rail pads are held in position for some 30 years and, accordingly, the clips on the foot of the rail do not undergo any special maintenance work during this period. In a study for the Swiss Federal Railways (SBB) [3], individual rail pads were developed on six track sections distributed across Switzerland and examined with regard to their thickness and stiffness. Except for one location, the rail pads belonged to the type Zw 661a, which are made by the compound of ethylene-vinyl-acetate (EVA) and have a static stiffness of approx. 700 kN / mm and a thickness of approx. 6.3mm at initial installation. In special tests on the removed rail pads at laboratory, it was found that the plate thickness decreased with increasing accumulated axle load and the stiffness of the rail pads has also decreased (Figure 1).

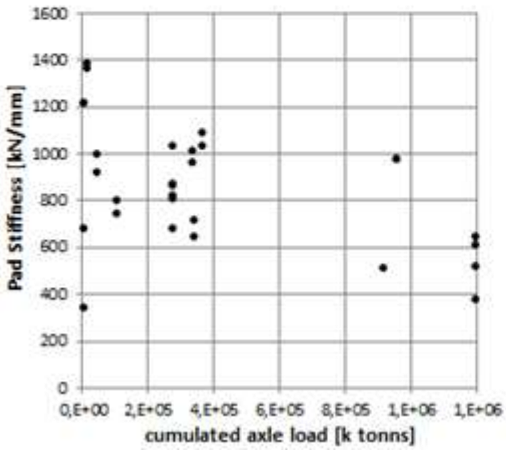

figure 1 Decrease of pad stiffness vs. cumulated axle load

The decreasing thickness of the rail pads has an effect on the clamp, which fixes the rail to the sleeper. At removed rail pads, a reduction in the thickness of up to 1 mm was observed. This change causes a decrease in the clamping force of the clip on the rail foot, which can be equated with a lower tightening torque of the screw (Figure 2). When installing the rail, the tightening torque should be approx. 180 Nm - 200 Nm.

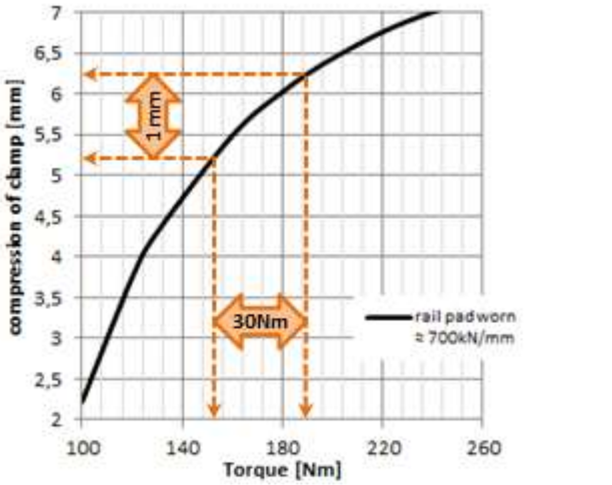

figure 2 Change of the torque due to loss of pad thickness

This reduction of the holding force has a major impact on the vibration behavior of the rail, it can move more freely. Figure 3 shows the change in vertical mobility of the rail at different tightening torques

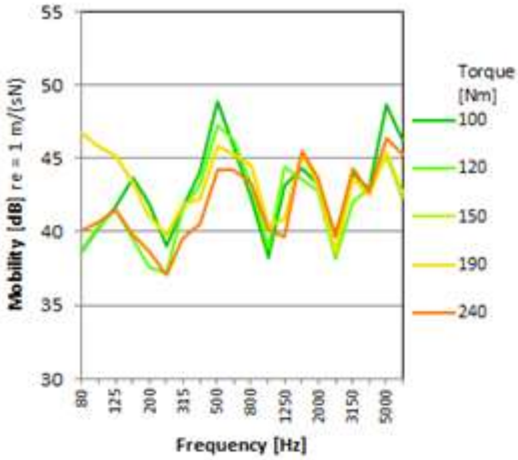

figure 3: Change of the vertical mobility at rail head due to the torque of the screw

In the frequency range below the pinned-pinned mode of approx. 1.1 kHz, the changes in mobility are clearly recognizable. Above the pinned-pinned mode, the rail is cut free from the track superstructure, so that in this frequency range only slight differences occur due to the holding forces on the rail foot.

In the study [3] the vertical local mobility of the rails above 11 consecutive sleepers was investigated. According to the cumulative axle load and the wear of the rail pads, it had to be stated that in some cases main changes of the vertical mobility can be observed even in very short track sections. Figure 4 shows the vertical mobility averaged over 11 measurement points and the maximum and minimum deviations thereto. These results were obtained before this section was revised.

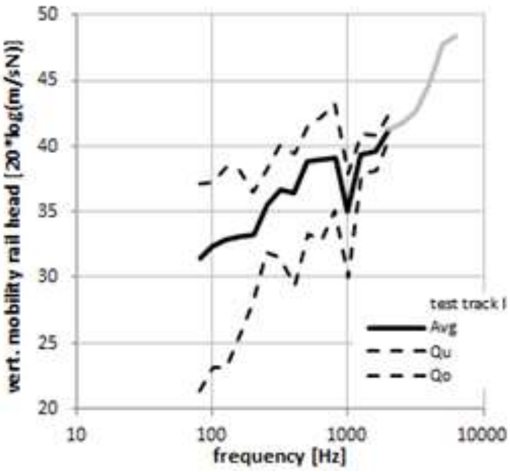

figure 4: Averaged vertical mobility at 11 consecutive positions above sleeper

As the study proceeded, this track section underwent a maintenance in which the screws were tightened by hand with a steady tightening torque of 180 Nm. The rail pads were not renewed in this section. It can be clearly seen that the deviations of the vertical mobility were significantly reduced and at the same time the absolute value of the mobility was reduced, which means that the rails were again coupled much more strongly to the sleepers.

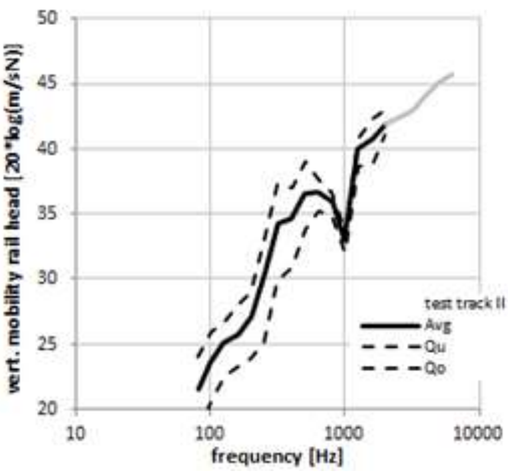

figure 5: Averaged vertical mobility at 11 consecutive positions above sleepers after track maintenance

3. Method of Measuring and Calculating TDR equivalent to EN 15461

EN 15461 presents a methodology for capturing the TDR in a section of track that can be accomplished with a 2-channel measuring system. At the starting point of the measurement grid, a vibration sensor is fixed to the rail and an instrumented hammer is used to introduce multiple impacts into the rail at increasing certain distances and the transfer functions between the transmitting and receiving locations are analyzed and then calculated according to a given formalism.

This methodology is based on a method with only two sensors and thus requires that no significant changes in the mobility of the rail head occur throughout the examination area.

In a complete examination, the measurement setup would have to consider another vibration sensor attached close to the impact location. The attenuation of the vibrations is then calculated from the ratio of the transfer function in the near range FRF_{near} to the transfer function in the far range FRF_{trans}.

In the case of no or minimal changes along the grid, the FRF_{near} will remain constant and can be eliminated. However, as shown in Figure 4, it must be assumed on tracks in heavy use with worn rail pads that the desired consistency along the examination area will not be guaranteed.

It should be noted here that in EN 15461 the possibility to measure the TDR by means of the impulse entry into the rail at fixed position and a roving vibration sensor is allowed, as the complete system of the superstructure is considered to be passive and linear in the relevant frequency range.

4. Influence of irregularities in track on the calculation of TDR

In a laboratory test on a limited track construction with a length of approx. 6m, the possible deviations of vertical mobility were examined in more detail. It turned out that the vertical mobilities detected above the sleepers differ much more than the mobilities in the mid-span. It should be noted that significant deviations can only be observed below the pinned-pinned mode.

From these investigations it could be concluded in a first approximation that the deviations of the mobilities above sleepers are found in the mid-span with about half the deviation. The mobilities in the mid-span are estimated as shown in figure 6.

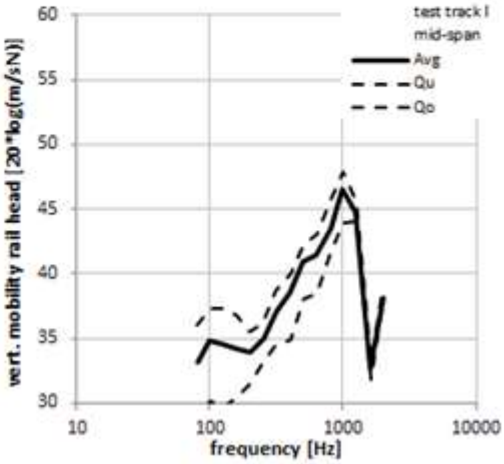

figure 6: Estimated vertical mobility of a rail in mid-span position

From Figure 6, it should be noted that the local mobility in the mid-span is subject to a fluctuation of up to 6 dB in this example. It follows that the method of EN 15461 for determining the TDR with only one vibration sensor is subject to a high degree of inaccuracy, since the calculation is based on mobility at the starting point of the measurement grid. The further consequence of this is that only a shift of the grid by one sleeper bay will result in a quite different calculation of the TDR.

5. Advanced measurement technique for the determination of TDR

As it is mentioned in Chapter 3, more than just a vibration sensor should be used to determine the TDR at general railway tracks. With today available low-cost multi-channel measurement systems a 4-channel AD-converter may be used, having 3 channels to detect rail vibrations and 1 channel to record the impact of the hammer.

This extends the requirement in Chapter 3 by a further channel. The advanced measurement technique aims to design a measurement grid that measures the TDR in both directions along the rail at the same time starting from a central point (Figure 7).

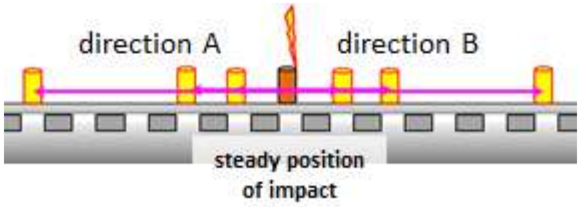

figure 7: Schematic of the advanced measurement technique for the determination of TDR

At the central position of the measurement grid, a fixed vibration sensor and the impact hammer are operated, the two mobile vibration sensors are moved in the opposite direction along the rail at defined positions equivalent to EN 15461. From this, the direction-dependent values of the TDR can be recorded in one measurement run. This is advantageous to obtain the determination of the TDR close to the position where the noise radiation from track is to be determined.

In EN 15461 it is required that in order to find a suitable track section for the layout of the measurement grid, local mobility should be measured at three positions with high similarity in frequency characteristics. In the case of reference tracks it is assumed to be very easy to accomplish. In the case of tracks in standard duty, it may be necessary to set up the measuring grid for the TDR at an unwanted distance from the position of the microphone. Furthermore, EN 15461 requires that the TDR be determined in at least two test runs in one section of track. This is achieved with the new methodology presented here.

The measurements to determine the TDR on standard railway lines are usually carried out under normal operating conditions. This means that several persons are needed to carry out the measurements while ensuring safety in the hazard zone. Therefore, the use of a further vibration sensor in this method requires no additional staff. The measurements according to the new method are comparatively faster and still feasible, as it is achieved at the individual measurement positions for both measurement grids at once within only one break between two train pass-bys, whereas for the two time measuring operations like EN 15461 recommends two times the breaks between train pass-bys are needed.

6. Results

The diagrams below show the TDR values obtained using the methodology of EN 15461 and the new method, measured on an old track section with S49 rail and a hard rail pads. Figure 8 shows that in this section, the vertical mobilities along the rail differ considerably. It is therefore to be expected that the new methodology will deliver values closer to the true situation.

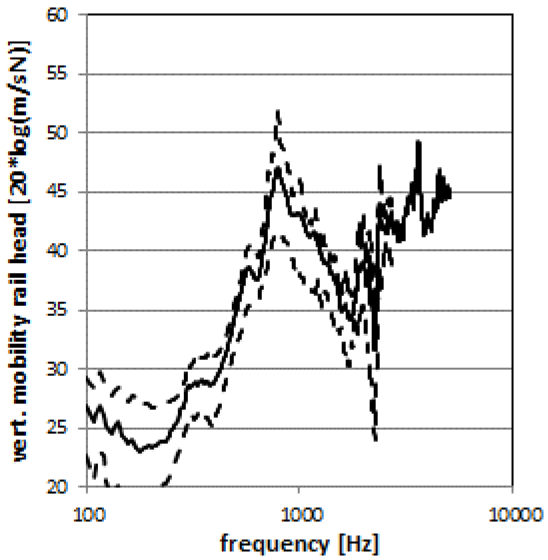

figure 8: vertical mobility of an old track section with S49 rails and stiff rail pads

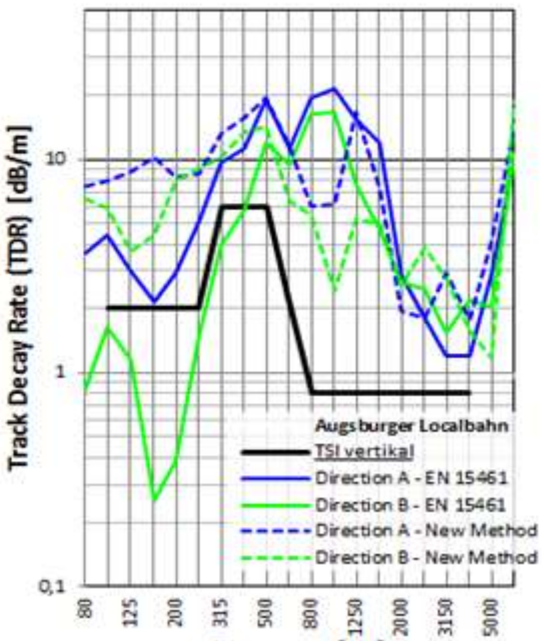

figure 9: Comparison of TDR data measured and calculated via EN 15461 and new method

Figure 9 shows the TDR values determined by the different methods in this section. It can be seen that, especially in the frequency range from 800 Hz to 1.2 kHz, significant deviations occur between the new method and EN 15461. However, a large deviation in the mobility of the rail is observed in this frequency range too (Figure 8).

7. Conclusion

The EN 15461 describes a method to develop the TDR values at a railway track. Hence the former aim of this standard was to determine the acoustical quality of reference tracks, today this method is more and more in use to determine the quality of regular railway tracks.

As regular railway tracks from the acoustical point of view are maintained to a reduced quality stage the elementary set up for the measurement of TDR is not sufficient as the variation of the vertical mobility of the rail is too high, producing a high uncertainty of the reference transfer function at the starting position of the measurement grid.

An advanced measurement method has been developed to determine the TDR at those worn track sections. The main changes in the measurement set up include switching from roving hammer to roving vibration sensors and adding two more vibration sensors. This provides a much more reliable method for determining the TDR. The duration of carrying out this new method is reduced compared with the execution of two necessary measurement grids per EN 15461.

References

[1] Railway applications - Noise emission - Characterisation of the dynamic properties of track sections for pass by noise measurements; German version EN 15461:2008+A1:2010.

[2] Railway applications - Noise emission - Rail roughness measurement related to rolling noise generation; German version EN 15610:2009

[3] ACCON GmbH: Erprobung Schienendämpfer - Bestimmung Faktor X - Stardamp Tool Eine Studie über die Einflussfaktoren aus dem Trassenaufbau auf die Wirkung von Schienendämpfern durchgeführt an den Monitoringstationen der SBB, ACB-1015-6374/6, Greifenberg 18.12.2015 not published.