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A MEASUREMENT PROTOCOL FOR CURVE SQUEAL NOISE

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ABSTRACT
Curve squeal is the intense tonal noise that can occur when a railway vehicle traverses a curve or a switch. This paper presents the literature study and the development of a measurement protocol to standardise curve squeal noise measurements. The lacking of a uniform measurement protocol is considered to be one of the problems that make squeal noise so hard to understand, in spite of all the research that has been done so far. From literature and interviews, parameters that are held responsible for the appearance of squeal noise have been identified and categorised. The measurement protocol helps to accurately define the measurement situation and to determine all relevant parameters. Some first experiences with this protocol in a measurement campaign are reported.

1 - INTRODUCTION
Though a large number of different measures against curve squeal (wheel dampers, lubricants, alternative bogies) has become available in recent years, the effectiveness or the reliability of most of these measures is rather disappointing. It is concluded that a full understanding of the mechanisms and parameters that influence squeal noise is still lacking. As the physics of the problem is very complicated, a thorough investigation of all relevant parameters and their interaction is required to find adequate measures against it.
For this reason, the Dutch Ministry of the Environmental Affairs has initiated a research programme into curve squeal. This paper presents a list of parameters affecting squeal noise and the development of a measurement protocol that form the basis for this programme [1]. A literature study provides a survey of different mechanisms, but is intended primarly to produce a list of all possible parameters that are associated with the generation of squeal noise. Additionally, a few national and international experts in the field of curve squeal noise have been interviewed. Their opinion about the influence of these parameters was asked. With this information a final list of relevant parameters has been composed. After identification of these parameters, a measurement protocol is proposed that will help to define the measurement situation and to identify all relevant parameters. The protocol has three levels of investigation: simple, standard and advanced.

2 - SQUEAL NOISE MECHANISMS
A first attempt to understand curve squeal noise was given by Stappenbeck [2]. Though based on visual and auditory observations only, his description gives a fair physical insight in the matter. It does, however, not explain why some vehicles squeal and others do not. A thorough mathematical description is first given by Rudd [3]. He argues that in principal three possible excitation mechanisms should be considered:

1. longitudinal slip between inner and outer wheels on a solid axle;
2. wheel flange rubbing against the rail;
3. lateral creep of the wheels on top of the rail.

The first and second mechanism can be eliminated by applying independently suspended wheels and lubricating the wheel flange, respectively, but still squeal noise appears in tight curves. Moreover, the excitation force in these two mechanisms is directed along the tangent of the wheel tread, while the wheel modes that generate squeal are axial modes. Therefore it is concluded that lateral creep is the most important mechanism responsible for squeal noise, though other mechanisms like flange rubbing and longitudinal slip may play a role as well.

3 - PARAMETERS

The *lateral creep* (in the following, all relevant parameters are written in italics) is defined as the speed in the lateral direction (slip) devided by the speed in the rolling direction:

$$\xi = v_{\text{slip}}/v_{\text{rolling}}$$

The behaviour of ξ depends on the *coefficient of friction* μ. This is depicted in Figure 1.

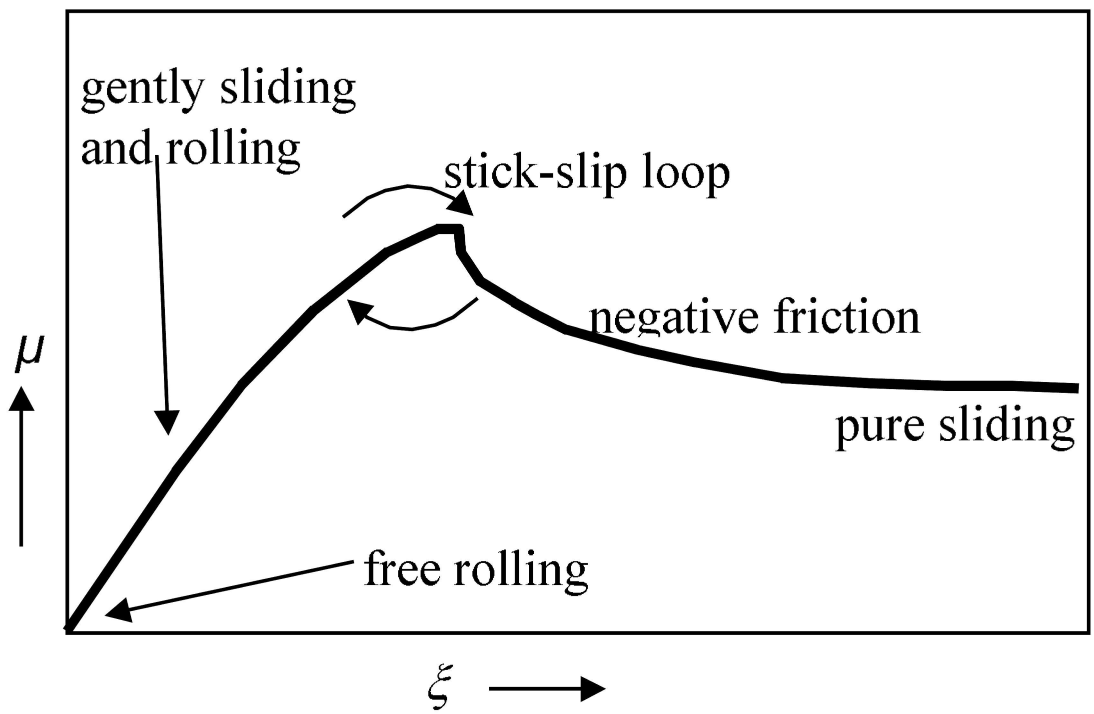

Figure 1: Relationship between lateral slip and the coefficient of friction.

In the contact patch between wheel and rail, the friction will initially be proportional to the creep. The presence of a maximum of μ is essential for a stick-slip motion to occur. Unfortunately, the stick-slip curve can only be measured under laboratory conditions by using a carefully tuned roller rig. For in situ measurement a rail tribometer is used, yielding only the dynamic coefficient of friction in the rolling direction. This leaves creep and lateral friction perhaps the only relevant parameters for squeal noise that cannot be measured directly.

In order to identify other parameters that influence squeal noise, more than 90 documents (reports, articles, data sheets) have been studied and 10 experts in this field were interviewed about their experience with squeal noise of railway systems.

Directly related to the creep coefficient is the ratio between the *wheelbase* and the track's *curve radius*, as this ratio defines the angle between the plane of the wheels and the tangent to the curvature of the rails. Other geometrical parameters defining the motion of the bogie and vehicle are *wheel* and *rail transverse profile*, *cant* (tilt of the track), *track gauge*, *distance between the flanges.* In combination with rail and wheel *macro roughness*, the *axle load*, and *rolling speed* , these parameters determine the vehicle's course. To a certain extent, these quantities can be adjusted. External circumstances like *humidity* and *temperature of the air* may have a strong influence on the occurence, but are hard to control. On the other hand, the *humidity* and *temperature of the railhead* are important parameters that are certainly controllable (e.g. by sprinkling).

A different class of parameters characterises the modal behaviour of the wheels: the *internal damping,* the *modal stiffness* and *mass*, as well as the *Young's modulus* of the material used. A suitable method to measure these is by measuring the wheel impedance spectrum. Similarly, the rail impedance spectrum determines the dynamics of the *track superstructure*, involving rail pad stiffness, rail and sleeper mass, ballast damping et cetera.

4 - MEASUREMENT PROTOCOL

Now the relevant parameters have been identified, a measurement protocol can be designed. The application of this protocol has several advantages:

- it helps setting up a wheel squeal noise measurement;
- it enables comparison between different situations;
- it enables accurate use of wheel squeal models.

Because the measurement of the complete set of parameters is awkward in many situations, three levels of investigation are considered, each with its own version of the protocol: simple, standard and advanced. Table 1 gives the parameters that should be measured per level of investigation. Note that some of these single parameters include several of the parameters identified in the previous section (e.g. impedance). Only for the advanced protocol all parameters should be measured. In the simple version only a small number of parameters are actually acquired (by measurement or by giving a nominal value), while other parameters are described. Which version should be applied in which situation, is explained in the following.

Protocol	**Simple**	**Stand.**	**Adv.**	**Protocol**	**Simple**	**Stand.**	**Adv.**
M = measurement; D = description				***Track parameters***			
Vehicle parameters				Type of sleeper or slab track	D	D	D
Type of rolling stock	D	D	D	Type of rail	D	D	D
Type of bogie	D	D	D	Type of rail pads	D	D	D
Type of wheel (material)	D	D	D	Rail wear	D	D	D
State of maintenance of vehicle	D	D	M	Type rail joints	D	D	D
Wheel base	M	M	M	Rail gauge	M	M	M
Axle load	M	M	M	Curve radius	M	M	M
Rolling velocity	M	M	M	Rail roughness	D	D	M
Distance between both flanges	M	M	M	Rail transverse profile	–	M	M
Wheel tire height	–	M	M	Cant	M	M	M
Wheel radius	–	M	M	Impedance spectrum	–	M	M
Wheel transverse profile	–	M	M	Micro roughness	–	–	M
Which wheel squeals	–	D	D	***Interaction parameters***			
Wheel roughness	D	D	M	Coefficient of friction	M	M	M
Impedance spectrum	–	M	M	Lateral creep	–	–	M
Meteorological parameters				Rolling radius difference wheels	–	–	M
Air temperature	M	M	M	***Noise measurements***			
Relative Air Humidity	M	M	M	Squeal noise track	M	M	M
Humidity of rail	D	D	D	Squeal noise bogie	–	M	M
Dust or rust on rail and wheel	D	D	D	Vibrations bogie	–	–	M

Table 1: Parameter list per level of investigation; M = measurement, D = description.

4.1 - Simple investigation

A simple protocol is applied if only the occurence of squeal noise should be determined. The acquisition of more parameters than only the noise level allows for a comparison between different situations, e.g. before and after taking a measure against squeal noise. Also different measures applied in different situations can still be compared because the circumstances are described sufficiently. The measurement equipment needed for the simple protocol consists of relatively simple instruments that are used by most noise consultant agencies.

4.2 - Standard investigation

The standard protocol is applied if it is aimed to learn about the cause of squeal noise in order to take measures. It gives an answer to the question: why does it occur in this situation? By comparing differences in parameters and noise spectra for each train pass-by, relations can be established and analysed. In this way adequate measures can be selected for the situations under consideration.

4.3 - Advanced investigation

The advanced protocol is applied to determine the influence of certain parameters and the interaction between them. This protocol is used for research that aims at fully understanding squeal noise. By making a record of all parameter values, a certain squeal noise event (a vehicle traversing a curve) can be simulated in a vehicle/track model. By varying model parameters, insight is gained in the phenomenon. This protocol is not meant as a 'static' norm, but can be modified or improved if experience from measurements and theory impose this.

5 - EXPERIENCE WITH PROTOCOL

The measurement protocol has been evaluated in a test session on the Watergraafsmeer shunting yard near Amsterdam in December 1999. The set-up of the test session accounted for 4 days of measurement according to the advanced protocol. The first day was used for measurement of vehicle parameters. Meanwhile the vehicle was equipped with measurement instruments for the test runs. On the second and third day, a series of test runs were planned. The fourth day was reserved for measurement of the track geometry. Special emphasis was put on the determination of the lateral position of the wheel/rail contact. To this end, video cameras were mounted to the bogie just above the railhead, focussing on the contact zone between wheel and rail. The cameras rendered a clear picture of the relative position of the wheels and rails, enabling an estimate of the contact patch position.

Though the wet weather on the second and third day prevented generation of squeal noise, it is concluded that the protocol in its present state is suited for its purposes. Further testing, however, is necessary to evaluate the applicability of the measured values of the parameters in models.

6 - CONCLUSIONS

The literature study, which was based on a large number of documents, produced a large number of parameters that possibly influence the generation of squeal noise. Through consultation of a number of international experts in railway and tramway squeal noise, a selection could be made of those parameters that are most likely to play a role in squeal noise generation. With this selection of parameters, a measurement protocol is designed for use in squeal noise measurements. Three levels of investigation are accounted for: simple, standard and advanced measurements. The application of the protocol enables comparison between different situations and different solutions to reduce squeal noise. Therefore, research institutes and consultancies are encouraged to use this protocol (available via http://www.nl.aeat.com). Further testing and refining is necessary to evaluate the applicability of the measured values of the parameters in models.

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