PRELIMINARY MEASUREMENTS FOR CHARACTERIZATION AND LOCATING OF CURVE SQUEALING

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ABSTRACT

To investigate the problem of squealing trains, it is as a first step necessary to individuate the source of the noise.

First measurements have been done to detect the possible squealing coach and observe the influence of weather conditions. From the large number of acquired records it has been possible to identify squealing as a narrowband noise and therefore the Doppler effect has been used to trace its source approximately. Further measurements should enable to exactly locate the source along the train and also indicate if there is a particular segment of the railway line where squealing occurs.

No direct correlation between weather conditions and the occurrence of squealing noise could be established.

Introduction

Swiss railways have to deal with difficult topography, since a lot of mountains and hills run through Switzerland. As a consequence when rail tracks were built, railway constructors have chosen to design railway lines with small radii of curvature. It is a well observed phenomenon that in curves with small radii noise pollution is higher than in a straight line. The vicinity of railway lines gets more and more inhabited, so the population is exposed to this noise pollution.

To preserve people from noise pollution the government has introduced new laws concerning noise emission. As a consequence the Swiss Federal Railways have launched a cooperation with the Center of Mechanics from the Swiss Federal Institute of Technology in Zurich for analysing and resolving one such noise, namely, curve squealing.

Occurrence of Curve Squealing

Curve squealing occurs principally in curves with small radii. The value of the critical radius depends on the gauge and the distance between the wheelsets mainly, but not only these parameters influence the occurrence of curve squealing. All parameters concerning the position and the motion of the wheelset on the rail and the forces acting between wheel and rail, like train speed, torsional stiffness of the suspension, rail profile, wheel profile, wheel geometry and weather conditions are expected to be essential.[1]
To ascertain the essential parameters is the first step in understanding this complex phenomenon.

Procedure

The goal is to get an economically feasible solution for this problem. In order to accomplish this goal the below-mentioned steps will be followed.
Observation of the phenomenon and studies of preceding publications provides the basic knowledge of involved parameters and the way they interact in causing curve squealing. After these preliminary studies curve squealing will be modelled with a combination of different tools such as finite element methods, multibody modelling and others. Once a good agreement between simulations and measurements has been obtained, modifications will be applied on the computer models to study the influence of each parameter.
Simulated variations giving promising results concerning curve squealing will be verified by full-scale tests.

Field Measurements

First observations have been made to study the influence of weather conditions on curve squealing. Therefore long-term measurements have been done. During seven weeks meteorological parameters such as air temperature, rail temperature and air humidity have been recorded.
At the same time two microphones (Bruel and Kjaer 4198) were applied on both sides of the track and 3-axis-accelerometers were attached at the bottom of each rail (Bruel and Kjear 4504). For train and speed detection rail contacts were installed. All acquired signals were filtered by a band pass filter with a range of 0.1 Hz to 22.4 kHz and afterwards digitized with a sampling rate of 60 kHz.
This equipment was designed to verify whether the measuring point was suitable for long-term testing and for intensive measurements and to determine how often curve squealing occurred there.
Further questions were:

- Does the occurrence of curve squealing depend on meteorological parameters?
- Is it possible to detect on which side curve squealing occurs?
- Are there any other regularities?

The measurement equipment was designed for fully automatic running. No permanent support activities were necessary. Only periodic controls and data back up had to be done.

Statistical data:

- total number of data records: 3085
- total number of analyzed data for global overview: 1371
- number of train sets for detailed data analysis: 4
- → corresponding number of total train passages: 524
- air temperature range: - 6 .. 30 °C
- air humidity range: 25 .. 100 %

Technical data:

- gauge: 1435 mm
- curve radius: 199.2 m
- measured train speed at the noise measurement point: 5 m/s up to 12.5 m/s
- cant: 110 mm
- train type: suburban train (power car serie 560, two coaches and driving trailer (figure 1)
- location: at the end of an unmanned stopping point

The measurements have been done during four weeks in winter 2000/2001 with snow fall, rain, fog and sunshine and in the dry spring of 2001.

3085 train passages have been recorded. In order to avoid break noise only accelerating trains have been analyzed (1371 train passages).
Rail traffic was quite homogeneous. Mainly four types of suburban trains and a few freight trains crossed the automatic measurement plant. The composition of each passing train was known. As a consequence it has been possible to select one of the train types (see figure 1).
Because the trains of this type were the loudest and at the same time the most frequently passing trains, four representative trains of this type were selected for further signal investigation, corresponding to 524 train passages.
Also single statistics for each power car and its coaches could be done.

Figure 1: Analyzed suburban train

Signal Analysis

First all records out of the 524 evaluated train passages have been listened to and each train passage has been classified on the basis whether squealing had occurred or not.
These data were introduced in a plot containing all meteorological data (air temperature at 3 meter over ground, air temperature close to the rail, rail temperature, air humidity and water film on a reference sensor near the rail to detect rain).
The intuitive expectation has been to obtain a clear dependence of squealing on humidity and rainfall, but the recorded data didn't validate these expectations. Moreover some trains squealed during a period while others didn't. This meant that different trains, although consisting of the same type of vehicles, differed in a relevant way from each other.
Obtaining these differences will be an important aim for further measurements.
Also the acoustic and vibration signals have been recorded. The records of acoustic time signals and accelerometer measurements of each squealing train have been compared to each other to detect similarity. In a second level the fast Fourier transformed (FFT) signals have been analyzed to detect prominent characteristics. The resolution amounted to 8 Hz, with a shifting time window of 1/8 second. The resulting time dependent frequency spectra were plotted to study frequencies, their

characteristics and occurrence on the single signal detector, like microphones and accelerometers (Fig. 2).

With these analyses, narrow banded squealing frequencies could be detected. Moreover squealing was analyzed to check out if the frequency changes or remains the same.

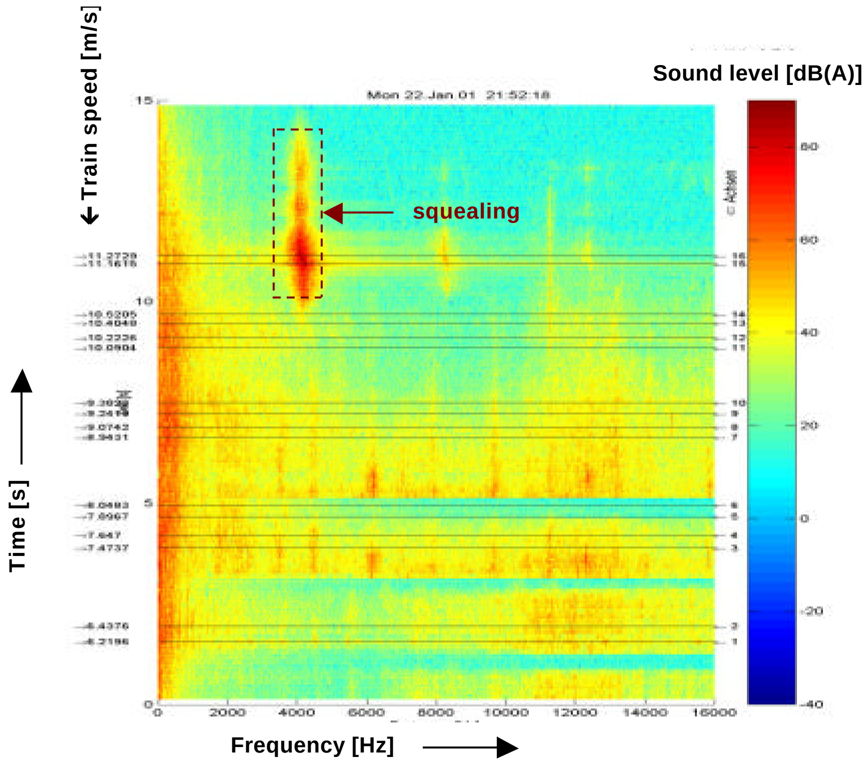


Figure 2: Overview of a time dependent FFT-plot. Horizontal: frequencies, vertical: time. Horizontal line: axle passing in front of the microphone, numbered on the right side, train speed on the left side.

The analyses show that the considered trains commonly squealed at a frequency in the range from 4000 to 4700 Hz. As a consequence of the Doppler effect, detected squealing noise changes its frequency depending on the speed of the sound source relative to the microphones. Figure 3 shows the frequency variation in dependence of time and microphone location for two microphones along the rail track for a uniformly accelerating train.

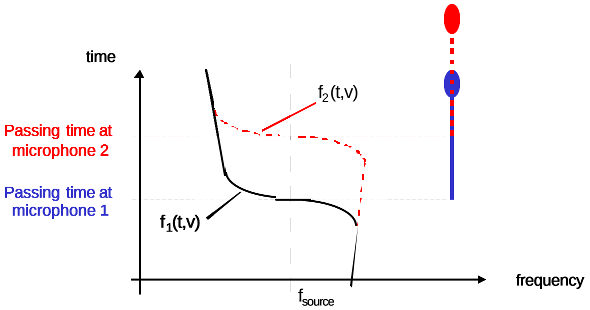
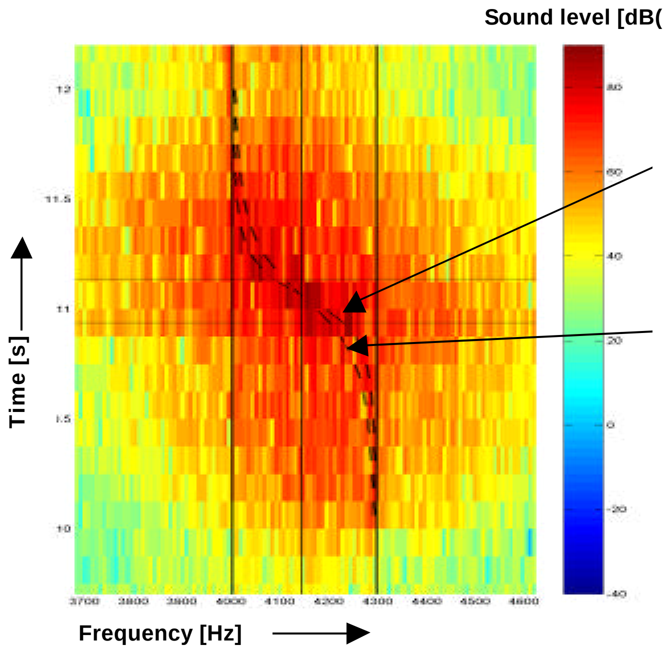


Figure 3: Doppler frequency versus time for a uniformly accelerating train and two microphones at different locations along the railway track (schematic)

The occurrence of the frequency shift is the indicator of a source passing close by the microphone. This phenomenon allows to locate relative to the train position a passing squealing source, whenever passing close to the microphone (figure 3). If the whole frequency peak shifts, this means that only one source exists and it is passing by the microphone. For sound coming from the closer side of the track the Doppler shift would be faster, otherwise slower. The corresponding curves are plotted in figure 4 (detail of figure 2).

The resolution is not good enough to get reliable results concerning the side of the source, but shows that the source has the same speed as the train and is in a realistic distance within the train/rail system.

The measured frequency doesn't depend on the source location, but only on the relative speed with respect to the microphones. Two microphones located along a railway track will nearly measure the same frequency and frequency increments as long as the frequency shift has not begun for any of the microphones. The frequency shift will begin at each microphone at a different time. After the frequency shift has terminated for both microphones, each of them will measure approximately the same frequencies and frequency decrement again.



Theoretical frequency shift for a source at the rail closer to the microphone

Theoretical frequency shift for a source at the rail farther away from the microphone

Figure 4: Measured frequency shift from 4300 to 4000 Hz, with curves for the theoretical Doppler shifts calculated for sources at the closer and the farther rail, respectively

Since the measuring point was located at the end of a stopping point, train speed varied a lot, as train acceleration varied, therefore the relative velocity of the sound source is not directly known. Thus neither the frequency of the source nor the correct variation of the signal frequency can be calculated without information about the relative speed of the noise source.

An estimation of the frequency before and after the passage of the source based on the frequency plots like in figure 2 leads to the approximate squealing frequency and source speed. Figure 4 shows a part of the time dependent FFT-plot of figure 2. The estimated frequencies were 4300 Hz and 4000 Hz, corresponding to a train speed of 11.9 m/s and a source of 4145 Hz. Small differences in frequencies have a drastic influence on the results. For example if one considers a shift from 4280 Hz to 4000 Hz, it corresponds to a train speed of 11.15 m/s and a squeal frequency at 4135 Hz.

The comparison between the value of the train speed determinated approximately with the Doppler effect and the one measured with two wheel detectors (the value on the left side of figure 2) indicates that the source moves at the same speed as the train.

The wheel detectors were also used for determination of the time when wheel sets are closest to the microphone, plotted as horizontal line in the FFT-plots (e.g. figure 2), with wheel set number on the right side.

It happened that most of squealing occurred when the source was close to the microphone. As a consequence it could be observed, that curve squealing is a phenomenon moving with the same speed of the train and localized in the area of the bogie and the rail.

Outlook

The applied measurements allowed the source position detection with the precision of a bogie distance, but there was no means to determine which component in the area of the bogie was emitting the squealing noise. This means, it was not possible to state to what extent the rail and the wheels contributed to the squeal emission. Further investigations have to be done for this purpose.

The use of only one microphone on each side of the track allowed the analysis of only a short part of the train. At a train-speed of about 10 m/s and a squealing time of about 4 seconds only forty meters of the train can be scanned, not enough for a train with a length of nearly 100 m.
By using more microphones it is possible to monitor a longer distance and check whether the sources keep the position relative to the train. This would be observed by the frequency shifts at different times at different locations in dependence of train speed as schematically drawn in figure 3.
By using a large number of microphones, the correct detection of the horizontal position of the noise source and its tracking is possible.

Conclusions

The evaluation of the squealing occurrence in the light of the measurements has not revealed the expected connection between meteorological parameters and curve squealing.
The squealing noise has a train specific character.
By the frequency spectra analysis of the squealing trains it could be seen that curve squealing is a narrow banded noise around 4000 – 4700 Hz. Curve squealing seems to be a very local phenomenon, since in most measurements only one source per train passage could be detected. This was determined by the frequency shifts, due to the Doppler effect.
Further measurements are necessary in order to determine the conditions that exist during curve squealing between rail and wheel.

Acknowledgments

Special acknowledgments to the Swiss Federal Railways (SBB) and Mr. Roland Müller from the SBB for the permission to publish this paper.

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