Curve squeal control of metros and trams

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Introduction

Curve squeal of rail vehicles is generally dominated by pure tone high frequency components. Noise levels up to about 100 dBA can be recorded at 7.5 m from the track, thus exceeding usual rolling noise levels by more than 15–20 dB. Therefore curve squeal turns out to be one of the prime sources of nuisance of urban rolling stock such as metros and trams.

In the past ten years, Vibratec has been involved in different projects dealing with curve squeal noise, including field measurements [1], test rig measurements [2] and modeling [3]. The present paper summarizes main findings and adds unpublished field measurement results.

Excitation mechanisms

Longitudinal creepage due to differential slip is often thought of as a squeal generation mechanism. However, steering by wheel conicity can to some extent balance the path difference of inner and outer wheel. Moreover, independent wheels do prevent differential slip but can still squeal.

Wheel lateral creepage is in fact considered as the prime cause of squeal generation [4, 5]. Most bogies are made of non steerable axles. Consequently, both wheelsets cannot be tangent to the rail when traversing a curve and an additional sliding velocity V_y is added to the longitudinal speed V_x. The resulting lateral creepage, defined as the ratio between lateral and rolling velocities, initiates lateral contact forces. Those finally lead to a stick-slip excitation of the wheel. In steady state conditions, the average lateral creepage on one wheel can be considered to be equal to the angle of attack α, defined as the angle between the wheel and the rail tangent directions. For small angles one has

$$V_y = \alpha V_x \qquad (1)$$

Rough simplifications of the geometry in tight curves allow an estimation to be made of the angle of attack versus geometric parameters; the following formula is given in Ref. [5] as applying to the leading axle

$$\frac{W}{2R} \leq \alpha \leq \frac{W}{R} \qquad (2)$$

where W is the boogie wheelbase and R the curve radius. The upper limit *W/R* is reached on the leading axle when the trailing axle is nearly radial to the track. Rudd [4] gives a rule of thumb that no squeal would occur for ratios $W/R < 0.01$, i.e. a maximum angle of α = 10 mrad.

Although the angle of attack is the key parameter for squeal generation, the lateral position of the contact across the wheel tread can have some influence. This is especially the case for situations corresponding to flange contact [2]. In fact, flange contact often seems to bring a positive effect on squeal control.

Wheel and rail vibration and noise radiation

Generally, the wheel contribution in vibration response and sound radiation exceeds that of the rail when dealing with curve squeal [4, 5]. This result is likely to be related to the higher lateral mechanical receptance of the wheel at the contact: unlike the rail, the wheel presents many lightly damped natural frequencies in the lateral direction. The pure tone components arising are generally related to wheel natural frequencies: in most cases, these frequencies correspond to the 0L,*n* modes [7], i.e. out-of-plane wheel bending modes with no nodal circle and with *n* nodal diameters.

The geometrical parameters of wheels lead to a radiation efficiency close to 1 for axial modes above about 600 Hz. By taking radiation efficiency equal to 1 and by assuming that the lateral vibration velocity amplitude is limited by the average lateral sliding velocity V_y, the sound pressure level close to the wheel can be approximated by

$$p \cong \rho c \alpha V_x \qquad (3)$$

ρc being the acoustic impedance of air.

Experimental validation

The field measurements performed on the Paris metro in November 2000 and the Grenoble tramway network in February 2001 have been published in reference [1]. Results confirm known trends concerning key parameters and are in agreement with literature concerning the position of squealing wheels.

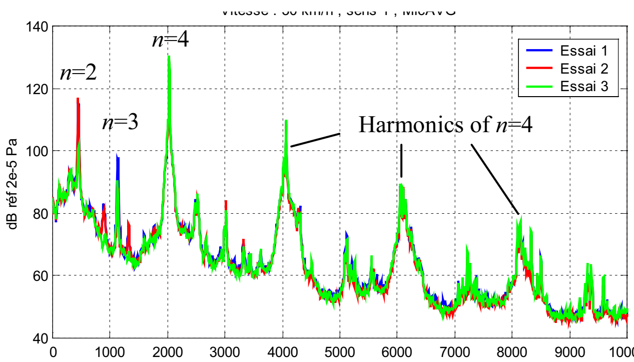

Figure 1: Spectrum recorded close to the front inner wheel of a metro boogie. Average along the length of the curve (100 m). The dominant wheel mode is 0L,4.

Figure 1 shows a typical spectrum recorded on the metro system. The highest squeal levels were observed on the inner wheel of the leading axle, no squeal was found on the outer wheels. For the tramway system the front inner wheel of the motor bogie was also the highest squeal radiator at low speeds whereas squeal only occurred on the rear outer wheel for higher speeds. On the metro system with monobloc undamped wheels, sound pressure levels close to the front inner wheel are in agreement with amplitudes estimated using Eq. (3). On the tramway with resilient wheels, noise levels remain clearly below the limit given by this formula.

Mitigation measures

Concerning the design of completely new rolling stock, one will probably think of steerable axles as the most effective means to prevent curve squeal. However, mitigation measures applicable to existing fleets and networks are also needed. Those may be divided into two categories: on-board systems and stationary systems. This paragraph deals with two measurement campaigns, each one concerned by one of these categories.

Metro lines are naturally better suited for fixed installations that are intended to treat a distinct curve or hot-spot. A relatively easy way to modify the contact parameters between wheel and rail is the spray of water onto the rail. The effectiveness of this measure has been investigated during measurements on a French metro line that had an issue with squeal in a curve next to a station. Sound pressure levels of up to 117 dB(A) at the main peak of 3425 Hz have been measured in the tunnel, corresponding to a level of 100 dB(A) on the platform. The tested device simply consisted of perforated hosepipes, usually used for irrigation. A more sophisticated system would of course permit to apply the water more economically. However, a watering during 15 seconds prior to the first pass-by (corresponding to a volume of approximately 4 litres) turned out to be sufficient to completely suppress squeal of two successive trains. Neither a more abundant watering nor the use of a wetting agent did increase the number of non-squealing trains. This is most probably due to the wiping effect of the wheels. However, the concerned trains were made up of only two cars; in the presence of much longer trains, a system that remains in operation during the pass-by would therefore likely be needed.

On tramway networks, fixed installations are generally not desired because the tracks are often embedded into the tarmac, especially in the city centres with high building density. Consequently, on-board systems are generally better suited for tramways.

The effect of such a system has been highlighted during a measurement campaign under operating conditions on a French tramway. Each train is equipped with an on-board wheel flange lubrication system intended to prevent rail wear in curves. A spray of anti-wear liquid, oriented towards the wheel flange, is triggered automatically, when the train enters a curve.

A curve of 30 m radius, which was claimed to squeal after raining periods, was cleaned during the night in order to create favourable conditions for curve squeal. Then, track-side noise levels were recorded during tramway operation from 6 a.m. to 11 a.m. Only 4 out of the first 24 pass-bys revealed squealing. A maximum noise level of 85.7 dB(A) was recorded at 5.7 m distance from the rail and 1.6 m height. Again, due to resilient wheels, measured as well as perceived squeal levels remained quite moderate.

All squealing trams were recorded in the first half of the measuring period. None of the four trams that had squealed during the first pass-by did so during the second one. The explanation of this behaviour is in fact the accumulation of lubricant on the rail during several hours of traffic. As long as the rail is not washed by any severe rain, and as long as the spraying system on board the tramways remains operational, no squeal would occur.

Conclusion

After a brief introduction to curve squeal, this paper presented an overview of different measurement campaigns with an accent on the monitoring of mitigation measures. Stationary watering of the rails as well as spray of lubricant from an on-board system both showed to be efficient against curve squeal. The former has the advantage of being cost-effective but is less suited for tramways. However, both systems represent the inconvenience of needing regular maintenance, which is sometimes neglected because curve squeal suppression is not a security relevant topic. In this case, the damping of resilient tramway wheels at least limits the occurring squeal level. In practice, the simultaneous implementation of at least two mitigation measures is advisable in order to eradicate squeal with confidence.

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