Is squeal noise really not to be predetermined?

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Motivation

The main number of studies about curve squealing will take care of getting many different trains measured, to obtain statistically satisfied results. Due to the fact that the wheel treads of these trains differ from each other, this technique leads to the assumption, that squealing noise is of stochastic or chaotic nature.

In a measurement campaign initialised by the Rheinbahn AG, Duesseldorf to validate the efficiency of mounted wheel absorbers to reduce the squeal noise in bends, trams with absorbers were tested against trams without absorbers. These trams ran through the curve several times at different speed. It was observed, that especially those trams without absorbers emitted at a certain location in that curve nearly identical noise levels. This effect lead to a second look on the pass-by levels, which will be described in this paper.

Test section

The test section is a terminal loop in Duesseldorf-Benrath with nearly constant radius of about 23m. Although the rail heads of this test section were really worn, it was possible to carry out the measurements.

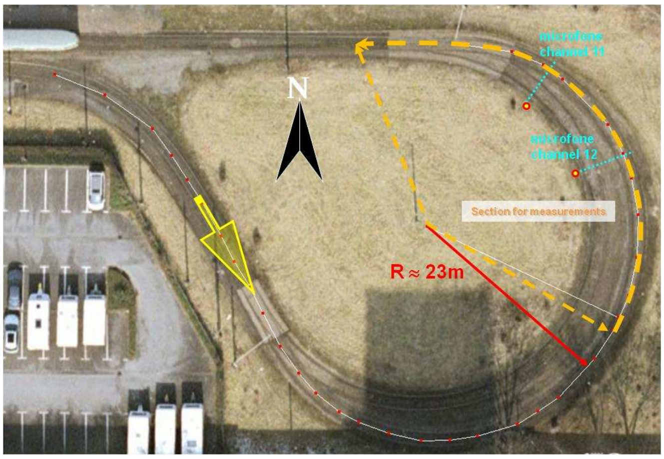

Figure 1: Terminal loop at Duesseldorf-Benrath

At the center of the test section (length about 80m) two microphones were placed, 7.5m beside the track center line, 1.2m above ground in a distance of 10m. The trams passed through this section at speeds of 12km/h up to 19km/h. All measurements were started and finished along the dotted orange line in figure 1 to enable a comparison of the pass-by noise levels.

The measurements were carried out on two different days with different types of trams without wheel absorbers. The modern tram type NF10 with 5 bogies and the older type NF6 with bogies at each end and single axle at the center wagon. Although the design of the trams is different the effect of squeal noise discussed in this paper is the same.

Figure 2: Measured trams NF6 (left) and NF10 (right)

Time level and spectra

In fig. 3 some noise levels of passing trams at different speed are plotted. For a better comparison they are stretched to the same length. High noise levels are representing squeal noise.

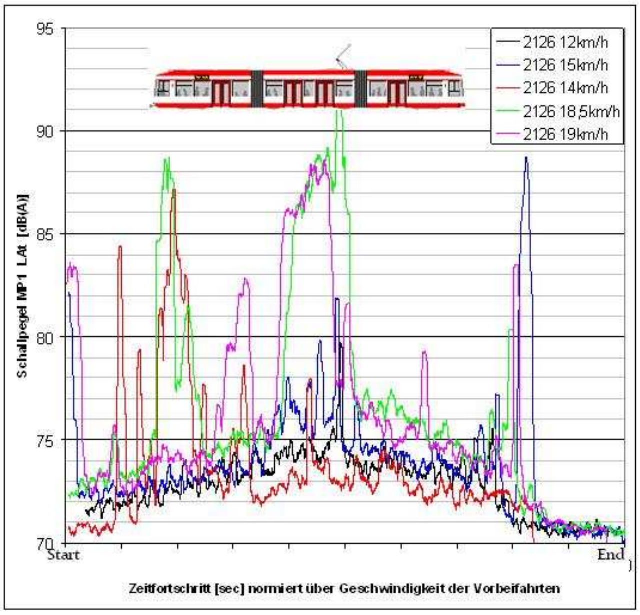

Figure 3: Pass-by noise levels of the same tram; type NF6

The following analysis is to look at the time-spectral-level (Campbell-diagram). This will give additional information about the frequency mixture over time (fig.4).

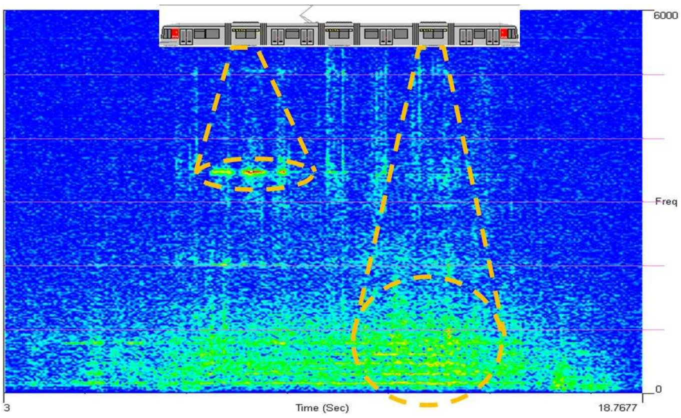

Figure 4: Campbell-diagram of a NF10 pass-by

From the Campbell-diagram it can be taken easily, that the consistence of the higher noise levels is different, one bogie is creating squeal noise (left orange area) with a sharp frequency band at 3.5kHz while the other bogie is emitting flanging noise, which has a broad band character.

Time-level to Way-level transformation

This phenomenon was found every time this tram passed the test section. Hence it was necessary to investigate, if it is really at the same location along the test section.

Because the trams had a constant speed during the pass-by and the measurements started at the same point it was possible to transform the time level of the pass-by noise into a way level by using the equation (1)

$$V_{Tram} = \frac{length_{test\ section}}{duration} \left[\frac{m}{s}\right] \qquad (1)$$

can be converted to equation (2)

$$track\ position\ (t) = V_{Tram} \times time \qquad (2)$$

With equation (2) the time level can be transformed to a noise level along the way of the test section.

With this transformation it is possible to have all measurements plotted in one diagram although the trams had different speed.

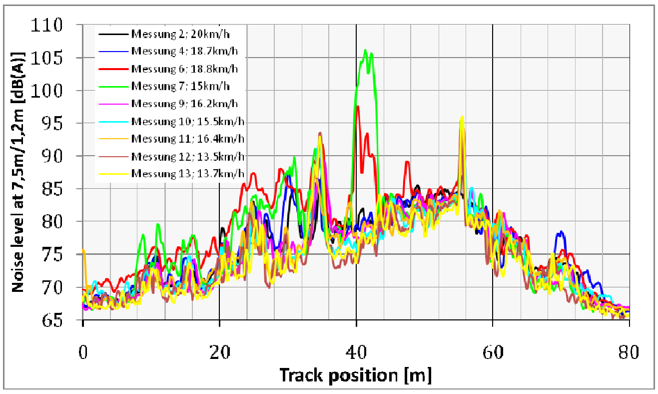

Figure 5: Way level of tram 2020 (NF10) at microphone11

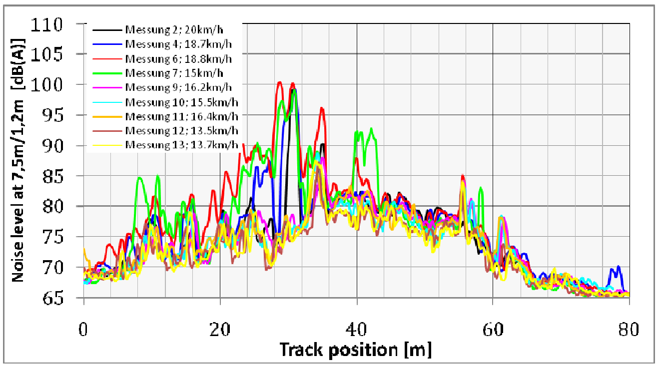

Figure 6: Way level of tram 2020 (NF10) at microphone12

From the diagrams fig.5 and fig.6 can be taken, that squeal noise and/or flanging noise will occur always at the same position at the curve.

More information can be obtained by subtracting the level of mic11 from mic12. as it is shown in fig.7. This difference in noise level is describing the vicinity of the tram to each microphone by plus or minus values as they are marked in fig.7. On the other hand it can be derived from fig.7, that squealing or flanging noise will not occur in the center of the tram. Mainly this will happen at the beginning or at the end of the tram presented by a high deviation of the main values. In the case of the NF10 this means, that the first and the last bogie tend to emit more squealing noise.

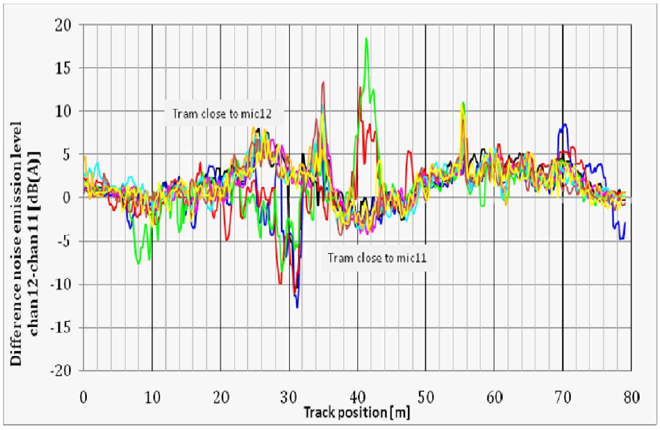

Figure 7: Difference of the noise level of mic12 – mic11

Trial to estimate the time function of the stip-slick movement from the noise spectra

Up to this point is is shown, that the high noise levels given by squealing or flanging noise will occur at the certain track lengths along the curve. It was necessary to analyse the frequency contents during these sections by a deeper investigation.

Again the pass-by of tram 2020 (NF10) as it is shown in fig.4 is taken. In figure 8 the time level of this pass-by is shown.

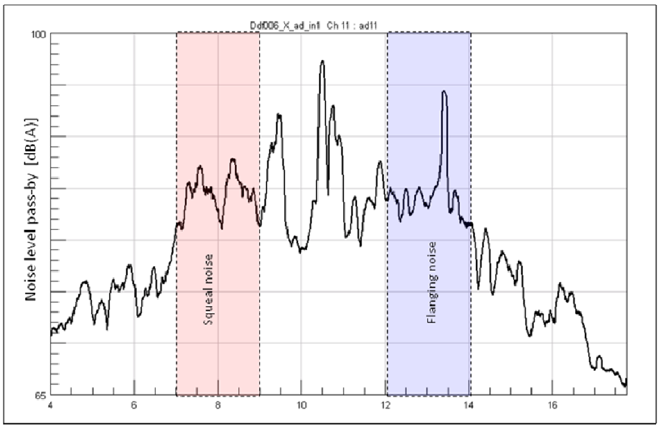

Figure 8: Noise level of the pass-by tram 2020 (NF10)

The FFT-analysis of two time slices of 2 seconds as they are marked in fig.4. The red area is representing the squeal noise while the blue area stands for flanging noise.

In the first step the multiple resonances (groups I and II) below 2kHz are neglected. The resonance frequencies signed by numbers 1 – 6 are representing the resonance frequencies of the wheel. The squeal noise is built by 2 main resonances (1 and 6) while the flanging noise is represented by all 6 resonance frequencies.

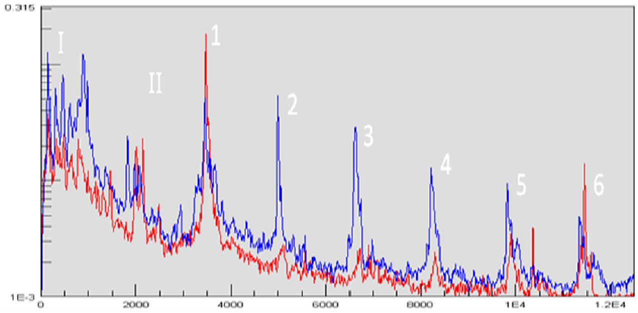

Figure 9: FFT-analysis of 2 time slices of a pass-by noise

A direct comparison of the resonance frequencies will give, that squeal noise is generated at slightly higher frequencies.

With this result it was tried out to estimate the movement of the wheel by an Inverse-Fourier-Transformation (IFT) and following by this, to estimate the stip-slick-movement.

The first approach with IFT led to irregular time signals, so a second attempt was made by including resonance frequencies out of the groups I and II. Because of the high density of the resonance frequencies in these two groups, it is not possible to pick these values directly from fig 9. Hence they were calculated by using the fact, that the resonance frequencies 1 – 6 are equally spaced.

With this new set up time signals for squealing and flanging were calculated (thick lines in figures 10 and 11). Thin lines are calculated by differentiating the equivalent time depending transition from static friction (stip) to gliding friction (slip).

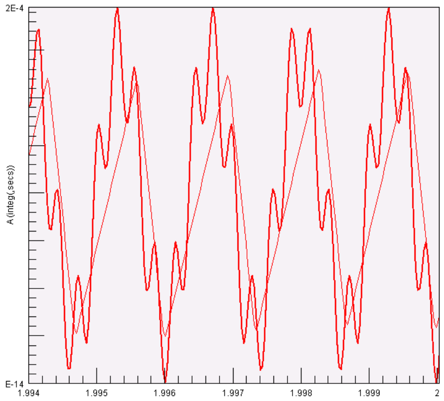

Figure 10: Estimated signal of stip-slick movement during squealing noise

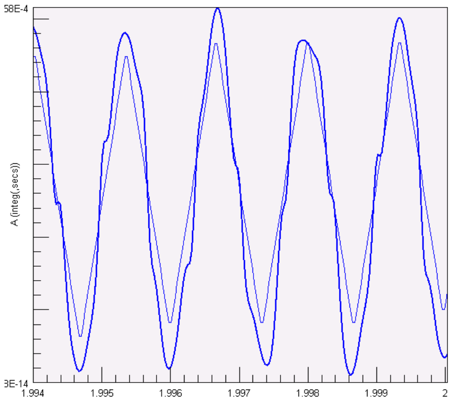

Figure 11: Estimated signal of stip-slick movement during flanging noise

The time signal of the squeal is very rough compared to the flanging signal. This may be due to the fact, that only two main resonances were calculated within the IFT. Higher frequencies were lost because of the limited frequency range during the measurements.

The two equivalent time signal of squeal and flanging (thin lines in fig.10 and fig.11) are compared in figure 12.

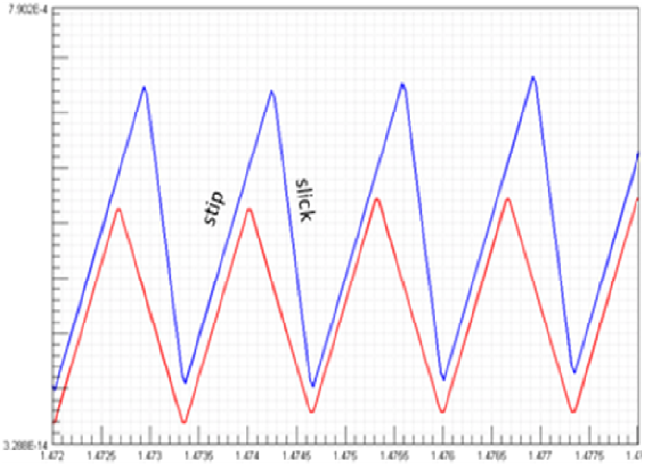

Figure 12: Time signal of the equivalent squeal and flanging noise

From fig.12 can be derived, that flanging will lead to longer duration of the stip = static friction, which will lead to a higher tension. The following slip-movement = gliding friction lasts for a shorter time. The result can be seen as a saw tooth signal, which sounds sharper to the ear.

Squeal has got the same gradient over time during the stip-movement, but it will last shorter and hence leads to lower tension forces. The time gradient of the slick movement is less steep than those of the flanging.

This result of different time gradients of the slip movement is described by the theory of sliding friction. As the static friction is described by a constant coefficient, the sliding friction is depending on the velocity of the sliding body. With higher velocity the coefficient of the sliding friction decreases.

The time gradient of the slick movements for both time signal in fig.12 are to be seen as an averaged value over this duration. While the flanging is starting on a higher tension level, this will lead to higher velocities during the sliding movement and hence to a steeper gradient.

Conclusion

During measurements to prove the efficiency of wheel absorbers a steady emission of squeal and flanging noise at certain location within the test track was observed. These locations were depending on the trams but not on the speed. With a transformation from time level to way level this assumption was testified.

This result and the effect of squealing noise and flanging noise at different locations, it was tried out to estimate the stip-slick movement of the wheels by using the IFT of the resonance frequencies.

Although this is the first attempt to recalculate this movement of the wheels and the results are not optimal at the moment, it is possible to describe the differences of the sliding factor during the slick movement.

Additionally it is to be mentioned, that the repeated emission of squealing noise by passing a curve at the same locations of the same tram, the assumption squeal noise is completely of stochastic nature seems to be false. The main problem is still remaining, to observe all parameters which will lead to squeal noise.

References

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