The dynamic stiffness as an indicator of the effectiveness of a resilient rail fastening system applied as a noise mitigation measure: laboratory tests and field application

The dynamic properties of the resilient layers of rail fastening systems play an important role with respect to noise and vibration emission from railway lines. In order to achieve low noise radiation from the rails, the application of a rather stiff rail fastening is advisable, whereas for vibration reduction rather soft fixtures would be preferable. Firstly, this article addresses a test method which has been used to measure the dynamic stiffness of a special resilient rail fastening system, and presents examples of results obtained in this respect. Secondly, the effectiveness of this type of resilient rail fastening applied as a noise mitigation measure on a steel railway bridge in Berlin, Germany, is shown, by presenting measurement results which were obtained both before and after installation.

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Laboratory tests

The dynamic properties of rail fastening systems are determined from measurements. In order to have comparable results, a CEN-Standard has been written, which is consistent with the method described in ISO 10846 for laboratory measurements of the dynamic stiffness of resilient elements [1].

Dynamic stiffness measurements of elastic elements aim at defining a physical value which characterises the test specimen, independently of a certain installation situation. According to ISO 10846 [1], the dynamic transfer stiffness has to be used to characterise a resilient element. It describes the force transmitted via the element for a given excitation deflection, which can be used as an input parameter for model calculations to predict the insertion loss of such an element in a given application situation. Referring to this standard, a test method for "Special fastening systems for attenuation of vibration" is described in ENV 13481-6 [2].

The diagram in Fig. 1 depicts the rail fastening placed on a force measuring assembly (see points 4 and 5), which measures the blocking force. The static and dynamic loads are applied via a short section of rail. The excitation level is measured on the loading device (see point 3) by accelerometers placed in parallel. The static preload is applied via elastic elements (see point 2), in order to separate the loading device from the top of the rig. The static preload is generated via the hydraulically powered top of the rig, whereas the dynamic load is generated via an electrodynamic shaker (see point 1). Fig. 2 shows a picture of the test rig at Müller-BBM.

Test results

Fig. 3 shows the measurement results obtained for two types of baseplate pads (i.e. Sylomer® S 750 and Sylodyn® N 70750), which were obtained using the test rig of Müller-BBM [3].

Fig. 4 shows the load deflection curve of the Sylodyn® baseplate pad, type Zwp 110, which - as will be presented in the section "Field application" below - was used for the resilient rail fastening system installed as a noise mitigation measure on a steel railway bridge in Berlin. It features the typical gradient for cellular polyurethane (PUR)-elastomers, with a degressive spring characteristic in the medium load range. According to [4], this curve yields a static spring rate of c_{stat} = 18 MN/m as a secant between 18 kN and 68 kN.

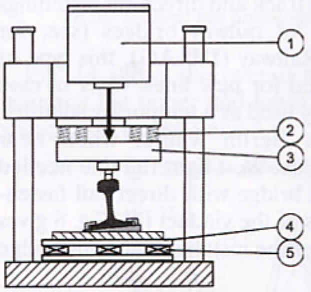

Fig 1: Schematic drawing of the test rig for dynamic measurements of resilient elements according to ISO 10846-2 [1], or of rail fastening systems according to ENV 13481-6 [2]

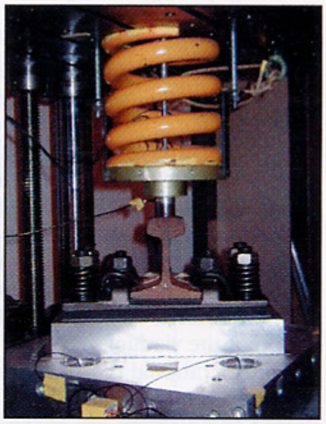

Fig. 2: Test rig for dynamic measurements, featuring an installation for rail fastening systems according to ENV 13481-6 [2], (see Fig. 1 for explanation of the functions) - (Photo: R.J. Diehl, Müller-BBM)

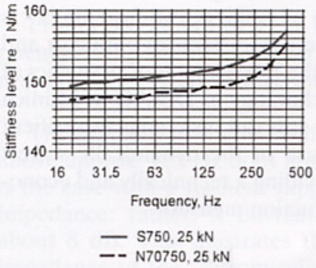

Fig. 3: Dynamic stiffness of a resilient rail fastening system, type Ioarg 314: dynamic stiffness level, dB re 1 N/m (140 dB ≙ 10 MN/m)

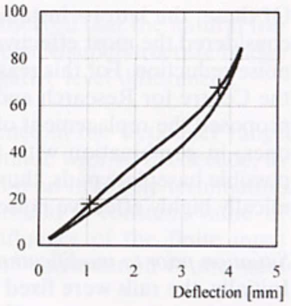

Fig. 4: Load deflection curve of the Sylodyn baseplate pad, type Zwp 110, secant stiffness between 18 kN and 68 kN: c_{stat} = 18 MN/m

Fig. 5 shows the dynamic stiffness of the Sylodyn® type Zwp 110 baseplate pad, as measured on the so-called 'Hydropulse test rig' of Getzner at a frequency of 40 Hz, together with the static stiffness, both as a function of load. It presents the relation between dynamic and static stiffness, thus showing the "dynamic stiffening" of the baseplate pad. In the relevant load range of between approx. 40-50 kN, this is characterised by a factor of about 1.4 only.

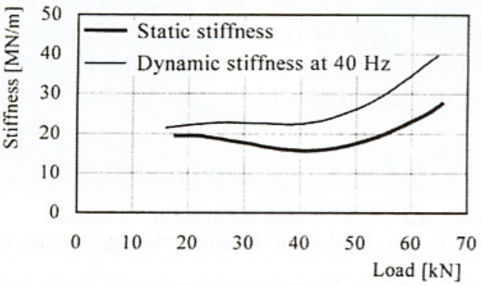

Fig. 5: Static and dynamic stiffness of the Sylodyn baseplate pad, type Zwp 110, as a function of load

As can be observed from Fig. 5, the dynamic stiffness of the Sylodyn® type Zwp 110 baseplate pad has a value of approx. 22 MN/m for a static preload of 25 kN. This value equals a dynamic stiffness level of approx. 147 dB re 1 N/m, which is exactly the same level as that which was measured in the lower frequency range (up to about 50 Hz) for the complete rail fastening system, as shown in Fig. 3.

Field application

Steel bridges featuring ballastless track and direct rail fastenings are amongst the noisiest types of railway bridges (see, for example, [5], [6]). On German Railway (DB AG), this type of bridge structure is no longer used for new lines. Only in case tracks are being renewed, are they used as a temporary solution.

This was also the case in Berlin where, when near Humboldthafen viaducts of the East-West light rail line needed to be restored, an auxiliary steel bridge with direct rail fastenings was built over nine segments of the viaduct [7]. Fig. 6 gives an impression of the situation after the installation of this bridge on top of the viaduct segments.

For operational reasons, this solution has to remain in place for several years. As people living in the immediate vicinity started complaining about the noise radiating from the bridge structure, a measure to reduce the noise had to be sought.

In principle, reduction in the level of noise emission from ballastless steel railway bridges can be effected by (for more details see [6]):

— the installation of a ballast bed along the entire bridge span;
— the installation of ballast between the sleepers;
— the application of a sandwich coating on the structure;
— the installation of vibration absorbers;
— the installation of resilient rail fastenings.

Of these, the latter - installation of resilient rail fastenings - is considered the most effective solution in terms of both cost and noise reduction. For this reason, the Department of Acoustics of the Centre for Research and Technology of DB AG in Munich proposed the replacement of the stiff rail fastenings by resilient ones, in combination with the use of the dynamically softest possible baseplate pads, thus providing a technically and economically highly effective noise reduction measure.

Situation prior to modification

Initially, the rails were fixed rigidly to the steel bridge by means of standard German type K fastenings (see Figs. 7 and 8). This construction uses a stiff rail pad, featuring a static stiffness c_{stat} = 500 MN/m between the rail and the baseplate. However, this did not provide any noticeable damping for the structure-borne noise created at the wheel-rail interface which excites the bridge structure, and thus resulted in a high level of airborne noise.

Fig. 6: Underside of the auxiliary railway bridge, which has been installed on top of the viaduct segments (Photo: W. Weißenberger, Müller-BBM)

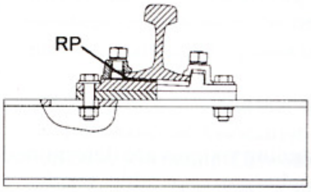

Fig. 7: Schematic drawing of the stiff rail fastening system in use <u>before</u> modification of the auxiliary steel railway bridge: RP ≙ rail pad with very high stiffness, static stiffness: c_{stat} = 500 MN/m

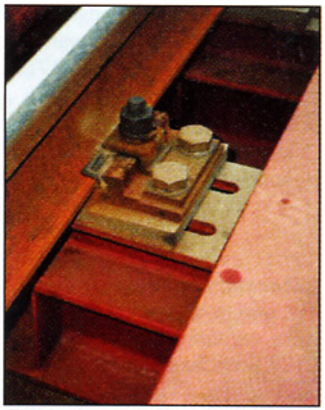

Fig. 8: Picture of the stiff rail fastening in use <u>before</u> modification of the auxiliary railway bridge (Photo: W. Weißenberger, Müller-BBM)

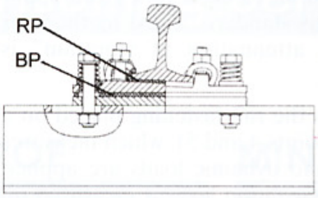

Fig. 9: Schematic drawing of the resilient rail fastening system, type Ioarg 314, <u>after</u> modification of the auxiliary steel railway bridge: RP (rail pad with very high stiffness, BP ≙ dynamically soft Sylodyn baseplate pad, type Zwp 110, static stiffness: c_{stat} = 18 MN/m

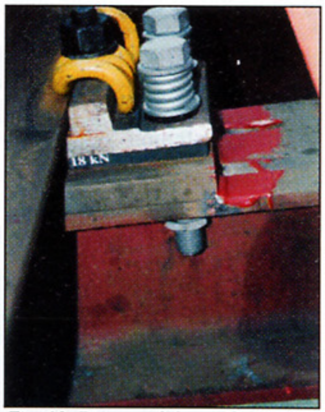

Fig. 10: Picture of the resilient rail fastening in use <u>after</u> modification of the auxiliary railway bridge (Photo: W. Weißenberger, Müller-BBM)

Situation after modification

Resilient rail fastenings of type Ioarg 314 were installed. As shown in Figs. 9 and 10, the rails are fastened to the baseplate by means of clips and stiff rail pads (RP). The acoustically important component is the baseplate pad (BP), which separates the rail from the bridge structure. The assembly is fixed to the bridge by means of anchor bolts and coil springs. Optimisation trials, performed on the same test rig as shown in Fig. 2, yielded that when using this type of rail fastening, the dynamic insulation provided by the baseplate pad is influenced by this fixture only at frequencies of above approx. 630 Hz (for more details see [8]).

Noise measurements
Before and after the installation of the resilient rail fastenings, measurements were taken at identical locations during the passage of various types of light rail vehicles (LRVs) on tracks 3 and 4 of the four-track line. Structure-borne noise of the bridge structure, as well as the airborne noise near the bridge and in the surrounding area, were measured (the complete measurements and their respective results are given in [9]). Measurements of airborne noise, taken at the locations shown in the table below, show the effectiveness of the changes.

Measurement location	Measurement distance from axis of track 4	Measurement height above top of rail	Measurement height above ground
Under the bridge	0 m	-1 m	7.7 m
In front of the house of the complainant (0.5 m in front of an open window on the first floor)	27 m	-3 m	6.0 m

Airborne noise measurement locations

It should be noted, that the rails were not replaced in the course of the reconstruction. From this, it can be concluded that the condition of the rail surface (a most important source of noise creation) after modification did not differ significantly from that of before.

Results
Typical results of the airborne noise measurements for the measurement location under the bridge, which were obtained both before and after the installation of the resilient rail fastenings, are shown in Fig. 11, whereas those for the location in front of the house of the complainant are shown in Fig. 12. The data, which were collected during the passage of type ET 477 LRVs on track 4 (located close to the house of the complainant), are displayed as 1/3-octave-band spectra of the noise level. In both cases, the data represent averages taken from multiple train passages.

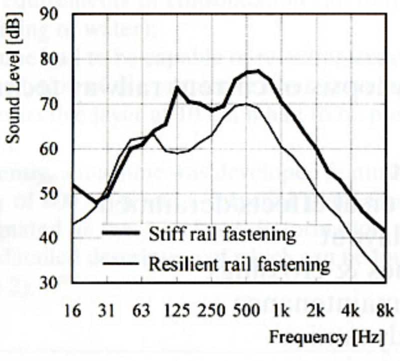

Fig. 11: 1/3-octave-band spectra of the noise measured under the bridge during the passage of LRVs, type ET 477

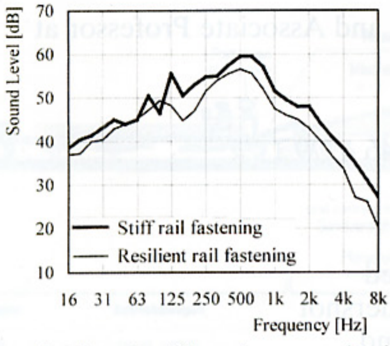

Fig. 12: 1/3-octave-band spectra of the noise measured in front of the house of the complainant during the passage of LRVs, type ET 477

As can be observed from Fig. 11, directly under the bridge, the noise emission in the frequency range above 80 Hz was reduced by an order of magnitude of 10 dB. At the house of the complainant, located about 27 m to the side of the railway line (where the influence of the rolling noise is dominant), the noise reduction achieved within the same frequency range was between 5 and 6 dB (Fig. 12).

In order to determine the level differences for the various types of LRV which passed on tracks 3 and 4, the average 1/3-octave-band spectra of the measurements obtained under the bridge, both before and after the installation of the resilient rail fastenings, found in [9] were used. From this data, an average 1/3-octave-band level difference for all the types of LRV was calculated. The results obtained in this respect are shown in Fig. 13, graphed separately for tracks 3 and 4.

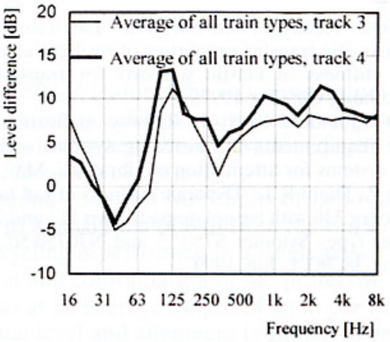

Fig. 13: 1/3-octave-band-level difference measured under the bridge during the passage of LRVs, both before and after installation of the resilient rail fastenings

Fig. 14 shows the overall average of the level differences, including the upper and lower scatter boundaries, for all train passages on tracks 3 and 4.

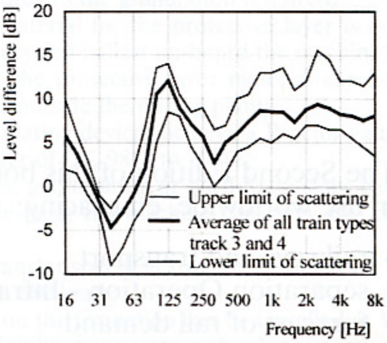

Fig. 14: 1/3-octave-band-level difference measured under the bridge during the passage of LRVs, both before and after installation of the resilient rail fastenings

From Figs. 13 and 14 it can be observed that the natural frequency of the vibration system of vehicle/superstructure/bridge is approx. $f_0 \approx 40$ Hz (notice the negative level difference).

The gradient of the level difference in the frequency range above approx. 125 Hz does not continue with 40 dB/decade, as is the case with a resilient support on an infinitely terminating impedance; rather, it fluctuates around a constant value of about 8 dB. This illustrates the influence of the finite input impedance of the "dynamically soft" construction of the steel bridge (see, for example, [6]).

Finally, with respect to Fig. 14, it is worth noting that the range of scatter with respect to the total average of the level differences for all train passages, both before and after the installation of the resilient rail fastenings, is exceptionally small, especially when considering that the various types of LRVs used in Berlin differ greatly in design.

Conclusions

As shown in this article, the use of the resilient rail fastening system with "dynamically soft" baseplate pads reduced the noise emission of the auxiliary steel railway bridge in Berlin by approx. 8-10 dB in the frequency range above 125 Hz. This, in turn, led to a reduction in the level of noise directly in front of the house of the complainant of approx. 6 dB(A), so that no further complaints were made.

It must be stressed that the low ratio of dynamic to static stiffness of the baseplate pad is essential for the effectiveness of a noise mitigation measure, especially when implemented on a steel bridge, the bridge deck of which features a low input impedance as opposed to that of a concrete bridge or a tunnel floor (see, for example, [10], [11]).

References

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