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Journal of Sound and Vibration 293 (2006) 728–734

JOURNAL OF SOUND AND VIBRATION

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Combating Curve Squeal: Monitoring existing applications

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Accepted 26 August 2005
Available online 17 February 2006

Abstract

Curve squeal is the intense high frequency tonal noise that can occur when a railway vehicle traverses a curve or a switch. The high noise level causes annoyance for people who live in the neighbourhood of the squealing railway track as well as for the passengers waiting in stations with curves. The Combating Curve Squeal project is sponsored by the International Union of Railways (UIC) in order to develop tools to reduce curve induced squealing. The focus is to obtain applicable solutions. In phase 1, an overview of the extent of the noise problem for railways and a toolbox with methods and solutions to combat squeal noise were produced. In addition, work on a theoretical model was further advanced. As a conclusion, it was found that in principle solutions do exist, but several questions connected to their application have not yet been answered. Phase 2 of the project addresses these questions by concentrating on noise monitoring of existing solutions against squeal noise. Mainly infrastructure-based solutions to combat squeal noise in hot spots such as friction modification and asymmetric grinding will be assessed for further analysis. The aim is to obtain a preliminary design manual for practical solutions for the railways to reduce squeal noise. A measurement protocol and rig tests support these efforts. This paper focuses on the presentation of the applications and the development of the test procedure.

1. Introduction: the ongoing problem curve squeal noise

The noise arising from curve squeal is still a problem that has not been solved satisfactorily. Many research projects have been carried out in the last years with the goal to provide a fundamental understanding of the phenomena and the parameters for the generation of squeal noise. For the railways, the International Union of Railways (UIC) started under the management of ERRI in 2002 a three-phase project. Its final product is planned to be an overall problem-oriented guideline which covers different problems and offers applicable solutions against squeal noise.

Curve squeal is the tonal, high frequency noise which is about 10–30 dB higher than rolling noise. This noise may occur when a vehicle passes a small-radius curve. This noise does not occur permanently and cannot be predicted totally reliably. There exist no official regulations regarding squeal noise, accordingly squeal noise is not included in official noise calculation models and is not integrated in noise mapping (with the exception of the German Schall 03 [1]). Therefore, neither railways nor authorities are aware of the number and the location of the curves and the annoyance potential of squeal noise for a network. However, squealing curves

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0022-460X/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jsv.2005.12.005

get attention when complaints from passengers or nearby inhabitants exceed a certain limit or when maintenance engineers become aware of the problem.

2. UIC project—first phase

The objective of the first phase was to survey the extent of the problem within the railways: to compile a "Toolbox of solutions", to develop further a model of squeal noise and to integrate it into a software which can be connected to the current railway noise calculation software TWINS [2], as well as to create an inventory of suitable rig tests for validation of model results and test of effectiveness of solutions [3].

2.1. Extent of the problem

A standardised questionnaire was sent out to the railways and its findings extrapolated. It showed that about 12% of the inhabitants disturbed by rolling noise in Europe are disturbed by curve squeal noise as well, which equals about 1.5 million (see Fig. 1). The extrapolation concerning railway clients [4] showed that about 7% of railway passengers using the services daily are exposed to curve squeal noise (see Fig. 2).

2.2. Toolbox of existing measures

In order to compile existing measures for reduction of squeal noise, an extensive literature and Internet search was carried out. The following types of measures were included and described in detail [5]:

- Wheel-based measures (ring dampers, constrained layer dampers and resilient wheels).
- Track-based measures (rail dampers).
- Lubricants and friction modifiers.
- Coatings.

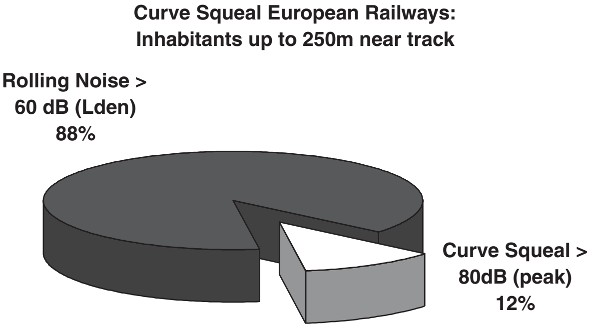


Fig. 1. Percentage of people affected comparing rolling noise and curve squeal (inhabitants in Europe living in a distance 250 m and less from a track).

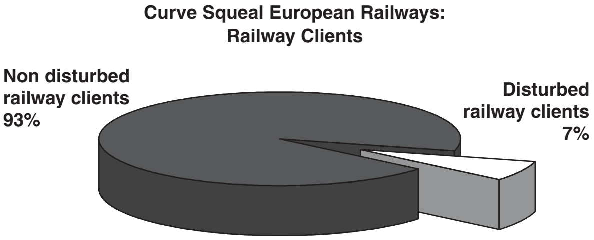
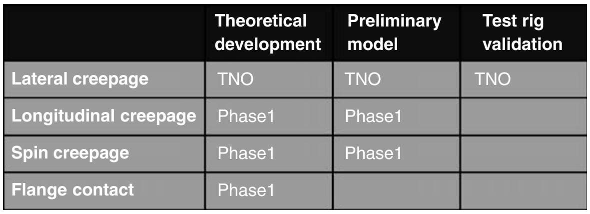


Fig. 2. Percentage of railway clients affected by curve squeal.



	Theoretical development	Preliminary model	Test rig validation
Lateral creepage	TNO	TNO	TNO
Longitudinal creepage	Phase1	Phase1	
Spin creepage	Phase1	Phase1	
Flange contact	Phase1		

Fig. 3. Modelling carried out in phase 1 of the UIC Curve Squeal project.

- Asymmetric rail profile.
- Steerable axles.

Further, measures have been identified, but were not further considered: train speed adaptation, shielding and adaptation of curve radius.

It was not possible to compare the measures concerning their effectiveness against squeal noise, because comparable measurement data did not exist. Squeal noise must be treated in terms of the likelihood of occurrence and the level of noise, and for most cases the likelihood of occurrence was not evaluated.

Some of the measures are still very theoretical and do not receive much confidence from the railways in terms of costs, environmental concerns, technical feasibility and safety.

2.3. *Model development*

Observations indicate that the highest squeal noise is usually generated by the leading inner wheel of a four-wheeled bogie or two-axle vehicle. This noise has been associated with stick-slip lateral motion at the contact between the wheel tread and the rail, referred to here as "squeal due to lateral creepage". A theoretical model for curve squeal has previously been developed [6]. This model is based on excitation by unstable lateral creepage. As a part of phase 1 this model, a new calculation module named SLYNX, was linked to TWINS 3.0 [7].

The contact between the wheel flange and the rail, which occurs at the leading outer wheel in sharp curves, has generally been found to reduce the likelihood of stick-slip squeal at this wheel. However, it is thought that flange contact may generate a different form of squeal noise, which can be a source of considerable annoyance. The model was developed further by including longitudinal and spin creepage into the model [8]. Flange contact was not included but its theory developed further. The computational model developed in the framework of this project includes lateral, longitudinal and spin creepage terms [7,8] (see Fig. 3).

2.4. *Inventory of test rigs*

Rig testing has two objectives: the assessment of the effectiveness of treatments for curve squeal noise and the gathering of data for the validation and extension of the theoretical model of curve squeal noise.

Nine different types of rigs were reviewed and three were analysed in detail [9]: the TNO test rig in Delft, the DB test rig in Brandenburg-Kirchmöser and the DB roller rig in Munich. The TNO 1:3.86 scaled test rig and the DB full-scale test rig in Brandenburg-Kirchmöser allow detailed investigations of the wheel/rail contact under well-defined and well-controlled conditions. The roller rig facility in Munich comes closest to reality (tests possible which are very much the same as on a real track). Due to the fact that the rig was shut down this year, it can no longer be used.

3. Second phase of the UIC project

3.1. *Selection of existing applications for monitoring*

The second phase of the project started in 2004. Some measures will be tested on test rigs as well as on several curves on the networks in France, UK and Switzerland. Priority is given to improve the level of confidence in the selected measures concerning environmental performance, costs and safety. A preliminary design manual for selected measures will be produced at the end of this phase.

As not all measures in the toolbox can be tested a selection must be made. Budget restrictions are one of the most important factors defining the selection. Within this restriction, varying factors are the number of measures that can be tested and extent of testing, e.g. more measures mean less in-depth testing and vice versa. In general, rig testing will be less expensive per measure; however, the confidence level is not as high as in situ tests. Out of these variables, the optimum combination must be found. This, however, is difficult, due to a lack of experience. The options are shown graphically in Fig. 4.

The selection of measures was made according to a variety of criteria, which led to the decision to test infrastructure-based friction modifiers only and a programme with the following steps [10]:

(1) To develop standard measurement protocols for rig tests and field tests.
(2) On the reduced scale rig a large number of parameters and friction modifiers are measured.
(3) Field tests with friction modifiers in Switzerland, France and UK.
(4) Final rig tests on full-scale test rig based on open questions from point 3.

Tests and measurements are planned to be carried out in summer 2004, final results are expected for 2005.

3.2. Selection of sites and test/evaluation procedure for acoustic measurements

The aim of the field tests is to evaluate if a selected measure reduces curve squeal for the collective of passing trains at the test site. Acoustical evaluation should not focus on every single wheel or bogie, but should answer the question whether, for the given range of passing trains at this site, squeal noise was eliminated or reduced. This means that for a test site it would be important to arrive at an acceptable number of train pass-bys per day in order to keep the costs for monitoring as low as possible. For the tests in Switzerland, three curves on the S-Bahn network with reasonable traffic and one curve with combined freight and passenger traffic were, therefore, chosen.

In order to get an equal evaluation of all results, a squeal noise measurement protocol was drafted [11]. Measurements according to this protocol should fulfil certain criteria:

- Measurements take place before and after the installation of the measure: in order to show the noise reduction at the particular site, it is important that baseline measurements are made.
- Weather conditions (dry weather).
- Number and position of microphones including measurement distance, dependent on radius and length of the curve.

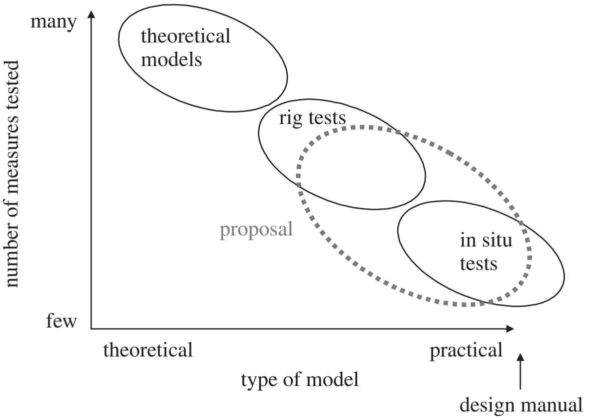


Fig. 4. Range of selected measures [10].

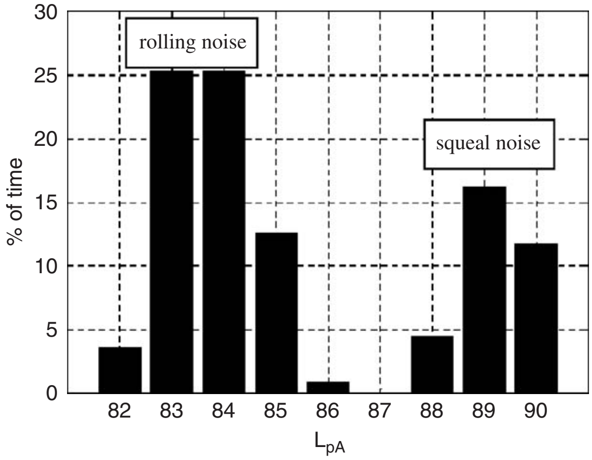


Fig. 5. Illustrative example of histogram for partial squeal: for one pass-by, the distribution of the $L_{\mathrm{pA,max}}$ levels (125 ms) is noted according to their partition in the total pass-by time. Rolling noise and squeal noise can be separated [11,12].

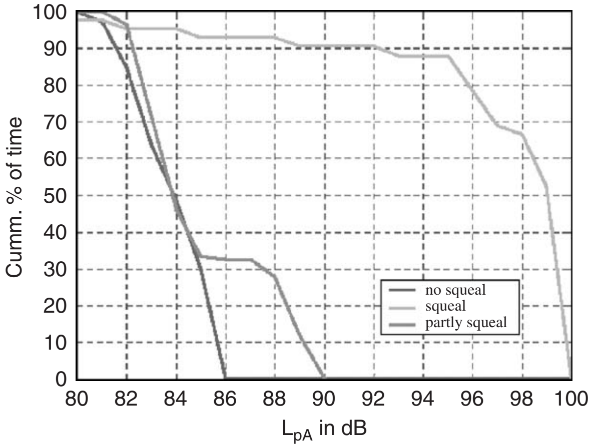


Fig. 6. Cumulative histograms for three situations based on three pass-bys with "no squeal" (dark line), "partial squeal" (medium grey line) and "squeal" (light grey line).

- Noise level ($L_{\mathrm{pA,max}}$, option fast with 125 ms integration time).
- One-third-octave frequency spectra have to be provided with the measurement.

In addition, the protocol requires histograms based on a minimal number of 10–25 train pass-bys. Histograms for single pass-bys and cumulative histograms help to identify and to evaluate curve squeal (Figs. 5 and 6). With this method the situations before and after the installation of the measurement can be compared and the effect of the installation can be assessed. It is important that sufficient train pass-bys per day are included in the evaluation, as some sites may exhibit ephemeral behaviour [13].

3.3. Non-acoustic criteria for site testing

The evaluation of an installation to combat squeal noise would not be complete if only the acoustic performance is taken into consideration. Railway infrastructure is a complicated system with high importance on safety issues and economic performance (in terms of low maintenance costs) of its elements. Safety issues encompass conditions for braking and adhesion on the railhead (friction coefficient no worse than for wet rail), electrical conductivity and the behaviour of the substance at rail joints.

Moreover, substances with a negative effect on the environment are not tolerated. Substances, therefore, need to be bio-degradable, especially in cases where the curves are situated in areas with special conditions concerning water protection.

Life cycle costs include the following costs:

- material costs for the installation,
- installation costs,
- substance cost (e.g. cost per axle of the substance needed),
- maintenance costs (costs for surveillance of the system, frequency of replacement of parts of the system, frequency need for refilling of the substance),
- removal and replacement costs.

On the other hand, it is expected that a reduction of costs can be attained by reducing the wear in the curve.

It is a task of the second phase of the UIC project to try to assess those elements for the different installations tested. Concerning the friction behaviour and the amount of substances to be applied the tests on the test rigs will give further answers.

4. Open question: effect of pure flange lubrication versus effect of top of rail squeal excitation

The acoustic evaluation of the monitoring campaign is measuring squeal noise from top of rail stick-slip effect and flange rubbing. Important for the assessment is the overall effect in squeal noise reduction. It is one aim to be able to get information on the difference of those two effects. Differences in frequency range were proposed by Eadie and Santoro [14] from 1000–5000 Hz for top of rail squeal and 5000–10000 Hz for flanging noise. During the evaluation process with possible friction modifiers two products which are originally pure flange lubricators have been included in the assessment as well (using substances which do not affect the railhead). Those substances have lower costs and do not need to meet the same safety conditions as top of rail friction modifiers. As a certain percentage of curves seems to show mainly flange rubbing as principal effect of squeal noise, such installations would satisfy the needs of railways and have a probably a better cost–benefit ratio. The open question remains, whether, for a given range of trains and a given track condition, the reasons for squealing can be predicted and whether the analyses of the one-third-octave band histograms of a given curve give sufficient information on the type of squeal and the subsequent effect. However, in this case, it would have to be clear whether flange rubbing and top of rail excitation are two independent phenomena or in what way the excitation effects influence each other. From literature, it is known that the presence of gauge face lubrication increases the angle of attack and the magnitude of lateral forces [14] which would probably lead to an increase in squeal due to stick-slip on the top of the railhead. Further, theoretical development and field experiments should give an answer to this question.

Acknowledgements

The work described was sponsored by UIC. Phase 1 of the project was led by ERRI and phase 2 is led by SBB. Project partners are DB, SNCF, TNO, AEA Technology and ISVR.

References

[1] Schall 03 (Akustik 03): Richtlinie zur Berechnung der Schallimmissionen von Schienenwegen, Ausgabe 1990 - DB Netz AG Zentrale, Frankfurt.

[2] D.J. Thompson, M.H.A. Janssens, TWINS—track-wheel interaction noise software, Theoretical Manual, Version 2.4, TNO Report TPD-HAG-RPT-930214 (Revised), 1997.

[3] K. Hofstra, Combating curve squeal final report—phase 1 ERRI report C242.1, 2003.

[4] B. Müller, Curve squeal WP2 inventory of the extent of the problem, UIC, Report Prepared by SBB, 2003.

[5] B. Müller, E. Jansen, F.G. de Beer, Curve squeal WP3 tool box of existing measures, UIC, Report Prepared by SBB and TNO, 2003.

[6] F.G. de Beer, M.H.A. Janssens, P.P. Kooijman, W.J. van Vliet, Curve squeal of railbound vehicles—part 1: frequency domain calculation model, in: *Proceedings of the Internoise*, Nice, France, Vol. 3, 2000, pp. 1560–1563.

[7] M.H.A. Janssens, F.G. de Beer, SLYNX v1.0—a squeal noise calculation module for usage with TWINS, User Manual, TNO Report DGT-RPT-030002, 2003.

[8] D.J. Thompson, A.D. Monk-Steel, Curve squeal WP4a A theoretical model for curve squeal, UIC, Report Prepared by ISVR, 2003.

[9] M.H.A. Janssens, B. Asmussen, Curve squeal WP4b rig testing inventory, UIC, Report Prepared by TNO and DB, 2003.

[10] J. Oertli, UIC Curve Squeal Phase II Minutes Initial Workshop, 2004.

[11] H.W. Jansen, M.H.A. Janssens, Squeal noise measurement protocol (draft), TNO Report DGT-RPT-040028, 2004.

[12] F. Krüger, Das Kurvenquitschen im Schienennahverkehr, der Nahverkehr 7–8/95.

[13] M. Kerr, J. Kalousek, G. Elliot, F. Mau, D. Anderson, Squeal appeal: addressing noise at the wheel/rail interface, in: *Proceedings of the Conference on Railway Engineering*, Rockhampton, 1998.

[14] D.T. Eadie, M. Santoro, Railway noise and the effect of top of rail liquid friction modifiers: changes in sound and vibration spectral distributions in curves, in: *Sixth International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2003)*, Gothenburg, Sweden, 2003.