



Combating Curve Squeal Phase II

Final Report

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Abbreviations

AEAT: AEA Technology Rail
DB: German Railways
ERRI: European Rail Research Institute
HPF: High positive friction material
ISO: International Organisation for Standardisation
ISVR: Institute of Sound and Vibration Research, University of Southampton
 L_{Aeq} : The "equivalent" average sound level measured using A-weighting
 L_{den} : Noise level for day, evening, night
 L_p : Sound pressure level in dB(A) with a reference of 20 uPa.
 L_{10} : Sound pressure level that is exceeded 10% of the time during a train pass-by.
MMU: Manchester Metropolitan University
SBB: Swiss Federal Railways
SNCF: French National Railways
TNO: Netherlands Organisation for Applied Scientific Research
TWINS: Track Wheel Interaction Noise Software
UIC: International Union of Railways
WP: Work package

Appreciation

The project would like to thank the following companies for supplying installations and friction modification products: Kelsan/MBT; Railpartner Schweiz AG, VT AG, HY-Power, Equip'tec.

0. Executive Summary

Project aim: The UIC Combating Curve Squeal project was designed to find measures against the annoying high-pitched noise created during pass-bys of trains in certain curves. A first phase, completed in 2003, was aimed at analysing existing knowledge and developing models while the second phase, described in this report, intended to increase confidence in selected mitigation measures.

Methodology: A selection of friction modifiers (Keltrack by Kelsan, Headlub-0 by Railpartner, Moklansa by VT AG, TMP-2 by HY Power, Lubri'rail by Equip'tec) and water were tested on two different rigs (a scale rig at TNO and a full size rig belonging to the DB at Kirchmöser) and under field conditions in Switzerland, France and the UK. Not all friction modifiers were tested in all cases (compare **Table 0** below).

Results and conclusions: The results varied from curve to curve and are summarised in **Table 0**. A YES indicates that squeal noise was reduced.

test site	product and place of application in field tests					
	Keltrack by Kelsan	Headlub-0 by Railpartner	Moklansa by VT AG	TMP-2 by HY-Power	Lubri'rail by Equip'tec	Water top of rail
1:3 rig at TNO	YES (top of rail)	YES (top of rail)	YES (top of rail)	YES (top of rail)		
1:1 DB rig	YES (top of rail)	YES (top of rail)				YES (top of rail)
in-situ Switzerland	only on first half of curve (top of rail)	NO (top of rail)	NO (gauge face)	NO (gauge face)		
in-situ France	NO (top of rail)				YES (gauge face)	
in-situ UK	YES (top of rail)					YES (top of rail)

Table 0: Summary of results; a blank field indicates that no tests were undertaken in this combination.

No optimal solutions could be found that would work under all circumstances. For each curve the trade-off between performance, dosage and costs must therefore be evaluated separately.

Proposal for next steps: The project team proposed creating an international curve squeal network, in which new results would be shared on a regular basis. A structure for a report to be used for this purpose was developed. It is suggested that this network is organised by UIC or delegated to one of the project partners.

Project Team: The project leadership was with SBB; collaborators were the DB, SNCF, TNO, AEAT and ISVR.

Reporting: The results were presented a workshop attended by 35 delegates in March 2005. Partial results were presented at the 8th International Workshop on Railway Noise and at the UIC Environmental Coordinators Conference in Berlin in November 2004.

1. Background

1.1 Curve Squeal as a railway problem

Curve Squeal as an annoying high-pitched noise: Curve squeal is an intense tonal noise that may occur on curves or on switches. The high noise level causes annoyance for people living in the vicinity of a squealing railway track as well as for passengers waiting in stations with curves. The character of the noise is very intense with high frequencies (up to 10,000 Hz) and high amplitudes that can be up to 100 dB(A) in 10 m distance.

Causes of curve squeal: The following possible mechanisms for the generation of curve squeal can be considered [1]:

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

Lateral creep is considered to be the most important mechanism responsible for squeal noise, although the other mechanisms should not be neglected [2]. In a curve, the wheels of a vehicle cannot align themselves tangentially to the rail. Therefore the speed of each wheel has two components: rolling speed (tangential to the wheel) and the crabbing speed (perpendicular to the wheel). The oscillations of the wheel are radiated as sound with high efficiency through the wheel causing squealing. Although the wheel is the main source, the rail radiates sound as well.

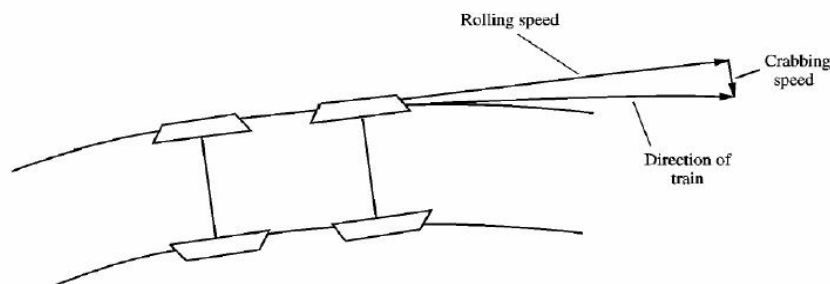


Figure 1.1. Situation of a railway vehicle in a curve [2].

1.2 The UIC Project

UIC initiates project: The annoyance caused by squealing curves prompted the UIC to initiate a project to combat this noise in railways. In a first phase, led by the now defunct ERRI (European Railway Research Institute), five work packages were aimed at developing applicable measures against curve squeal. These were

- WP1: Project management and communication
- WP2: Inventory of the extent of the problem
- WP3: Toolbox of existing mitigation measures and solutions
- WP4a: Theoretical model for curve squeal
- WP4b: Rig test inventory

This work was undertaken in 2002 and 2003.

Conclusions of Phase I led to Phase II: The work in Phase I showed that there was limited confidence in the mitigation measures. Therefore, a second Phase was started to test solutions on test rigs and in the field. This led to the following additional working packages:

WP5: In-situ tests

WP6: Rig tests

WP7: Reporting and dissemination of the results

This report focuses on the second phase of the project. Included in chapter 1.3 is a summary of the results of Phase I. The reports of Phase I may also be found in **Annex A.1**

1.3 Results and Conclusions of Phase I

1.3.1 Extent of problem

The detailed report may be found in **Annex A.1.2**.

Methodology: The extent of the problem was determined by a questionnaire sent to railways throughout Europe. Five railways (Banverket, Czech Railways, DB, Railtrack/AEAT and SBB) answered the questionnaire. A total of some 100 curves with squeal noise could be evaluated, some of which had mitigation measures in place.

Results: The evaluation showed that a large number of parameters such as track, vehicle and weather conditions influence squeal noise occurrence. Both passenger and freight traffic can produce squeal noise. The number of people affected by squeal noise was extrapolated from Swiss data to Europe. It was found that:

- It was estimated that 12% of the inhabitants within 250 m of the track with noise above 60 dB (L_{den}) were additionally exposed to curve squeal with peaks above 80 dB(A). This results in about 1.5 million persons throughout Europe.
- In railway stations about 7% of all clients are disturbed by squeal noise.

These numbers show that the squealing curves are indeed a significant problem.

1.3.2 Toolbox of mitigation measures

The complete toolbox is given in **Annex A.1.3**.

Systematic documentation of measures against curve squeal: A toolbox of existing mitigation measures against curve squeal was systematically documented and presented. These measures were compiled from results of research projects, existing applications available on the market, and specific measures used by different railway companies. The main mitigation measures included in the toolbox were:

- *Top of rail friction modifiers* are a successful measure against squeal noise. Friction modifiers must be reapplied continuously.
- *Wheel flange lubrication* is aimed at reducing the wear and is commonly applied in most European railways and shows mixed results for squeal.
- *Wheel dampers* show a good potential to eliminate squeal noise, however the damping effects must be considerable to eliminate squeal noise.
- *Resilient wheels* affect wheel damping but do not guarantee squeal elimination.
- *Asymmetric rail grinding* is indicated by research to be an effective mitigation measure. However, no success from projects in practice has been reported.

- *Combination of measures*: To date there have been no investigations with a mix of different mitigation measures.

Difficulty in comparing mitigation measures: Because there is no agreed definition for squeal noise, and because of the large inherent variability in the nature of squeal noise, it is difficult to describe the effectiveness of the measures. Normally, noise reduction is indicated in dB, but for squeal noise the rate of occurrence and duration are also important. This makes it very difficult to compare the effectiveness of the different measures, since different evaluation methods were used in each test. Furthermore, no measurement standard has been defined. It is important that judgements concerning mitigation measures are not only based on one measurement before and one measurement after implementation; testing squeal noise measures requires long-term monitoring on various locations, since some measures may only be effective in specific situations. In the cases cited in the toolbox, there was little information on long-term campaigns. Also there was too little cost information to make conclusive cost-benefit statements.

1.3.3 Theoretical model for curve squeal

Further development of the theoretical model for curve squeal: In Phase I, a model for the excitation of curve squeal was developed that includes lateral, longitudinal and spin creepage terms. This is the first such model to allow for contact conditions other than a horizontal contact plane on the top of the railhead, which allows flange contact to be considered as well as top of rail. The new model has been implemented as preliminary software in the MATLAB environment. Further information is given in **Annex A.1.5**.

Implementation within the TWINS program: As a part of Phase I, a computational model developed by TNO was linked to the existing TWINS 3.0 software for rolling noise assessment. This was achieved by creating a new calculation module, named SLYNX, which can be addressed from within the TWINS 3.0 software. For the current version 1.0 of SLYNX no alterations to the TWINS graphical user interface are necessary. The module is available on CD-ROM and comes with a report, which describes the theoretical background of the model as well as the installation and usage of the new SLYNX 1.0 software in relation to TWINS 3.0. Additional details may be found in **Annex A.1.6**.

1.3.4 Rig test inventory

The rig test inventory may be found in **Annex A.1.4**.

Test rig inventory: An inventory of existing test rigs in Europe was made in anticipation of tests in Phase II. Nine different rigs were reviewed and three were analysed in detail: the TNO test rig in Delft (NL), the DB wheelset test rig in Brandenburg-Kirchmöser (D), and the DB full vehicle roller rig in Munich (D). These three facilities represent a wide range of research tools in view of curve squeal investigations, not only with respect to their specific possibilities, but also with respect to the costs.

Possibilities of most promising test rigs: Both the TNO test rig and DB wheelset test rig allow for detailed investigations of the wheel/rail contact under well-defined and well-controlled conditions (forces, rolling angles, location of the contact patch, friction coefficients, et cetera). The TNO test rig does this with a scaled model (1:3), while DB test rig uses real full-size wheel sets. However, the advantage of using original wheel-sets, possibly equipped with real damping measures, is obtained at the expense of higher costs (about €25,000 compared to about €12,500 for a five-day test). A comparison of results obtained on both facilities might be interesting in order to check the validity of predictions made on the basis of scaled models.

1.3.5 Summary of conclusions of Phase I

- *Extent of the problem:* Extrapolated to all of Europe, it was estimated that 12% of the inhabitants within 250 m of the track with noise above 60 dB (L_{den}) were additionally exposed to curve squeal with peaks above 80 dB(A). Furthermore it was estimated that 7% of railway clients were disturbed.
- *Toolbox of existing measures and solutions:* The toolbox includes wheel-based measures such as ring dampers or wheel absorbers, track based friction modification, water spray installations, rail profile modification and vehicle based measures such as steerable axles.
- *Theoretical model:* The theoretical model for lateral unstable creepage was implemented in TWINS (in a programming element called SLYNX) while the lateral, longitudinal and spin creepage was implemented into preliminary software in MATLAB.
- *Rig test inventory:* Of the rig tests considered the TNO 1:3 scale model rig test and the DB 1:1 roller rig were considered the most promising.

Although a number of solutions were reviewed, lack of testing over long periods of time and under different conditions, the confidence in the measures was not very high. The essential element of Phase II was therefore the testing and monitoring of selected solutions to reduce squeal noise in clearly defined test conditions with a standardised protocol.

2. Project Description for Phase II

2.1 Project aims

Based on the conclusions of Phase I, the aims for Phase II were defined as follows:

- *Increased confidence for selected curve squeal reduction methods.* Confidence is understood in terms of environmental performance, costs and safety.
- *A preliminary guideline for selected mitigation measures.* Provide a text structure in which curve squeal experience could be passed on to the individual railways. This structure could be supplemented with further information from other projects after the end of the project.

2.2 Deliverables

The project results in a final report that includes the individual reports of Phase I and Phase II as well as a text structure that may be used to exchange further information.

As a basis for this work three work packages were defined:

WP 5:

- Develop a standard measurement protocol for in-situ testing
- Report on measurement and performance of selected methods in the field

WP6:

- Standard measurement protocol for rig testing
- Report on measurement and performance of selected methods when tested on rigs

WP7:

- Reporting

2.3 Project Design

2.3.1 Choice of mitigation measures to be tested

Budget restriction necessitated selection of mitigation measures for testing: Not all measures in the toolbox of Phase I could be tested within the available budget. Therefore, a selection had to be made. Within the available budget, varying factors determined the number of measures that can be tested and extent of the 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 test. The options are shown graphically in **Figure 1**:

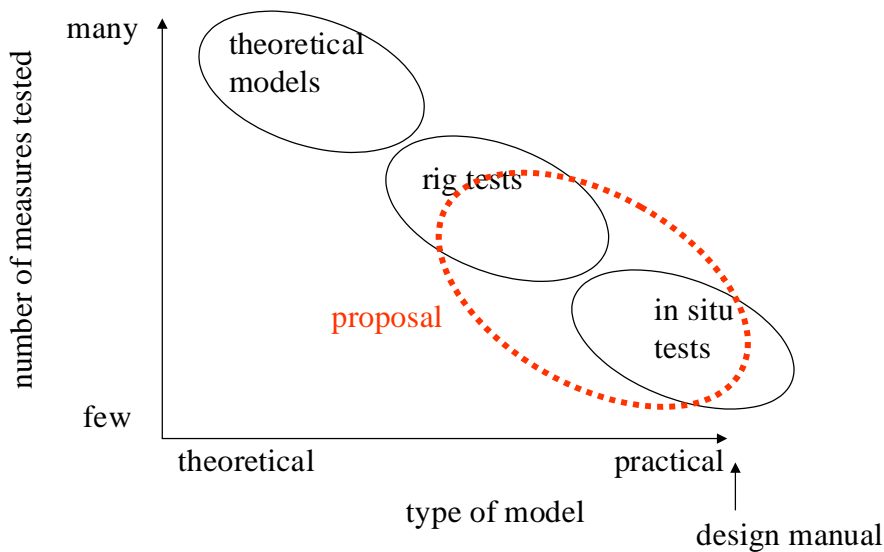


Figure 1: Testing options in phase II of project.

The actual choice of measures was based on a set of criteria given in Table 1.

measure	overall squeal elimination	practical applicability	gain in knowledge	link between modelling, rig and in situ tests	fits in time and cost frame of phase II	increase in confidence	applicable across Europe	solution ready to use	solution has good cost-benefit ratio	railway interest	can be used in full scale railways	comments
lubricants	xxxx	xxxx	xx	xxxx	xxxx	xxx	xxxx	xxxx	xxx	xxxx	xxxx	
friction modifiers	xxx	xxxx	xxxx	xxxx	xxxx	xx	xxxx	xxxx	x	xxxx	xxxx	
water spray	xxxx	xxxx	xx	xxxx	xxxx	xx	x	xxxx	xx	xx	xxxx	
wheel flange lubrication	?											
wheel dampers	xxx	x										
rail dampers	x											
rail coating	?											
rail profile	xxx	xx	xxxx	xxxx	xx	xx	xx	xx	xxx	xxx	xxxx	

<i>steerable bogie or axles</i>												industry responsibility
<i>gauge narrowing</i>	xxxx	x										
<i>curve radius adaptation</i>	xxxx											not testable
<i>shielding</i>	x											
<i>adjustment of train speed</i>	?											
<i>resilient wheels</i>	?											industry responsibility

Table 1: Criteria for measure selection. Number of X denote potential of Phase II. If a measure had no or very little potential for one of the criteria, it was not analysed further. The number of X were determined by consensus of the project group at their first meeting.

Based on **Table 1**, friction modifiers were chosen as the preferred mitigation measures to be tested. Water spray information was to be obtained from the UK via AEAT.

Definition of friction modifier: A friction modifier is a material added to the wheel-rail contact zone that changes the friction condition relative to the case of clean steel-steel contact. In the case of high positive friction material (HPF) the friction is altered in such a way that no negative slope is found in the creepage curve (friction coefficient versus creepage for rolling contact) for a significantly larger range of creepage values than usually found in the case of a clean steel-steel contact; whilst at the same time exhibiting friction coefficients that are not very small relative to the case of clean steel-steel contact. This friction coefficient is necessary to run trains safely. A friction modifier is distinguished from a lubricant, which is any substance that reduces friction by providing a smooth film covering the rail.

2.3.2 Testing procedure

The testing was undertaken in the following steps:

- Development of measurement protocols for rig tests and field tests.
- Rig tests
- Field tests with friction modifiers in Switzerland, France and UK.
- Final rig tests on 1:1 DB rig

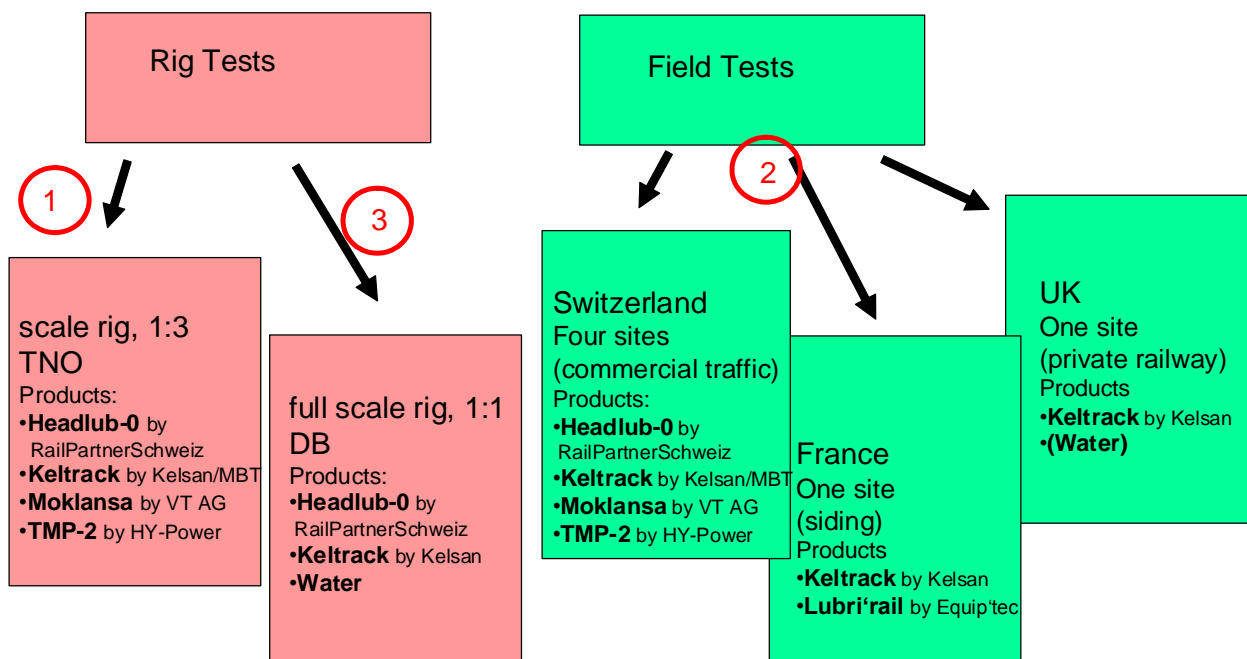


Figure 2.3.2: Testing procedure. Numbers indicate testing order.

2.4 Division of labour

The work was divided among the project partners in the following way:

SBB: Jakob Oertli Bernhard Müller	<ul style="list-style-type: none"> • Overall project leadership • Leadership of WP 5 • Leadership of WP 7 • Measurements on four in-situ sites in Switzerland • Participation in measurement protocol for WP5
DB Bernd Asmussen	<ul style="list-style-type: none"> • Participation measurement protocol WP6 • Full size rig tests • Project management WP 6
SNCF Franck Poisson	<ul style="list-style-type: none"> • Participation measurement protocol WP5 • Installation and measurement of two in-situ sites in France • Participation in reporting on safety, environmental performance and costs
AEAT UK James Block Steve Cawser	<ul style="list-style-type: none"> • Participation in measurement protocol of WP5 and WP6 • Installation and measurement of one site in Britain • Providing water spray data
TNO Marcel Janssens	<ul style="list-style-type: none"> • Leadership of measurement protocols WP5 and WP6 • Scale rig tests
ISVR David Thompson	<ul style="list-style-type: none"> • Provide link to theoretical models (UK project) • Participation in rig tests

Table 2.4: Division of labour among participants.

2.5 Summary project design

A summary of the entire project design including Phase I and Phase II is given in **Figure 2.5**.

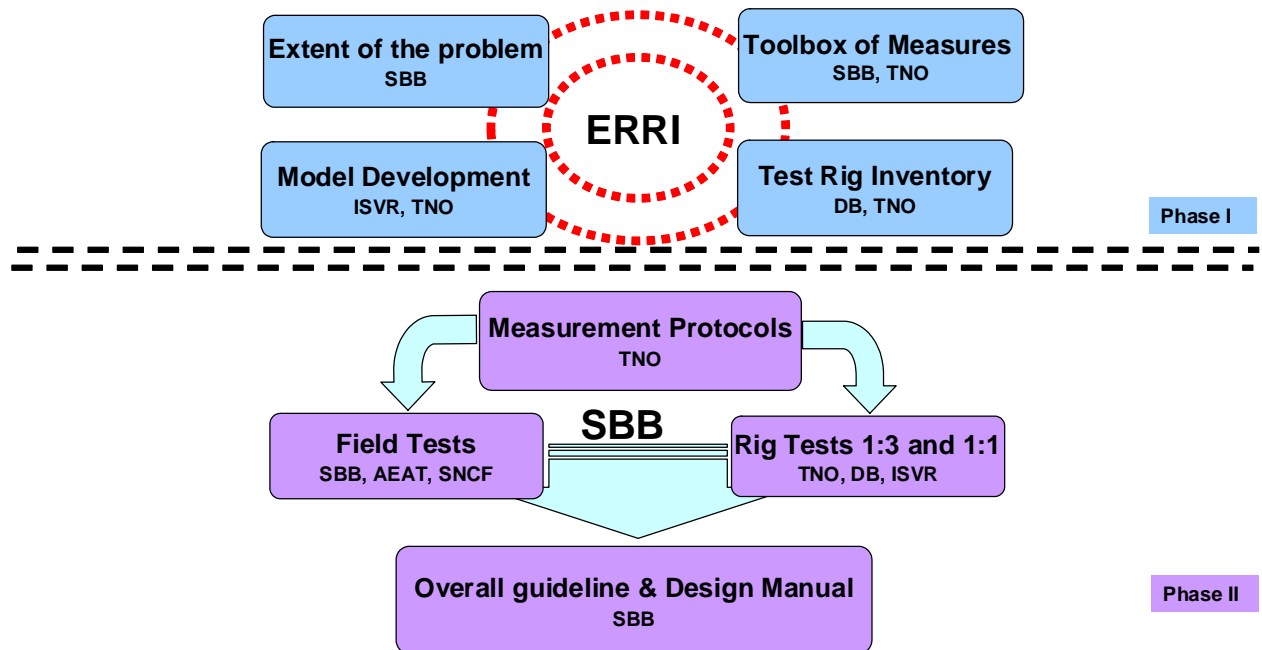


Figure 2.5: Overall project design.

3. Measurement Protocol

The full measurement protocol for field tests is given in **Annex A.1**.

Comparability of results necessary: Curve squeal measurements have been difficult to compare because of varying measurement setups and analyses. One objective of the project was to develop a common measurement protocol for field tests. For rig testing a common protocol was not defined, since this is strongly dependent on the particular rig. The rig test measurement protocols may be found in the rig test documents (**Annexes A.4.3** and **A.4.4**).

Nature of curve squeal noise must be considered: Since squeal noise is of intermittent nature it is usually presented as pass-by levels. These are determined by the sound level when squeal noise occurs (which also includes rolling noise), the percentage of pass-by time during which squeal occurs and the distance of the microphone relative to the location where squealing occurs.

Protocol conventions: A selection of conventions for the protocol were:

- The rails should not be wet. This is determined by visual inspection.
- A series of microphones are required to describe a curve (compare Figure 3.1).
- The preferred microphone position is 7.5 m distance from the track centre line at a height of 1.2 m. These are the same positions as used in the draft ISO 3095 standard.
- The sound levels are recorded in the setting “FAST” (1/8 of a second).

The results are presented in L_{Aeq} pass-by and in histograms for L_p . L_p denotes the sound pressure level in dB(A) with a reference to 20 μ Pa. The L_n values (or the sound pressure level that is exceeded in n % of the time during a curve pass-by) used were: L_{10} ; L_{50} and L_{80} (compare **Figure 3.2**). A reduction in squeal noise is mostly seen in the L_{10} values since

these occur at the highest noise levels. In the main report these are presented in tables summarising the histograms in the annexes.

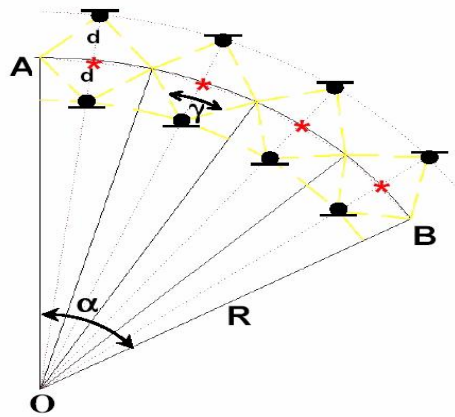


Figure 5.1 Schematic view of a curve with microphone positions.

Figure 3.1 Example of microphone positions in a curve. The curve goes from A to B, whereas R is the curve radius, α denotes opening angle, and microphone positions are shown by \blacktriangledown . For example, a curve with a radius of $R=150$ m, $\alpha=45$ degrees and a length of 118 m would require 8 microphones.

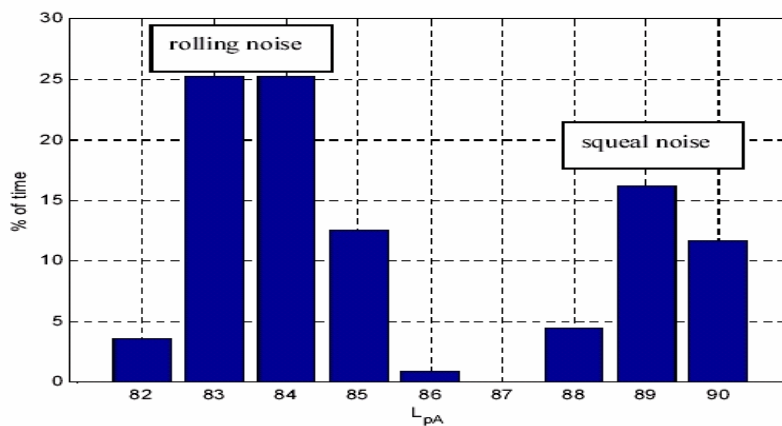


Figure 3.2 Example of a histogram. L_p denotes the sound pressure level in dB(A) with a reference to $20 \mu\text{Pa}$.

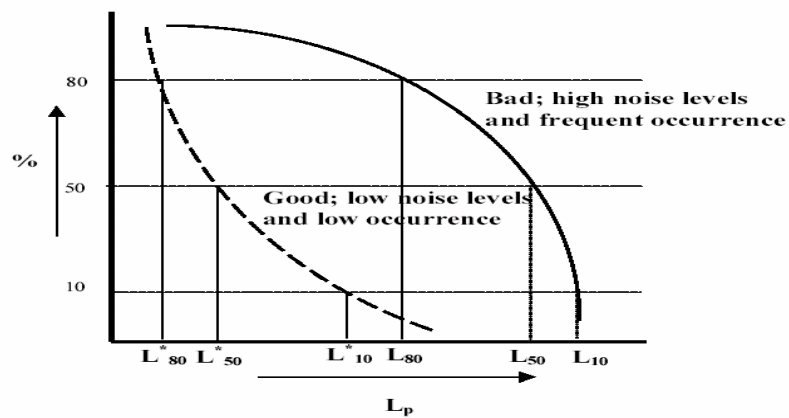


Figure 3.3 Example of L_p representation. X-axis shows cumulative percentage of occurrence. L_p denotes the sound pressure level in dB(A) with a reference to $20 \mu\text{Pa}$. L_n is the sound pressure level that is exceeded in n % of the time during a curve pass-by.

This measurement protocol was used successfully in the field tests: The results correspond to the observations made when visiting the sites. In certain instances, however, the protocol had to be adapted due to budget constraints. In particular this pertained to the number of microphones that could be placed in the vicinity of the curve. This is discussed in more detail in the next chapter.

4. WP5: Field tests

In the following descriptions of the field tests, only the peculiarities of the particular location are noted. In all cases the manufacturers advised on the dosage and assisted in the installation. They agreed on the proper time to undertake the measurements. Three products (Moklansa, TMP-2, and Lubri'rail) were only admitted for use on the gauge face, while the others (Keltrack, Headlub-0 and water) could be used on the top of the rail. Please note that L_p values from different sites cannot necessarily be compared due to different traffic and track conditions. All detailed information may be found in **Annex A.3**.

4.1 Switzerland

For a detailed report, please see **Annex A.3.1**.

Objectives: To test the curve squeal reduction potential for four products on four different sites in the greater Zürich area. Two of the products were applied to the top of the rail while two others were only applied on the flange.

Methodology and description of curves and traffic: A description of the four curves, the traffic, the installations and the applied substance may be found in **Table 4.1.1**. The number of microphones had to be reduced from the number given in the protocol due to budget restrictions. The speeds on all curves were between 40 and 80 km/h.

Site name	Traffic	Curve	Installation	Substance
Zürich Tiefenbrunnen	passenger traffic	$r = 280$ m, length ca. 130 m	RPS Schienenschmieranlage, Rail Partner Schweiz	Outer rail: Tramlub F234 (only gauge face lubrication) Inner rail: Headlub-0 (top of rail application)
Zürich Stadelhofen	passenger traffic	$r = 350$ m, length ca. 250 m	Keltrack Trackside by Kelsan, supplied by MBM Industrietechnik	Outer and inner rail: Keltrack Trackside (top of rail friction modification)
Zürich Flughafen	passenger traffic	$r = 480$ m, length ca. 400 m	Schienenschmiersystem Moklansa E3S by VT AG	Outer rail (gauge face lubrication):Moklansa KUB-2K-20
Eglisau	mixed passenger and freight traffic	$r = 300$ m, length ca. 350 m	Schienenschmiergerät ST-50, TMP-2 by Hy-Power Flexomatic Hydraulik HandelsgesmbH	Outer rail (gauge face lubrication):Schienenschmiermittel TMP 2, Naturfarbe hell

Table 4.1.1: Summary of curve, traffic and installations for the four sites used in Switzerland (r denotes curve radius).

Results: The results are given in **Table 4.1.2**. Values considered were those L_{pmax} values above 85 dB(A) at 7.5 m distance.

location	L_p					
	Untreated			Treated		
	L_{10}	L_{50}	L_{80}	L_{10}	L_{50}	L_{80}
Zürich Tiefenbrunnen	92	87.5	86	94	88	86
Zürich Stadelhofen	92	88	86	92	88	86
Zürich Stadelhofen Ost (first half of curve)	93	88	86	90	87	86
Zürich Flughafen	94	89	87	95	89	87
Eglisau	96	91	87	96	92	88

Table 4.1.2: Summary of results for test sites in Switzerland. L_p : Sound pressure level in dB(A) with a reference of 20 μ Pa. L_n is the sound pressure level that is exceeded n % of the time during a curve pass-by.

There was some improvement in the reduction of squeal noise in Tiefenbrunnen after the installation was adjusted after the measurement campaign of the current project was completed.

Conclusions:

- There is no consistent reduction of squeal noise for any of the products if the entire curve is considered. The only place where a reduction in squeal noise could be observed is on the first half of the Stadelhofen curve with Keltrack. Probably there was insufficient material on the rails to reduce curve squeal in the second half of the curve.
- The curve squeal protocol is a useful guideline. However, in this particular case it had to be adapted to different constraints such as budget limitations.

4.2 France

For a detailed report, please see **Annex A.3.2**.

Objectives: To test the rail lubrication Lubri'rail supplied by the Equip'tec company and the friction modifier Keltrack supplied by Kelsan.

Methodology: The test involved making noise measurements before and after installing the two squeal reduction systems in accordance with the measurement protocol. For safety reasons it was impossible to install the systems on lines with traffic. Therefore the test was undertaken on an SNCF siding in Villeneuve-Saint-Georges. A series of preliminary noise measurements were made in August 2004 supported use of this site. A test train was used instead of commercial runs originally planned in the protocol. The Keltrack product was applied on top of rail, while the Lubri'rail product was applied on the flange. All of the test runs were made on dry rail.

Description of curve: The test track consisted of U50 rails laid on a ballast bed on wooden sleepers, Nabla rail fasteners and ribbed baseplates with a thickness of 4.5 mm. The rails laid in the curve are of 18 m length on the inside of the curve and 36 m on the outside. The curve had a radius of 150 m, which is the most severe allowed on SNCF.

Description of traffic: The test train consisted of 5 wagons (both 2-axle and bogie types) and a locomotive. The running speeds were 10 km/h.

Results: Applying the test protocol allowed testing the effectiveness of the Keltrack and Equip'tec products in reducing squeal noise in curves. The successive runs wore in the rail and the test train wheels, which caused a gradual increase in the occurrence of squeal.

substance	L_p					
	Untreated			Treated		
	L_{20}	L_{50}	L_{80}	L_{20}	L_{50}	L_{80}
Keltrack	92	76	69	93	88	76
Lubri'rail	92	87	74	84	76	72

Table 4.2 Summary of results for the French test site. L_p : Sound pressure level in dB(A) with a reference of 20 μ Pa. L_n is the sound pressure level that is exceeded n% of the time during a curve pass-by.

Conclusion:

- **Table 4.2** and the report in **Annex A.3.2** shows that on the Villeneuve test site, the top of rail Keltrack did not reduce curve squeal, on the contrary, there was even an increase in noise levels and the nature of squeal noise seemed altered. Conversely the Equip'tec substance applied on the flange was able to reduce curve squeal.
- The curve squeal measurement protocol is a useful guideline to validate the efficiency of a solution.

4.3 United Kingdom

The results are given in **Annex A.3.3**.

4.3.1 Friction Modification with Keltrack

Objectives: To carry out in-situ of commercially available top of rail friction modification. The substance chosen was Keltrack by Kelsan.

Methodology: The measurements were carried out in accordance with the project's curve squeal measurement protocol apart from the number of microphones. Because the rails were jointed, a microphone was placed in the middle of each 20 m rail section, resulting in four microphone locations, equally spaced around the curve. All microphones were located 7.5 m from the track centreline and 1.2 m above railhead height. On the day of the measurements, the weather was fine with low wind speed. The railhead was in good condition with no excessive roughness or wear visible. The Keltrack material was applied to the track using Portec wiper bar applicators at each end of the curve. These were operated by hand pumps to provide the supply of the Keltrack material. The test train was run over the site several times before the beginning of the measurements to ensure good railhead condition. The initial reference case was measured over 12 pass-bys of the test train. This was followed by eight passbys with the Keltrack material present on the railhead.

Description of Curve: The measurements were undertaken at Rowsley in Derbyshire, adjacent to Rowsley South Station on a section of private railway that is of current UK standard railway construction. The curve is approximately 100 m in length and has a radius of approximately 290 m.

Description of Traffic: For the measurements a dedicated train was used. The train consisted of a Class 31 diesel locomotive and five Mark II coaches. The locomotive was set to idle while passing the test site to ensure as little noise contamination as possible. All passenger coaches were unoccupied. The average pass-by speed for the site was measured at 20 km/h, with all pass-bys falling into the 20 – 40 km/h band.

Results: The results are presented in **Table 4.3.1**.

location	L_p					
	Untreated			Treated		
	L_{10}	L_{50}	L_{80}	L_{10}	L_{50}	L_{80}
Location 1	82	79	77	80	78	75
Location 2	80	77	74	78	75	73
Location 3	83	78	76	79	76	74
Location 4	84	79	76	79	76	74
All	82	77	75	79	76	74

Table 4.3.1 Summary of results for the UK test site. L_p : Sound pressure level in dB(A) with a reference of 20 μ Pa. L_n is the sound pressure level that is exceeded n % of the time during a curve pass-by.

At this site, curve squeal noise was not very high at the beginning of the measurement campaign. The reduction in the highest noise levels can be seen in the L_{10} values, with these values reducing for all microphone locations. The data in **Annex A.3.3** show that squeal noise occurs at frequencies above 1 kHz. The squeal noise was of an intermittent nature, and no measurements of very high levels of squeal could be made. However, it appears that the application of Keltrack to the railhead reduces the noise levels emitted by a passing train, with either squeal eliminated or significantly reduced.

Conclusion: The tests carried out on the Rowsley site have shown that the levels of noise produced by a train traversing the curve are indeed reduced. The squeal was eliminated for passenger coaches, with levels for the locomotive significantly reduced.

4.3.2 Water Spray

Detailed results can be found in **Annex A.3.2**.

Objectives: The UIC project only included tests on commercially available friction modifiers. As shown in phase I of the curve squeal project, application of water can have the same effect. The following is a summary of data provided by AEAT UK on tests done for Network Rail.

Methodology: Water is supplied with a track mounted spray system. It is in operation from April to October. Outside of these months the pipe work is drained to prevent damage due to freezing. Due to the intermittency of curve squeal noise generation, the effectiveness of the mist spray system was assessed by automatic long-term monitoring of the noise generated by the passing trains, installed and operated by AEA Technology Rail. The system consisted of microphones, wheel detectors, video cameras, temperature and humidity sensors, plus a cellular modem for remote control and data retrieval. The measurement protocol was not used because these studies were not part of the UIC project.

Description of Curve: The track has an approximately 300 m radius on a 500 m long curve and is located in Barnt Green between Birmingham and Bristol.

Description of Traffic: Squeal noise was generated by Class 323 Electric Multiple Unit (EMU).

Results: The results are given in **Table 4.3.2**.

Mitigation	No squeal	Intermittent squeal	Squeal noise
No mitigation	60 %	26 %	14 %
Mist spray system	97.5 %		2.5 %

Table 4.3.2. Effect of the mist spray system on curve squeal. Percentages are based on time during which curve squeal occurs.

Conclusion: The track mounted mist spray system reduced almost all squeal noise. Operational and long-term reliability problems are being addressed by system improvements. Further reductions in the occurrence of squeal noise are expected following improvements.

5. WP6: Rig tests

5.1 Scale rig tests

The scale rig tests were undertaken on the TNO scale test rig, shown in **Figures 5.1.1** and 5.1.2. The reports are in **Annex A.4.3**. The scale factor of the rig was 1:3.68. Transformation of the results to full-scale situations can only be done by applying the appropriate scaling laws and considering both the specific rig conditions and the full-scale conditions. Please refer to the report in the mentioned annex for more information on this subject.

Objectives: The following tests were conducted on four different products (Headlub-0, Keltrack, Moksansa, Hypower):

- ability to eliminate squeal
- durability in test rig conditions
- friction coefficient on the test rig
- the effects of the rolling angle on friction

For this purpose, the following tests were undertaken:

- the change of friction over time
- the influence of rolling angle on friction
- the influence of dosage on friction
- the influence of dosage on sound levels
- measurement of sound spectra

Methodology: For each test, a known dosage was applied on the top of the “rail” in the rolling line. The rollers were cleaned between each measurement. The dosage was re-applied each time. An even layer of product was achieved with a run-in at a low speed.

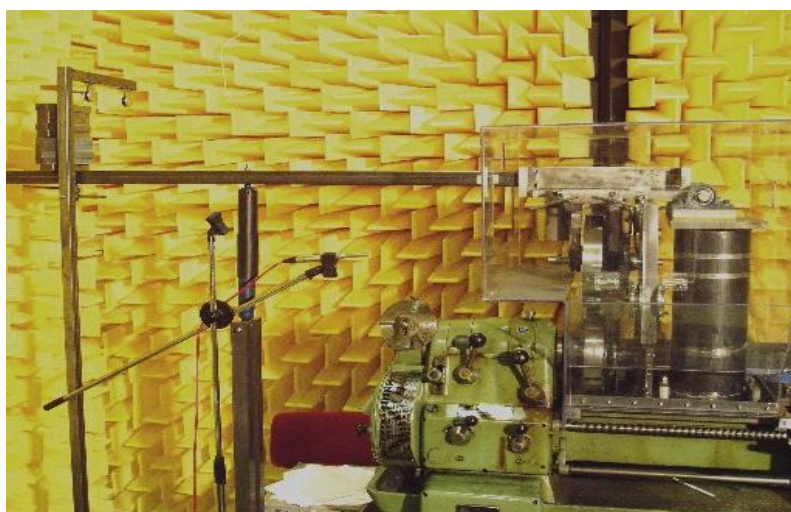


Figure 5.1.1 Photograph of scale test rig

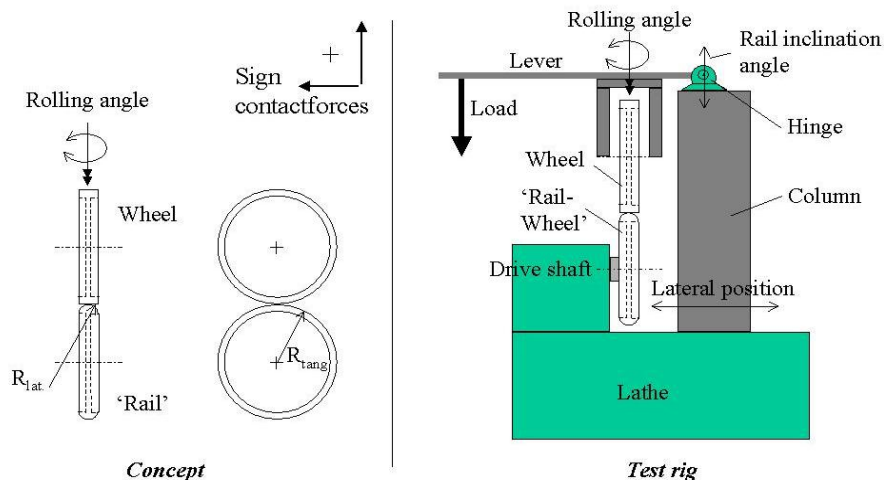


Figure 5.1.2 Concept and schematic drawing of scale test rig

Results and conclusions:

- All materials tested eliminate squeal in the testing conditions.
- The minimum dosage is equal to the dosage to cover test wheel rolling line.
- The Keltrack product was the only material that exhibited high positive friction behaviour, Headlub-0, Moklansa, Hy-Power yielded very low friction
- Keltrack eliminated squeal up to rolling angles of about 1.5 degrees. For higher rolling angles, friction was similar to that of the clean wheel and squeal occurred.
- The duration of the effect was short for Keltrack, intermediate for Moklansa and Hy-Power and long for Headlub-0.

5.2 Full scale rig tests

The full-scale rig tests were undertaken at the Brandenburg-Kirchmöser test site of the DB. Compare **Annex A.4.4** for detailed results.

Objectives: The objectives were to test the suitability of the rig to investigate curve squeal questions and to determine the ability of two friction modifiers (Keltrack and Headlub-0) as well as water to reduce curve squeal.

Methods: The tests consisted of two parts:

Preliminary tests to generate squeal noise: In a first stage it was necessary to simulate squeal noise on the roller rig. This required adjustment of speed, rolling angle and lateral displacement during each test to reach the “squealing state”. Unlike usual observations on track conditions, both the “inner” and the “outer” wheel squealed on the roller rig. The rail roller also squealed, but with considerably less energy. Both frequencies were consecutive in the spectrum with a resolution of 32 Hz. These frequencies correspond to eigenfrequencies of the wheel as shown by the frequency response function measurements of wheel and roller.

Tests with friction modifiers and water: In a second stage the effect on squeal of two friction modifiers, Headlub-0 and Keltrack as well as water was investigated. In each case proper application of the materials immediately suppressed squeal noise.

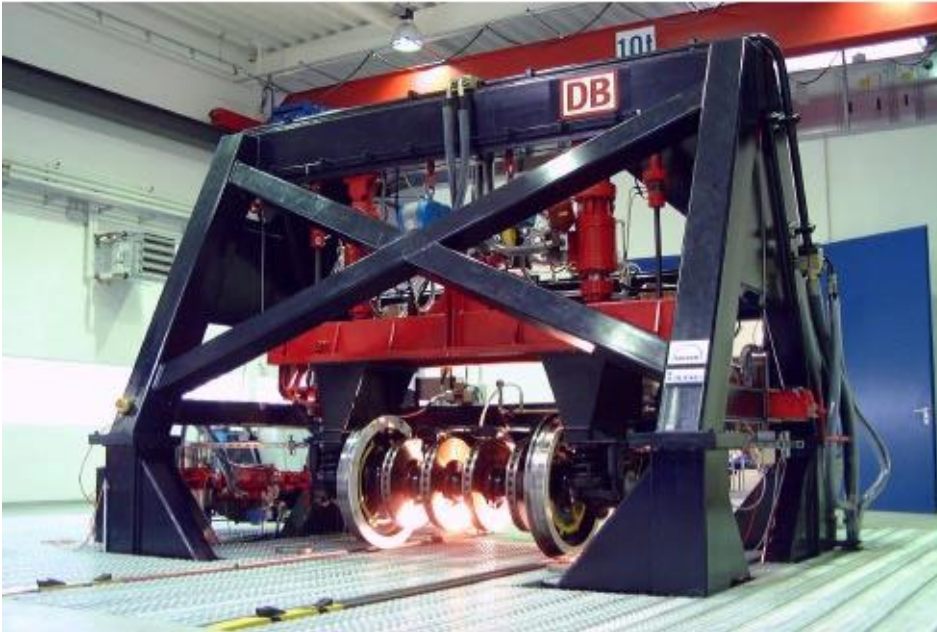


Figure 5.2. Photograph of full-scale rig.

Results and conclusions

- Applying Keltrack to the rail roller surface eliminated squeal for up to 5 minutes and reduced it for up to 16 minutes, depending on the product quantity, without a linear relation between the time and the amount of product applied. Squeal not only disappeared when Keltrack is applied to both rail rollers, but also if it was only applied to the inner or outer rail roller.
- Headlub-0 eliminated squeal for up to 13 minutes when applied to both wheels or to the inner wheel. The application to the outer wheel did not have any effect on squeal during the tests.
- Indications were found of a linear relation between product quantity and time for which the squeal noise was suppressed.
- The friction coefficient of both friction modifiers was between 0.2 and 0.3.
- When sprayed in sufficient quantity, water was also found to be a good solution to suppress squeal. Providing the surfaces were wet, squeal noise disappeared. It reappeared, however, as soon as the water was turned off.

6. Costs, environmental and miscellaneous issues

Comparing costs, life cycle times, environmental and other issues were not the main focus of the report. However, several qualitative observations were undertaken that are summarised here. More details may be found in **Annex A.3.1**.

Costs and life cycle: Cost and life cycle information was obtained directly from the suppliers. Investment and substance costs must be distinguished. In terms of investment costs, Keltrack and TMP were the lowest and Hypower-0 the highest. The other substances were priced between the costs for these. There is no breakdown of the costs for water, so this installation cannot be compared. In terms of substance costs (where known) Headlub-0 was the least and Keltrack the most expensive.

issue	product and place of application in field tests					
	Keltrack by Kelsan top of rail	Headlub-0 by Railpartner top of rail	Moklansa by VT AG flange	TMP-2 by HY-Power flange	Lubri'rail by Equip'tec flange	Water top of rail
investment costs in € per 300 m curve	€ 13,500	€ 20,320	€16,667	€ 13,000	€ 4,020	€ 330'000*
maintenance costs in €/y	no information received from supplier	€ 2,440	no information received from supplier	no information received from supplier	€ 200	
substance costs per four axle wagon in €	€ 0.0035	€ 0.00012	no information received from supplier	no information received from supplier	€ 0.0015	
years until replacement	no information received from supplier	10	no information received from supplier	no information received from supplier	15	

Table 6: Installation costs and life cycle. Prices are for location shown. *Price for test in the UK is calculated for 300 m and included installation, water for three years, all maintenance and all tests.

Environmental impact: The ingredients of the substances were evaluated by a chemist of the SBB Rail Environmental Center. None of them were found to have contents that may cause adverse environmental impact. It must be stated, however, that the Keltrack material remained very visible on the track and caused toilet paper as well as other litter and debris to become stuck to it.

Electrical conductivity: No problems could be observed with any of the substances.

Maintenance friendliness: All substances were friendly in terms of maintenance. Keltrack required the largest maintenance attention.

7. Other research activities

In Phase I of this UIC project a calculation model for curve squeal was developed [3]. Further development of this model is taking place in a related project in the UK. This is part of 'Rail Research UK' a consortium of 8 universities working together on railway research topics with around twelve projects grouped in three themes. Funding is provided by the Engineering and Physical Sciences Research Council (EPSRC) of the UK. This was launched in May 2003. The project of direct relevance to the Combating Curve Squeal programme is project A3 'Railway noise: curve squeal, roughness growth, friction and wear'.

Project A3 has brought together teams from Southampton (ISVR) and Manchester Metropolitan University (Rail Technology Unit) to investigate the problems of curve squeal noise and the development of roughness on rails. The latter problem is of importance for the control of rolling noise. These are different but related problems, both requiring a detailed knowledge of the wheel-rail contact and friction behaviour at high frequencies, wheel and track dynamic behaviour and vehicle dynamics. ISVR and MMU bring different aspects of this expertise to the collaboration. The project continues until September 2006.

The main achievements and outputs to date include:

- Further development of the prediction model for curve squeal that includes not only lateral motion but also longitudinal and spin motion, making it suitable for predicting the effects of flange contact.
- Implementation of a falling friction characteristic in a vehicle dynamics package (Sim-pack) and the development of bespoke curving prediction routines that can be linked directly to the squeal noise model.
- Development of a model for roughness growth which includes varying track support stiffness and longitudinal creepage and a 2D contact and wear model. This enables roughness growth to be predicted from an initially smooth rail. A 3D contact and wear model for roughness growth prediction has also been developed and initial results for sinusoidal initial irregularity produced.
- A series of tests has been carried out on a twin disk rig at TNO in Delft under a link with the UIC project. The rig was modified to study the effect of longitudinal creep [4]. This experience is invaluable in the development of test rigs at MMU and ISVR, which will be used for the validation of squeal and roughness growth models.

In September 2004 the Eighth International Workshop on Railway Noise was hosted by ISVR at Buxton, UK. A session on curve squeal included, as well as paper on the UIC project [5], three papers from a French consortium that have completed an investigation of curve squeal from urban railways [6-8].

8. Summary of Results and Conclusions

Measurement protocol works: This measurement protocol was used successfully in the field tests: The results correspond to the observations made when visiting the sites. In certain instances, however, the protocol had to be adapted due to budget constraints. In particular this pertained to the number of microphones that could be placed in the vicinity of the curve

Results vary from test site to test site: The results are summarized in Table 7. Keltrack eliminated squeal on the rigs, was successful in the UK, partially successful in Switzerland but failed in France. Headlub-0 only worked on the rigs in the tests undertaken, although further work outside of the project in Switzerland indicate that by improving product application squeal can be eliminated. Moklansa and TMP eliminated squeal on the test rig (where they were applied to the top of rail) but not in the field (where they were applied on the flange). However Lubri'rail, which was also applied on the flange, eliminated squeal in France. Water, finally, eliminated squeal both on the rig as well as in the field.

test site	product and place of application in field tests					
	Keltrack by Kelsan	Headlub-0 by Railpartner	Moklansa by VT AG	TMP-2 by HY-Power	Lubri'rail by Equip'tec	Water top of rail
1:3 rig at TNO	YES (top of rail)	YES (top of rail)	YES (top of rail)	YES (top of rail)		
1:1 DB rig	YES (top of rail)	YES (top of rail)				YES (top of rail)
in-situ Switzerland	only on first half of curve (top of rail)	NO (top of rail)	NO (gauge face)	NO (gauge face)		
in-situ France	NO (top of rail)				YES (gauge face)	
in-situ UK	YES (top of rail)					YES (top of rail)

Table 7: Summary of squeal elimination at the different test sites. A YES indicates that squeal noise was eliminated while a no shows that it was not.

Research to date shows no optimal solution: The tests undertaken show that to date there is no optimal solution against curve squeal. The trade off must be determined separately for each curve. Considerations include:

Keltrack: The product seems to work in most cases if enough of the product is on the rail. This may require application of the product at more than one location along the curve. It does not appear to work on very tight curves as at the test site in France. The product has a high positive friction, so that train braking is not impaired. However, the product is expensive and rather unsightly and may therefore be unsuitable in train stations.

Headlub-0: The product did not work in the field tests in Switzerland, although some success could be achieved when the application was adapted for tests in Bern and Tiefenbrunnen (outside of this project). If the adaptation leads to an increase in the dosage, then the effects on braking must be considered. The product showed high positive friction on the 1:1 rig but not on the 1:3 rig. The product is comparatively less expensive, however an extensive dosage optimisation must be undertaken and further tests on friction coefficients would be useful.

Moklansa and TMP: Tests in Switzerland showed that flange lubrication had no influence. However, it is possible that under special circumstances such as in were given in France, these products may show an effect.

Lubri'rail: This product was able to eliminate squeal on the curve tested in France. However, since no rig tests or other curves were tested, the information on this product is too small to allow an adequate discussion. Further tests are required on less severe curves with running traffic.

Water: Water eliminates curve squeal and displays an adequate friction coefficient. However, water is unsuitable at freezing temperatures.

Products must be tried on separately on every curve. It is suggested that the railways give the responsibility to the producers. A railway would only pay for a particular installation if it was actually successful in practice.

Curve radius may influence effectiveness of products: It is possible that curve radius is a factor in explaining the different behaviour in products tested under different circumstances. Results from the TNO rig tests show that for higher rolling angles, the friction was similar to that of a clean wheel and squeal occurs even though the product has been applied. Higher rolling angles may correspond to smaller curve radii, which may in turn explain why the product did not eliminate curve squeal in France. Curve radius may also influence the effectiveness of flange lubrication. Possibly, more squeal noise originates from flange contact in tight curves, which is therefore reduced with flange lubrication. However, more tests would be required, to substantiate this hypothesis.

9. Suggestions for next steps

The following next steps are suggested:

Increase top of rail dosage: It is possible that a higher dosage of top of rail products may improve squeal noise reduction. However, this will lead to a decrease in braking performance. Further tests should find an optimum between the two factors. Results outside of this project, where SBB is currently testing Headlub-0 in the Bern train station, show that increases in dosage reduce curve squeal, however at the French site in Villeneuve increasing Keltrack dosages did not eliminate curve squeal.

Network: Start a curve squeal network, where new results could be exchanged. The text structure in **Annex A.5** could offer a possible structure for such an exchange. However, a responsible institution must be defined. It is suggested that UIC undertake this job or delegate it to one of the project partners.

Improve application: Application improvements may also lead to improved effectiveness.

10. Reporting

Aside from this report, the results were presented at a workshop in Olten, Switzerland on March 9, 2005. This workshop was attended by 35 persons and generated a large interest. After the workshop a survey was undertaken and the large majority of the attendees were very pleased with the contents and the moderation. In addition, a part of the results were presented at the 8th International Workshop on Railway Noise in Buxton, UK and at the UIC Environmental Coordinators Conference in Berlin, November 2004.

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