Preventing railway Squeal Noise through railhead optimisation

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Abstract

A new development to prevent railway squeal noise is discussed in this paper; optimizing wheel-rail friction behaviour and wheel-rail contact position by introducing a new rail surface design. The technique of particle impregnation is applied to achieve this innovation. In this process material particles, selected to optimise the interface to reduce squeal noise and wear, are impregnated directly into the rail running surface resulting in a sustainable solution.

The introduction of new interface materials provides the unique and innovative opportunity to combine surface friction design with rail profile design. Squeal noise prevention combining surface friction and profile optimisation can produce a quiet and stable system.

The research on particle impregnated rail development is carried out within the National Dutch programme 'IPG' (Innovation Programme Noise). The approach and results of it's final phase (field testing) will be presented here. The paper will discuss prototype development, test site selection and preparation. Unfortunately field test results were not available in time to be included in this paper.

Introduction

When a train is negotiating a narrow radius curve or switch a high-pitch "screeching" noise can sometimes be heard. This type of railway noise is referred to as 'Squeal'. The origin of curve squeal occurrence has been reported in several papers [4,7,11]. Squeal is generated from lateral slip between wheel and low rail. Further it is understood that Squeal occurrence is dependent from the friction behavior in combination with the size and direction of the acting forces in the contact patch; more specifically the presence of the so-called 'stick-slip loop. Since high levels of lateral slip are mainly occurring in narrow radius curves, squeal is a phenomenon related to curves in this category. For most railways narrow curves typically are defined to have a radius below 500 meters in metro and tramway below 100 m.

Curve squeal is characterized by extreme high noise levels (up to 120 dB where 'normal' curve noise is of the order of 70 to 80 dB) resulting in a major discomfort to local residents, passengers and train operators. With train traffic increasing it is becoming more and more difficult to comply to national noise legislations and license, leading to bottlenecks in track capacity distribution resulting in efficiency decline of the rail business.

Early 2006 a project started within the national Dutch noise reduction programme 'IPG' (Innovatie Programma Geluid) aiming to develop and introduce a sustainable solution to prevent curve squeal within the Dutch rail infrastructure.

Figure 1, IPG logo 'Sustainable solution Curve Squeal'

Developing a sustainable solution

Squeal involves a so-called ‘on-off’ system; it is either there or not. The chance of squeal occurring can be reduced for a given site by taking preventive measures. The higher the ‘instability’ of a given site, the more frequent a situation will arise in which squeal occurs. The purpose of preventive measures is to make the instability of a site as low as possible, so that only in extremely unfavorable conditions squeal noise be can expected.
The occurrence of squeal is of a discontinuous nature. This is caused by the variation in contact positions, forces, profiles, track gauge etc. Weather conditions (air humidity) influencing friction behaviour also have a considerable influence on whether or not curve squeal occurs.
From the UIC final report on combating squeal noise [9], reporting a friction modifier benchmark investigation, it was understood that to date there is no optimal solution against curve squeal. In this report asymmetric rail profiles were recognized as a promising effective mitigation measure.

Understanding the ‘triggers’ for squeal noise occurrence, it was recognized that significant improvement can be obtained by enhancing the surface material properties (friction behaviour) in combination with profile optimization to act upon slip levels and wheel-rail contact position and forces. The selection process of the proposed sustainable solution together with laboratory testing results have been published in [15]. A short overview of the rail surface optimisation development process is discussed in the next two paragraphs. Subsequently intermediate results regarding field testing for squeal noise prevention are presented.

Rail friction optimisation

To manage friction behaviour in a sustainable way, we need to move away from the traditional steel-steel interface. Surface optimisation can take place through particle impregnation [12], resulting in a PI-rail®. In this impregnation process, material particles selected to optimise the interface to reduce squeal noise and wear are impregnated directly, without mechanical pre-treatment, into the rail running surface resulting in a sustainable solution. Hard wear-resistant ‘islands’ are produced that are load-bearing in the contact surface with the wheel, dominating the friction behaviour.
During the first phase of development and laboratory promising materials have been selected not only from a functional but also from a production technology point of view. Titanium Carbides (TiC) and Tungsten Carbide (WC) have been selected for their ability to provide a load bearing and wear resistant surface. Boron nitride (BN) has been selected to further enhance friction behaviour. BN is often referred to as ‘white graphite’. It is a lubricious material with excellent thermal stability. After the introduction of unleaded fuel, BN is introduced into the automotive industry as a valve seat insert material to take over the lubrication functionality of lead [8]. It is also used in brake linings of the Formula I race cars to reduce squeal noise during braking.

The development process on rail impregnation materials concentrated primarily on the friction characteristic of the impregnated surface and resistance to wear. These have been determined by means of a ‘twin-disk’ testing machine. On this type of test rig the wheel-rail contact is imitated to scale and the situation which normally leads to squeal noise can be simulated (1:3 scale model). At the DeltaRail twin-disk test rig the coefficient of dry friction was established in relation to longitudinal slip. Squeal behaviour is tested by applying and steadily increasing the yaw angle of one of the disks; the resulting lateral slip creates an increasing squeal instability.
The Swedish company Duroc AB has experience with the technique of impregnation and the use of wear resistant material on rail. For this reason Duroc was invited to participate in the project. Impregnation of all prototypes have been performed by Duroc.
Laboratory tests established that for two types of impregnation the friction behavior was very promising. For these types (TiC-BN and WC-BN) a significant decrease of the dry friction coefficient was measured. Around the operational slip of 1%, the coefficient of friction is 25 % below the value for the steel-steel combination. This will result in a significant reduction in squeal instability.

This was underpinned by the twin disk squeal tests; where the steel-steel combination already produced earsplitting squeal noise starting from a very small yaw angle, no squeal noise could be generated for the impregnated disks at even the maximum yaw angle (~ 2% lateral slip). From the laboratory endurance test (imposing 15 MGT of accumulated load at narrow curve contact conditions) the expected sustainability is very promising. For both tested impregnations an excellent behaviour was observed; no significant wear, dry friction coefficient stabilizing at f = 0.15. The wheel disk showed a smooth and regular surface with no signs of extreme wear or galling. Additional research concluded that the impregnations impose no negative effect on train detection nor ultrasonic inspection. Further details of the material development research is published in [15].

Rail profile optimisation

From earlier research and publications [1,2,3] carried out into profile optimization it was recognized that by using asymmetrical profiles a reduction can be obtained in the frequency of occurrence of curve noise. To decrease squeal instability rail profiles should: reduce lateral slip, position the contact of the wheel on the low rail towards the flange and stimulate longitudinal slip.

The efficiency of this asymmetrical ‘anti-squeal rail profile’ is also affected by the contacting wheel profile and running properties of the rolling stock. Design and effectiveness of a anti-squeal rail profile therefore partly depends on the local track and rolling stock characteristics. The development of the squeal optimised rail profile therefore is supported by means of train/track simulations (calculation of wheel-rail contact positions, occurring slip, stress levels). The required input of the model includes in addition to the track characteristics (such as curve radius, cant of the track, installation gradient, permissible speed) also the material data that affect the contact position between wheel and rail; for example the wheel profile and yaw stiffness of the wheel set. The design principals of the anti-squeal rail profile have been validated using the twin disk test rig. This is presented in [13].

Twin disk tests confirmed that the position of contact on the wheel at the low rail strongly influences squeal instability. The generation of squeal could be controlled by moving the contact position (see figure 2). Situation 1 (red) is generating squeal noise during twin disk testing. Due to the lateral slip a resulting moment is enforced on the wheel. When the contact between wheel and rail is positioned on the outside of the wheel (situation 1- red) the resulting moment will contribute to the loading of the contact increasing the vertical force (Q1>Q). This will result in an aggravating and instable process of increased lateral slip values followed by an increased resulting moment. Wheel vibration will occur followed by squeal generation. For situation 2 (green) the contact position is towards flange side of the wheel. The resulting moment is relieving the contact (Q2<Q), avoiding an instable process and decreasing squeal instability.

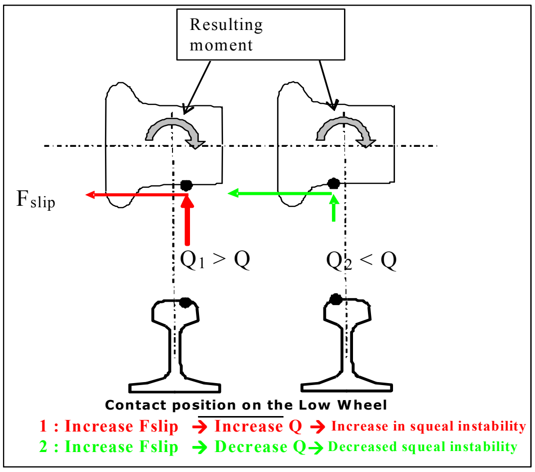

Figure 2, Influence of the contact position between wheel and low rail on squeal instability. The squeal test rig generated squeal only for the red situation. For the green situation squeal remained absent.

These validated insights were the starting point for further simulation work resulting in the designed anti-squeal profile. This work has been described in detail in [13]. The optimisation work has resulted in a anti-squeal rail profile, to be applied to the low rail, of which it is expected to reduce the squeal instability significantly (see figure 3). Profile optimisation of the high rail also was investigated but did not call for changes to the standard UIC 54 profile. From the modeling results it became clear that flange wear of the high rail and increasing track gauge will negatively influence the effect of the proposed measure on the low rail.

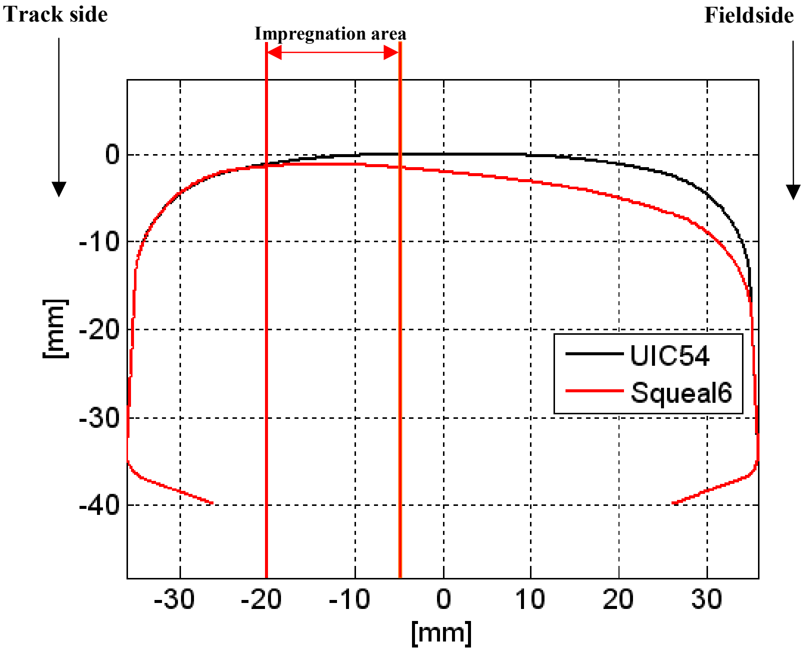

Figure 3, the proposed anti-squeal rail profile for the modelled situation (low rail). Area of wheel –rail contact, to be impregnated prior to field testing, is indicated.

Combining rail profile and surface friction optimisation

The stability of the selected anti-squeal rail profile is recognized as a potential risk; it could quickly lose its shape as a result of wear and plastic deformation. In view of the strength and resistance to wear of the impregnating materials selected, together with expected reduction in coefficient of friction, an acceptable life does however seem possible if in combination with the designed anti-squeal rail profile also rail impregnation is applied.

Field testing set-up

Following the promising laboratory results the project went into field testing phase. Early 2007 a site was selected where squeal noise is a known problem. At this site180 meter of particle impregnated rail, partly also fitted with the developed anti-squeal profile, will be put into track. The selected site is situated near The Hague central station. It is a narrow radius curve with a length of 450 m, curve radius 200 m. The high rail is lubricated. Track features of the existing situation are; jointed track, head hardened rail (year of manufacturing 1999, grade R350HT for both high and low rail), UIC 54E1 rail profile, wooden sleepers with base plate in ballast, cant is 65 mm, maximum speed 40 km/hr. Yearly accumulated tonnage is 10MGT. Traffic type is dominantly passenger: commuter Mat’64, DDAR, IRM and ICR coaches.

 	
Figure 4, test site location.	Figure 5, position of the microphone to the track -3,5 m (BS + 0.5 m).

Noise reference measurements were carried out in normal exploitation on a clear day in July (2007) located at 8 positions spread along 350 meters of track. Pass by speed varied between 25 en 40 km/h. Measurements were carried out in accordance with the measurement protocol for curve squeal noise [16,17].
During the reference measurement curve squeal was registered throughout the curve. Squeal noise levels varied from 100 dB(A) to 118 dB(A). As a comparison: the measured average noise level during a train passage without squeal is about 85 dB(A) with peaks up to 97 dB(A). These peaks are caused by rail corrugation on the low rail (for this situation characterized by high levels at the 125 to 400 Hz range, corresponding to the measured pass by speed).

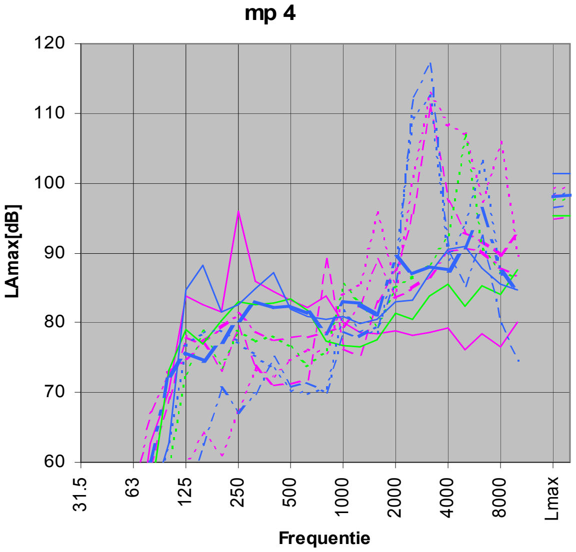

Figure 6, ten individual pass by measurements at measuring position 4.
Squeal is demonstrated at the 4000 Hz peaks, corrugation noise peaks at 250 Hz.

Beside noise reference measurements also visual track inspection and track geometry measurements were carried out (rail profile and track gauge). From this inspection it became clear that the current rail fastening system has been worn in extensively: throughout the curve the foot of the rail has worn in into the base plate resulting in a average gauge widening of 10 mm. Measured maximum gauge is 1452mm, measured maximum horizontal wear of high rail 8 mm.

Since gauge widening negatively influences the effect of the anti-squeal profile it was decided that together with installing 180 meter of prototype at the low rail, the high rail is to be replaced and also all wooden sleepers are to be replaced by concrete sleepers allowing to restore the track gauge to nominal value of 1435mm. This need to extend the scope of track renewal has led to the unforeseen obligation to tender the prototype installation work. Unfortunately the tendering process has led to a significant delay; the installation is now planned for summer 2008. For this reason field test results could not be included in this paper.

Prototype manufacturing

180 meter of prototype rail was manufactured:

n x 12 meter length	PI treatment	AS-profile	grade
3	TiC-BN	yes	R260Mn
3	TiC-BN	no	R260Mn
3	WC-BN	yes	R260Mn
3	WC-BN	no	R260Mn
1	yes	yes	R350HT
2	no	yes	R350HT

Table 1: Prototype overview.

Switch manufacturer WBN Wisselbouw Nederland B.V. (company within the VAE group) has machined the anti-squeal profile using a shaper (see figure 7). The finishing stayed within the specifications as draw up for this test: target profile +/- 0.5 mm, straightness ≤ 0.45 mm over 1500 mm length and roughness ≤ 10 µm. Subsequently the rails were transported to Duroc AB for particle impregnation. After completion of the surface treatment the rails were delivered back to Voest Alpine RailPro where they are stored, waiting for installation. The individual prototypes will be joined together using a conventional thermite welding technique.

Figure 7, machining the anti-squeal rail profile.

Figure 8, prototypes ready for installation.

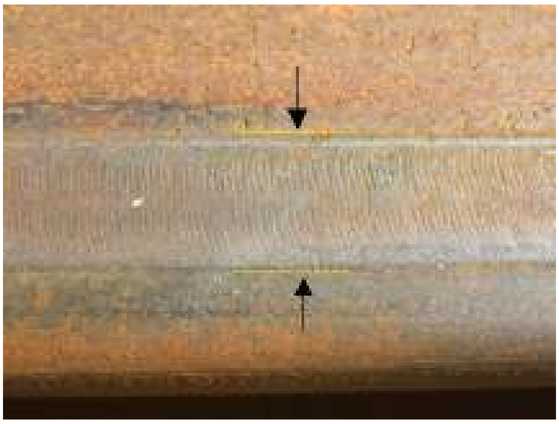

Figure 9, impregnated area.

Conclusions

Enhancing rail surface material properties through particle impregnation in combination with optimizing rail profile design, both designed to avoid stick-slip between wheel and rail, is recognised as a sustainable solution to prevent squeal noise.

Following the promising laboratory validation results the development has been rolled out from laboratory into full scale field testing. 180 meters of surface optimised rail have been manufactured, ready for installation in track; rail with surface impregnation, rail fitted with the developed anti-squeal profile and rail combining both optimisations. A reference has been established for the selected test site.

Effectiveness of these squeal preventing measures will be determined by the level to which the squeal instability is decreased. Combining the designed anti-squeal profile and surface impregnation is expected to be the most effective squeal noise mitigating measure, resulting in a maximum decrease in squeal instability and maximum increase in sustainability.

The potential of the presented squeal preventive measure is enormous. The presented solution is expected to provide a sustainable solution, requires no additional maintenance and can be tailored to any given situation. The alternatives that are in the marketplace today can not deliver these advantages.

The unexpected need to extend the scope of track renewal has led to the unforeseen obligation to tender the prototype installation work. Unfortunately this tendering process has led to a significant delay; the installation is now planned for summer 2008. For this reason field test results could not be included in this paper.

Future work

Field testing is to start directly after installation which is planned during the summer of 2008. The effect on squeal instability will become clear already within a short period (a few weeks). To judge its sustainability more time is required; expected is 6 to 9 months. These results will be disseminated in the near future. Also the expected positive effect of rail surface impregnation on detection and on combating slippery track can be incorporated in this research.

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