RIVAS – Mitigation Measures on Vehicles (WP5); Experimental Analysis of SBB Ground Vibration Measurements and Vehicle Data

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Summary. The goal of the EU project RIVAS (Railway Induced Vibration Abatement Solutions) is to take ground-borne vibration mitigation on open tracks an essential step forward. In this context, measures to be taken on the rolling stock are investigated in Work Package 5 (WP5). The influence of rolling stock was tested in comprehensive ground vibration measurements of regular trains carried out in the SBB railway network.

The vibration analyses were correlated with vehicle-specific data and out-of-roundness measurements. The analyses show that of all railway vehicle parameters, wheel condition and unsprung mass have the major influence on vibration emissions. These analyses result in vibration mitigation measures on the rolling stock with the goal of sustainably improving wheel condition and reducing unsprung mass. These measures have the potential of considerably reducing vibrations and will be further developed.

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1 RIVAS – Railway Induced Vibration Abatement Solutions

In 2011, the EU started a research and development project within the scope of the 7th Research Framework Program referred to as RIVAS. The goal of the three-year research project, which is financially supported by the EU (5 million euro of subsidies), is the development of innovative measures to significantly reduce the negative impacts of ground-borne vibration from railway traffic on the environment. At the same time it should maintain the competitiveness of European railways. The main focus of the project is on the freight traffic, open lines and existing tracks. Not only measures made on the infrastructure and on the propagation path (work packages

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3 and 4) are investigated but also measures on the rolling stock (work packages 2 and 5). The RIVAS project does not only test how to avoid symptoms on rolling stock (turning or replacing wheels) but is also searching for measures for existing and new vehicles.

After a state-of-the-art report regarding measures on rolling stock, the essential rolling stock parameters and their influence on ground vibration were investigated in detail. On the one hand the influence of rolling stock parameters was studied on the basis of numerical simulations, and on the other hand based on comprehensive ground vibration measurements in Switzerland, to make statistically reliable statements on a wide range of vehicles. This summary is concentrated on the results of the ground vibration measurements in Switzerland.

2 Overview of Measurements and Analyses

Ground vibration measurements on open track (distance 2 m and 8 m to the track axis) were made at three wheel load checkpoints (WLC) of the SBB for several days. Several thousand regular trains were recorded.

Together with the detailed WLC data provided for each vehicle (type, vehicle number, speed, wheel load), the measurements resulted in an extensive database for the statistical vibration emission analysis of the rolling stock used on the SBB railway network. All in all, approx. 1,000 bogies of locomotives and train sets, approximately 5,000 bogies of passenger coaches and approximately 10,000 freight wagon bogies were statistically analysed for vibrations.

The goal of this analysis was the quantification of vibration differences within and between the vehicle categories and to make a correlation with the rolling stock parameters. On the basis of these findings, the characteristics of low-vibration rolling stock can be determined.

The evaluations of the vibration measurements show that there are significant differences. Not only the average values per vehicle category differ, but also the variance differs (see Fig. 1 for the measuring point in Thun, stiff soil).

In Thun, vibration produced by Intercity trains as well as local trains and freight traffic (Lötschberg axis) with different freight locomotives / freight wagons were recorded. The minimum value, maximum value, median value and 95% value shown in Fig. 1 clearly indicate the great difference between the vibration emissions of different vehicle categories, and the different variance of the values for each vehicle category. While a high median value indicates the high vibrations generally caused by a vehicle type, high variance is a sign for different wheel conditions.

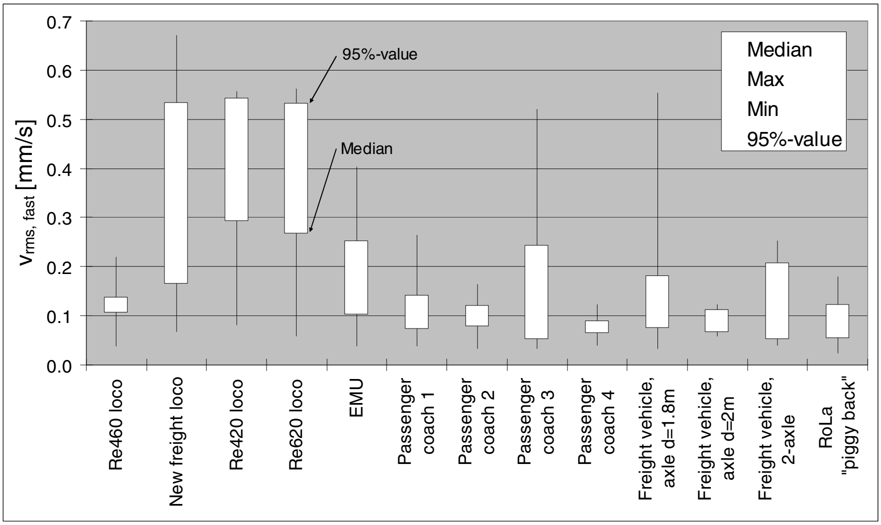

Fig. 1. Statistical values for ground vibrations v rms,fast in Thun at a distance of 8 m from the track, vehicle speed 60-70 km/h

The freight locomotives standing out on Fig. 1 are discussed in detail in the following chapter. Passenger trains usually are faster than freight trains. In such situations, the difference between the vibration values for passenger trains and freight trains are less obvious, because the vibration is increasing with speed.

3 Vibrations of Freight Locomotives

The measured freight trains in Switzerland show that freight locomotives rather than freight wagons are responsible for maximum vibrations. Therefore, possible measures should primarily be taken on freight locomotives of the older generation (Re420, Re620) as well as the newer generation to efficiently and effectively reduce ground vibrations.

The evaluations of the vibration measurements show that older freight locomotives with cast iron brake blocks and tyred spoke wheels such as in Re420 and Re620 cause the strongest vibrations. These are caused by spalling in the tread and by out-of-roundness of the wheel, which are accentuated by capacity bottlenecks for wheel maintenance in combination with higher unsprung mass.

The properties of the newer generation freight locomotives (compared to the SBB Re460 Intercity locomotive which was originally also used for freight traffic), that are decisive for vibrations are discussed on the basis of the example of a new generation freight locomotive that is very common for the standard Swiss railway network. The main difference between Re460 and the new generation freight locomotive is that the latter has a nose-suspension drive (drive mass directly coupled to the wheelset mass) and larger wheels with diameter 1250 mm (Re460 has diameter 1100 mm wheels) as well as disc brakes (Re460 has weak unilaterally acting sintered block brakes combined with permanent magnetic track brakes). Moreover, the Re460 has passively controlled radial wheelset steering. Tests were also carried out for the new generation freight locomotive regarding the introduction of radial steering. However, due to financial reasons, increased maintenance, and problems with approvals throughout Europe, radial steering was not introduced. Moreover, for a maximum speed of 140 km/h, the fully suspended drive (as used for BR 146 of the German Railway and Re460) was ruled out for financial reasons.

A direct comparison between Re460 and the new generation freight locomotive with regard to vibrations could be made at the WLC measuring point in Thun.

156 Re460 bogies and 72 new generation freight locomotive bogies were statistically evaluated in the frequency domain within the speed range from 60 to 70 km/h (Fig. 2).

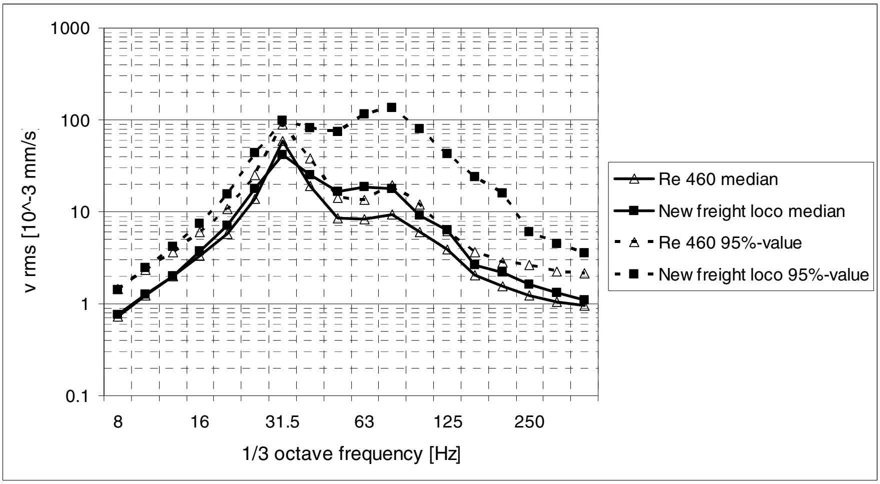

Fig. 2. Third-octave band spectra of SBB Re460 and new generation freight locomotive in Thun at a distance of 8 m from the track, vehicle speed 60-70 km/h

The comparison of the median curves shows significant differences between the new generation freight locomotive and Re460 in particular in the 50-80 Hz third-octave bands. Apart from that, the curves are similar despite the different bogie design. The main cause for these differences regarding the median values are possibly due to the different drive bearings and/or the huge differences in unsprung mass that are more than a factor two. The difference in 95 % values is much more significant. The difference between Re460 and the new generation freight locomotive in the 63 Hz third-octave band is almost a factor of ten. The only possible cause for the significant variance of vibrations within one vehicle type lies in the different condition of the wheels, because any other vibration-relevant properties of the vehicle such as unsprung mass, primary suspension stiffness etc. hardly change. In other words, the condition of the wheels is the dominant parameter for vibrations. There are various influences on the condition of the wheels. At least the following five aspects are decisive for this case when comparing Re460 and new generation freight locomotives:

1. Operation / railway: Freight locomotives operating in international freight traffic pull high loads over the Alps. Due to high adhesion utilisation, narrow curves, steep ramps, track switches and track conditions that are more severe compared to those of high-speed rail lines, freight locomotive wheels are subjected to high loads.
2. Unsprung mass: New generation freight locomotives with nose-suspension drive have high unsprung mass which results in high dynamic wheel-rail forces and lower natural frequencies in the coupled dynamic wheelset–track system. This may have negative impacts on the wheel condition.
3. Radial steering of the wheelsets: The wheelsets of freight locomotives have no radial steering which may result in high lateral loads acting on the wheels in narrow curves.
4. Block brakes: The sintered block brakes used in Re460 generate a very smooth (polished) tread.
5. Wheel material: The Re460 seems to have a well aligned wheel material

Following these results, out-of-roundness measurements were carried out on the wheels of new generation freight locomotives of two different manufacturers. Fig. 3 shows a typical measurement on the wheel circumference of two wheels on one model of the new generation locomotives.

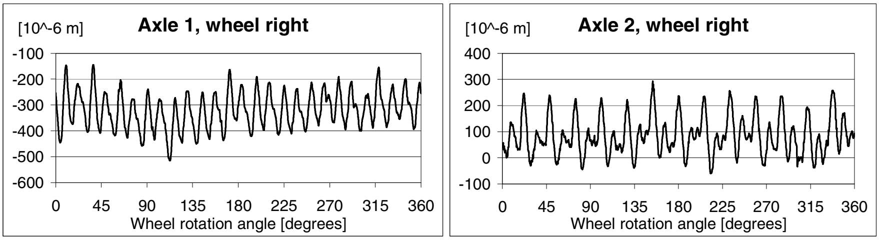

Fig. 3. SBB measurement plot of MARPOSS out-of-roundness measurements on new generation freight locomotive wheels

The diagrams of Fig. 3 show almost harmonic curves and/or polygons with 14 and 28 corners. The 14 corners exactly match the high increase in the 63 Hz third-octave band in Fig. 2 (excitation frequency at 65 km/h). This typical curve and almost equally high vibrations were also measured for the locomotives of the other manufacturer. The causes for this polygonization were investigated within the scope of the RIVAS WP5, Deliverable D 5.4 [13].

4 Vibrations of Freight Wagons

Different types of freight wagons were measured at the WLC measuring point in Thun. The most common bogie for freight wagons is the Y25 bogie with an axle distance of 1.8 m. There are also other bogie types with the same axle distance as well as bogies with an axle distance of 2.0 m including smaller wheels (Y33). The RoLa (rolling road, "piggy-back") has a bogie with four axles (axle distance. 0.70/0.75 m) with very small wheels (diameter 360 mm) and disc brakes. Fig. 4 shows the third-octave band spectra for the bogie categories with an axle distance of 1.8 m (e.g. Y25) and RoLa for the speed range between 60 and 70 km/h.

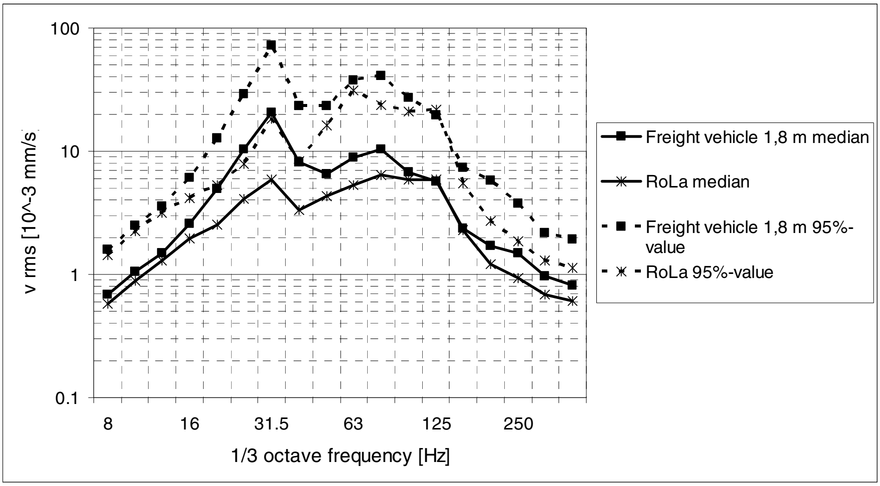

Fig. 4. Third-octave band spectras of RoLa and freight wagon with an axle separation of 1.8 m in Thun at a distance of 8 m from the track, vehicle speed 60-70 km/h

At sleeper passage frequency (31.5 Hz), the RoLa generates ground vibrations that are less by a factor of up to three. Possible causes are: Low unsprung mass, low static axle load, the small wheels of the RoLa leading to an out-of-roundness which has accordingly higher frequencies, or small axle distance and/or 4 axles per bogie. The variance within the two vehicle categories is significant, also for the RoLa where the small wheel diameter results in high wheel-rail contact stress (noise monitoring measurements carried out by Federal Office of Transport resulted in very high noise variances for the RoLa; variances for other freight wagons are lower).

The scattering of wheel out-of-roundness in freight wagons is directly related to the scattering of ground vibration. Since freight wagons have no slip-slide protection, there are many wheel flats that produce high vibration. Measures taken on freight wagons that reduce wheel flats are therefore important to mitigate ground vibrations. Moreover, an improved and more homogenous wheel quality will result in a better condition of the wheels.

5 Vibration Mitigation Measures on Rolling Stock

The evaluations and statistical analyses of the ground vibration of vehicles on the SBB network show that both the condition of the wheels and the unsprung mass have a dominating influence. For the unsprung mass, this was confirmed with numerical simulations in RIVAS WP5, Deliverable D 5.4 [13]. The condition of the wheels can be positively influenced by a design that reduces the wear of tracks and wheels (e.g. radial steering of the wheelsets, low unsprung mass) as well as by condition-based and prompt wheel maintenance.

The measures taken on the rolling stock to reduce vibrations can be classified in three categories: Maintenance / prevention, improvement of existing vehicles and improvement of new vehicles. The following measures taken on the rolling stock to reduce vibrations might be very effective (further measures are provided in [5, 6, 8, 10]):

- Automatic monitoring systems for wheel quality integrated in the network, allowing for condition-based and prompt maintenance.
- Improved interaction of the brake systems, slip-slide protection and wheel material qualities (e.g. special pearlitic-silicon and manganese carbon steels) that avoid wheel flats occurrence and spalling.
- The reduction of unsprung mass, especially for locomotives, will not only reduce vibrations but also the dynamic load on the wheels and tracks (e.g. more expensive hollow-shaft drive instead of nose-suspension drives, where the gearbox mass and most of traction motor mass are unsprung, if also reasonable for lifecycle costs).
- Radial steering of the wheelsets in the bogies (passive or active) to reduce the wear and polygonization of wheels and rails in narrow curves (proved by Re460 in service on the alpine lines for years, see [14].

6 Conclusion

Freight locomotives generate particularly high ground vibrations, mainly related to high unsprung masses and a high degree of out-of-roundness.

Possible measures for the rolling stock that effectively reduce vibrations should be developed and tested at a broader scale. Measures exist that do not require high investment and can be implemented within short time with high efficiency. Other measures exist that may lead to the desired result only in the long run and will require further discussions. Additional drivers for the implementation of measures besides vibration mitigation are, on the one hand, the reduced maintenance efforts for infrastructure and rolling stock due to low dynamic wheel-rail forces, and, on the other hand, the increased comfort demands of the passengers and the improved safety standards.

New rules and standards, provisions of regulatory authorities and requirements regarding track access charges could be an incentive to use low-vibration rolling stock in the future.

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