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Vibration problems at switches

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Abstract

In principle, any rolling load generates vibrations. When passing switches, there is an increase of vibration emission caused by railway traffic. Especially at high speeds and high axle loads, significant vertical forces occur due to dynamic loads at the tips of rigid frogs. Additionally, wheels striking the check rails induce jerky horizontal forces. In switches with movable frogs, compared to types with rigid frogs, the gap at the frog is closed. On the basis of numerous measurements on simple switches with rigid or movable frogs, the differences of the vibrations are investigated and compared with literature references.

The measurements of the selected switches show that, especially within the frequency range of 30 Hz and poor track quality, trains passing a switch generate a significant increase of vibration emissions. Furthermore, the vibration gain between switch and open track decreases with the distance from the switch to the observer.

In one measurement, all regional trains passed a switch with rigid frog with changing directions. Independent from the direction of travelling, these regional trains caused similar vibrations. Movable frogs, however, are suitable for vibration reduction: They amplify the vibration emissions less than switches with rigid frogs.

Keywords: vibration, switch, rigid frog, movable frog, vibration gain

1 Introduction

In civil engineering, vibrations and, in connection, protection against them, have been playing an increasingly important role over the last years. The increasing occurrence of noise immission reducing facilities (e. g. noise barriers or noise control windows) leads to a stronger perception of vibration immissions.

In principle, any rolling load generates vibrations. Vibrations are introduced into the ground and following spread out as vibrations. With the vibration propagation, the frequencies are altered and the vibrations are damped additionally. The vibration excitation including radiation is called emission and the vibration propagation is called transmission. Foundations of buildings are excited to oscillate by vibrations. The vibrations are generally significantly reduced by the effect of coupling. Via the foundations, the walls and ceilings are also activated to oscillate. The self-oscillation behavior leads to a significant gain of vibrations at ceilings. The entry of the vibrations into the structure of buildings and their perception by people is called immission.

Fig. 1 shows the variation of vibration propagation due to rail traffic and the decrease of vibration velocity with increasing distance.

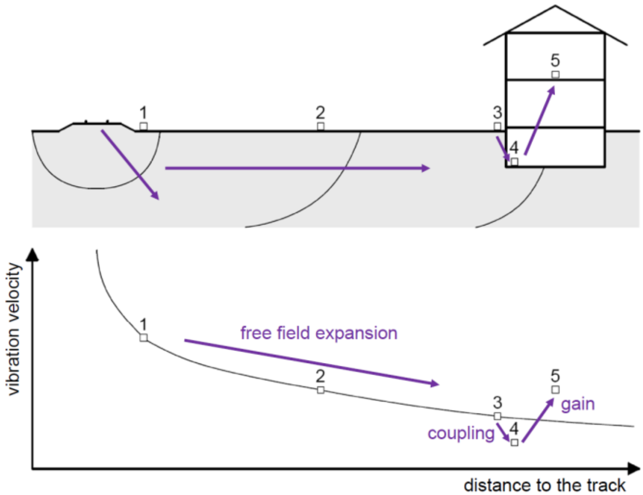

Figure 1. Vibration propagation

In the ideal half-space, two types of waves occur by an excitation at the surface. On one hand there are body waves, which spherically propagate in three dimensions, and on the other hand there are surface waves that mainly propagate horizontally with limited depth. Body waves are divided into primary waves and secondary waves, surface waves are divided into Rayleigh waves and Love waves. Primary waves oscillate in propagation direction. Secondary waves and Love waves oscillate transversely to the propagation direction. Rayleigh waves include both longitudinal and transverse motions. Rayleigh waves, which are very similar to water waves, assume the greatest part of the energy transfer for the vibration propagation in the ground, caused by rail traffic.

Trains in motion generally resemble a line source. When passing switches, there is an increase of vibration emission caused by railway traffic. Especially at high speeds and high axle loads, significant vertical forces occur due to dynamic loads at the tips of rigid frogs. Additionally, wheels striking the check rails induce jerky horizontal forces. These vertical and horizontal forces are similar to a point source.

Vibrations are damped during their propagation. A differentiation can be made between material damping and geometrical damping. The energy loss in the material damping is caused by internal friction. The reduction of the geometric damping is caused by the fact that the introduced energy is distributed across an increasingly larger area.

Table 1 shows the propagation in the ideal half-space for geometric damping. The greatest reduction occurs by body waves at point sources, while surface waves at line sources move unchanged.

Table 1. Propagation in the ideal half-space for geometric damping [1]

Type of wave	Reduction for point sources	Reduction for line sources
Body wave at the surface	$v = v_0 * (\frac{r_0}{r})^2$	$v = v_0 * (\frac{r_0}{r})^1$
Surface wave	$v = v_0 * (\frac{r_0}{r})^{0,5}$	$v = v_0 * (\frac{r_0}{r})^0$

v	vibration velocity in distance to the source
v_0	vibration velocity in reference distance to the source
r_0	reference distance to the source
r	distance to the source
exp.	damping exponent for geometric damping

2 Measurement of vibrations

2.1 Measuring system

For vibration measurements, the measurement instrument MR 2002 by Syscom was used. Frequencies between 1 and 315 Hz with amplitudes between 0.0001 mm/s and 115 mm/s could be measured.

2.2 Measurement points

For the location of measurement points, special emphasis was put on the following points: Switches in the area of flat and open terrain were selected. Embankments and incisions, buildings or other barriers would affect the results and the measurements would be difficult to compare. Furthermore, it had to be considered that only one simple switch is located in the area of the chosen measurement. Switches in the immediate vicinity would affect the results of the measurements.

Only double track lines were selected. The gain factor is calculated by the vibrations from the track with a switch divided by the track without a switch. In addition, it was important that there are no joint clearances in the area of the measurement points. Joint clearances would also affect the results.

2.3 Vibration analysis

For the analysis, only trains in similar velocity ranges were evaluated. For this reason speed normalizations could be avoided. Fig. 2 shows a typical time signal without the influence of a switch. Fig. 3 shows a signal with the influence of a switch. The vibration velocity is plotted in mm/s on the vertical axis and the horizontal axis represents the time in seconds.

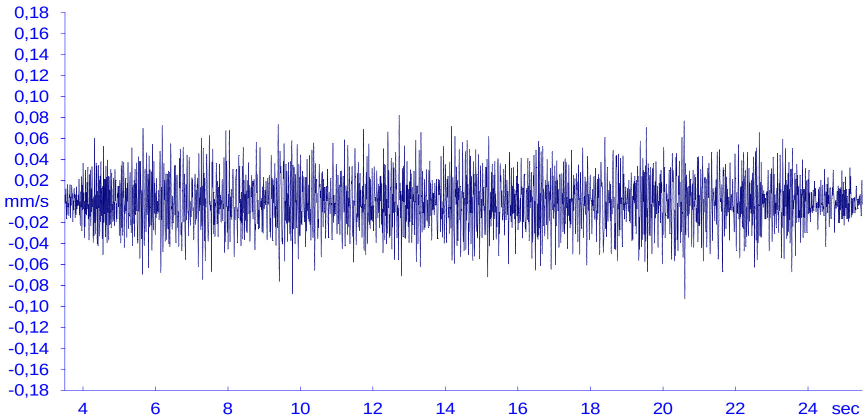

Figure 2. Typical time signal without the influence of a switch

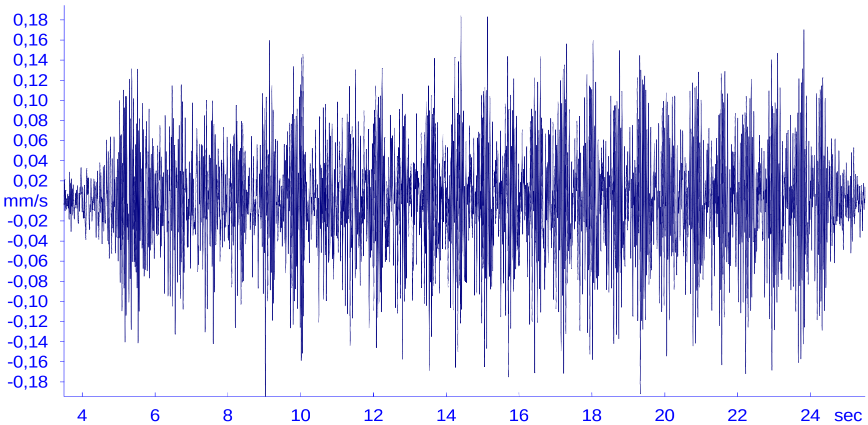

Figure 3. Typical time signal with the influence of a switch

3 Results of measurements

3.1 Results of rigid frogs

In one measurement, all regional trains passed a switch with rigid frog with changing directions. Therefore, a comparison of the vibrations in relation to the direction of travel was possible.

Fig. 4 indicates the functions of regional trains in movement direction towards the start of the switch or towards the end of the switch. These regional trains caused similar vibrations independent from the direction of travelling.

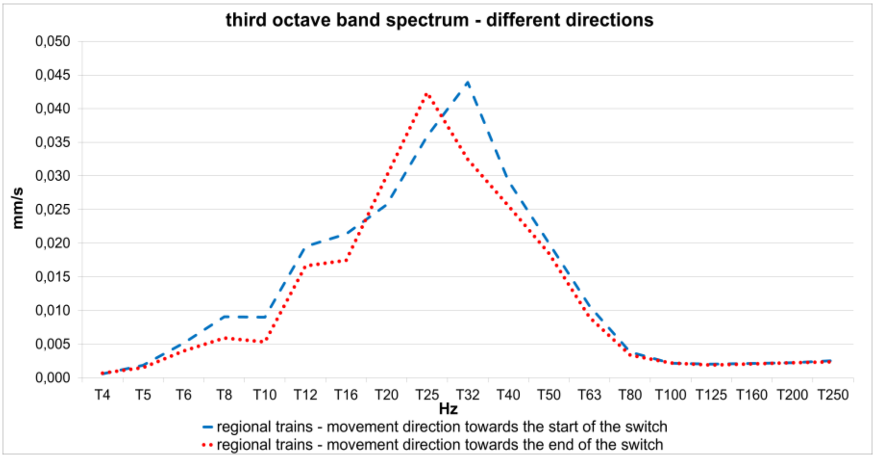

Figure 4. Third octave band spectrum – different directions

Fig. 5 shows a summary of all results for rigid frogs, divided into sections < 25 m, 25 m – 40 m and > 40 m distance at right angles to the track axis.

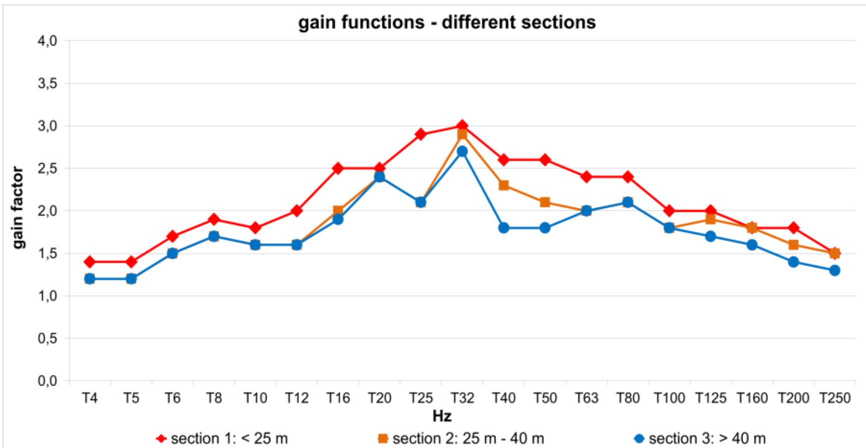

Figure 5. Gain functions – different sections

For the generation of the gain function for the section < 25 m, results of measurements series with good and poor track quality were available. The gain function for this range agrees well with the functions from the literature (see Section 4). The unexpectedly large gains and the small decrease in gain with increasing distance for the sections ≥ 25 m can be traced back to the poor track quality in the area of these measurements.

The measurements of the selected switches show that, especially within the frequency range of 30 Hz and poor track quality, trains passing a switch generate a significant increase of vibration emissions.

3.2 Results of movable frogs

For the measurements with movable frogs, the distance from the switch to the measurement instrument was selected with approximately 16 m. The investigated switches have a spring-mounted sideways movable frog tip.

In one measurement, long-distance trains drove across a switch with a movable frog with different speeds. The rapid trains drove at speeds of approximately 180 km/h and the slower ones passed at approximately 90 km/h. Fig. 6 shows a comparison of the gain function of these long-distance trains. Interestingly, for fast trains the gain function is lower than for slow trains in several third octave band frequencies between 6 Hz and 125 Hz. Only the range of 10 Hz, 12 Hz, 50 Hz and 125 Hz show higher gains for fast trains.

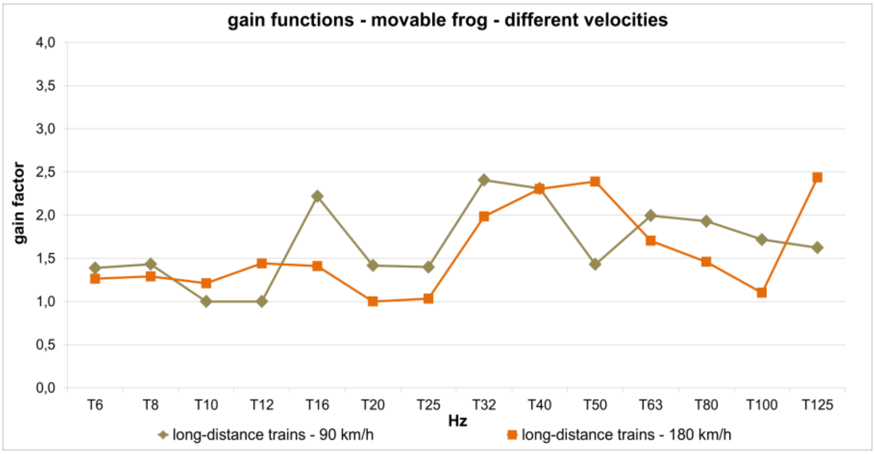

Figure 6. Gain functions – different velocities

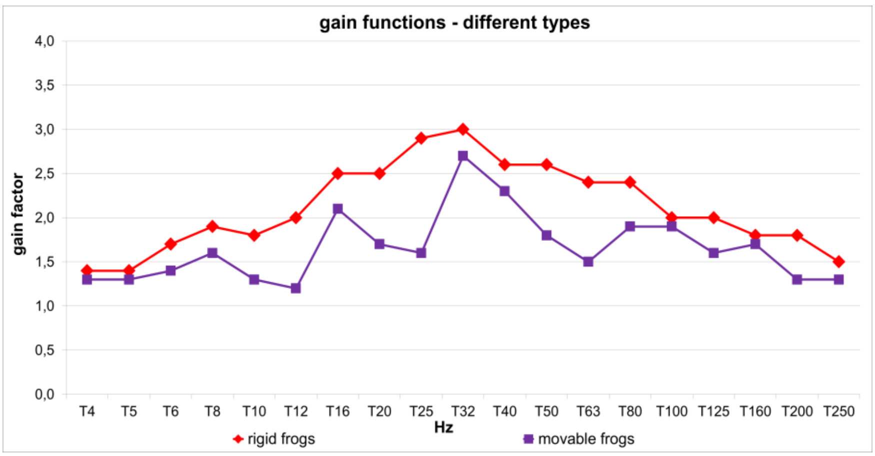

Figure 7. Gain functions – different types

Fig. 7 shows a comparison of the gain function of rigid frogs with movable frogs for distances of approximately 16 m. The gain function with movable frogs is lower than that with rigid frogs in the entire relevant frequency range, with the largest improvements in the third octave band frequencies of 12 Hz, 25 Hz and 63 Hz.

According to the analysis of this work, movable frogs are suitable for vibration reduction. They amplify the vibration emissions less than switches with rigid frogs.

4 Comparison with literature

This chapter provides information on data in the literature of the influence of switches. It should be noted that the data in the literature varies significantly. Furthermore, the influence of switches is sometimes expressed in decibels and not in factors. With Eq. (1) one can convert decibels into factors.

$$a = b^{\frac{x}{20}} \tag{1}$$

a	factor
b	base (value 10 for sound)
x	decibels

Fig. 8 shows several functions from the literature for switches with rigid frogs and distances < 25 m. For comparison, the red function with rhombuses from Fig. 5 is also shown.

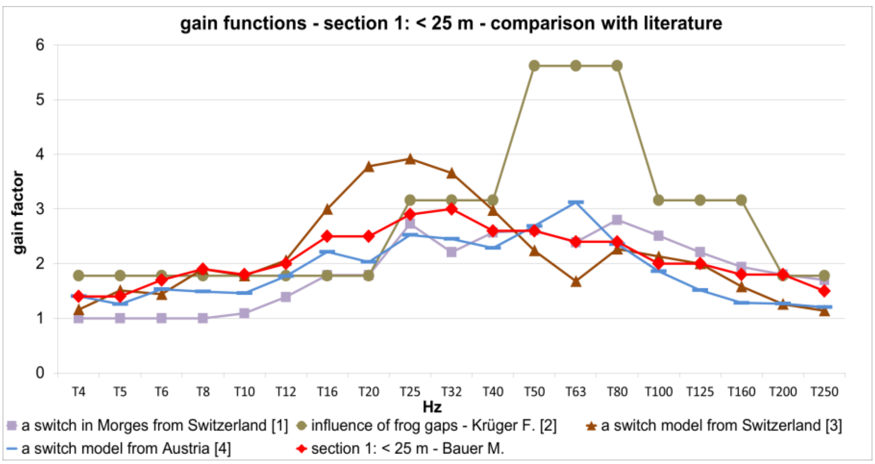

Figure 8. Gain functions – section 1: < 25 m – comparison with literature

The violet function with squares shows the influence of a switch in Morges, Switzerland [1]. This gain function is usually lower than the red one of this investigation. The low factors may be associated with the fact that a short period between measurement and installation of the switch is available and the switch therefore has a very good condition.

The green function with circles describes the influence of frog gaps [2]. The gains are in the upper frequency range above the defined function of this work. The maximum gain occurs at a factor of 5.6 in the range of 60 Hz. High frequencies are rapidly attenuated with increasing distance. Therefore, it can be assumed that this gain function applies directly to the area of the wheel-rail-interaction or, for short distances, to the gap of the switch.

The gain function of a switch model from Switzerland applies to distances of 8 m [3]. This brown function with triangles results from numerous measurements. The results of these individual measurements vary greatly. This brown function is in numerous frequency ranges high which can be attributed to the short distance between switch and measurement instrument.

The blue function with straight lines shows a switch model from Austria [4]. In addition to numerous measurements from switches with rigid frogs, a switch on a slab track was also taken into account for the determination of this function. In a large frequency range, this gain function is lower than the function of this investigation. In the third octave band of 63 Hz the factor is well above the factor for section 1.

5 Conclusion

The measurements of the selected switches show that, especially within the frequency range of 30 Hz and poor track quality, trains passing a switch generate a significant increase of vibration emissions. Movable frogs, however, are suitable for vibration reduction: They amplify the vibration emissions less than switches with rigid frogs.

The investigations carried out allow for a more precise model for vibration predictions with respect to the distance from the affected object and also from the frequency dependence of the vibration gain.

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