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ACOUTRAIN: simplifying and improving the acoustic certification process of new rolling stock

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Track21: reducing noise and vibration from ballasted track

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Track21: reducing noise and vibration from ballasted track

The worldwide demand for transport keeps growing yet there is an urgent need to reduce the emission of greenhouse gases, particularly those produced by transport. In response to this, the European Commission White Paper on Transport 2011 identified a goal of achieving a 50% shift of medium distance inter-city passenger and freight journeys away from road, to rail and waterborne transport. In an attempt to meet increased demand, European railways are expanding by upgrading the capacity of the rail network, building new high-speed lines and establishing freight corridors.

Noise and vibration

Although rail is an environmentally-friendly means of transport, it is perceived as noisy. Noise can produce annoyance or, in more extreme cases, adverse effects on human health such as increased stress, high blood pressure or cardiovascular diseases. Public opposition to new rail developments is often focused on the noise impact, either because this is the perceived nuisance or sometimes because it is a convenient handle to legitimise objections.

It is the aim of European legislation, in the form of the European Noise Directive (END), to define a common approach to dealing with environmental noise through the use of strategic noise maps and the introduction of harmonised indicator quantities for measuring noise. Resulting from the END, Action Plans are being produced to reduce noise in targeted areas. While these often concern the installation of noise barriers, recent thinking has started to favour noise control at source as a potentially more cost-effective method of noise control.

Another aspect of European legislation is the introduction of noise emission limits for rail vehicles through the Technical Specifications for Interoperability (TSI-Noise). This has the effect of limiting the noise attributable to the vehicles, but since noise is produced by both vehicle and track, in many cases just as much if not more noise is produced by the infrastructure and this is not controlled by the TSI. Thus there would be little benefit in a quiet vehicle if it runs on a noisy track.

The most important source of noise from moving railway vehicles up to approximately 300km/h is wheel/rail rolling noise. This is a broad-band noise covering frequencies from about 100 Hz to 5 kHz. At higher speeds, aero-dynamic noise also becomes significant. Rolling noise is often exacerbated at elevated structures by vibration transmitted through the track and radiated as noise by the bridge structure.

Wheel-rail interaction is also responsible for vibration of the track at lower frequencies. Between about 4 and 80 Hz, vibration transmitted through the ground is perceived in nearby buildings as ‘feelable whole body’ vibration. The highest levels are usually produced by freight trains, but for high-speed lines there is also the possibility of direct excitation of the ground by high-speed trains. This has resulted in special and costly track/support structure design, for example on HS1. At higher frequencies (around 30 to 200 Hz), vibration transmitted through the ground gives rise to structure-borne noise in buildings. This is common for trains in tunnels, especially metros, but it is also an increasing concern for surface lines in situations where the direct sound is attenuated by noise barriers or other shielding objects.

Track21

Track21 is a UK research programme funded by the Engineering and Physical Sciences Research Council (EPSRC) for a five year period (2010-2015). Led by the University of Southampton, it also includes the Universities of Birmingham and Nottingham as well as participation from Network Rail, London Underground and other industry partners. The aim is to develop a fundamental and linked understanding of the engineering, economic and environmental performance of railway track that will provide the science needed to underpin a radical overhaul in techniques for railway track design, construction and maintenance.

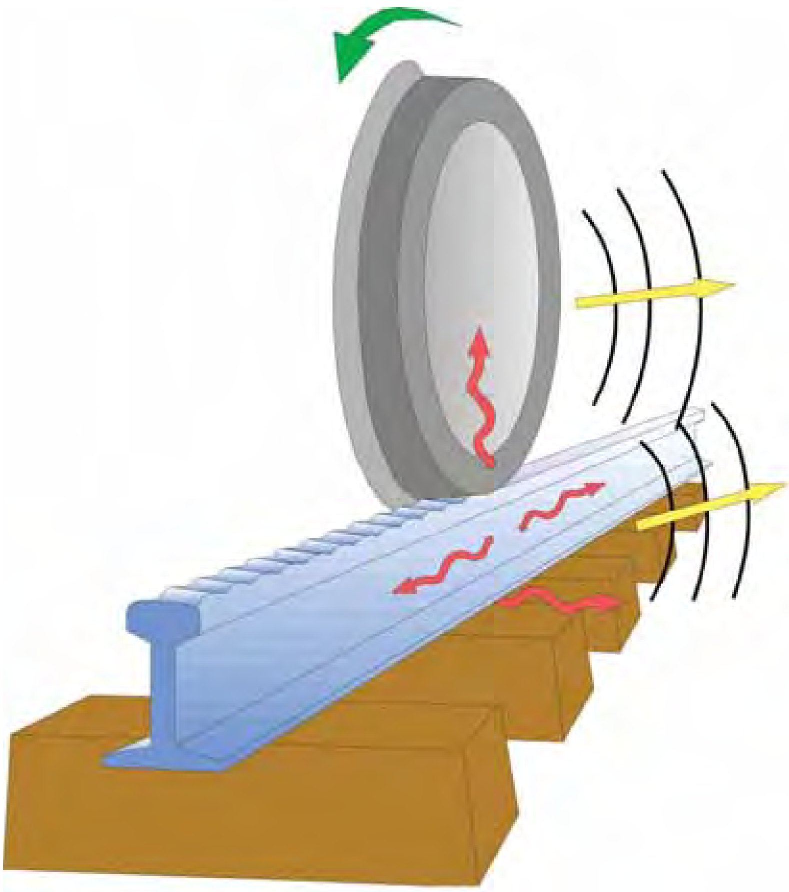

Figure 1: Schematic diagram of the process of generation of rolling noise

Noise and vibration forms one of the key areas of performance that is being investigated.

Rolling noise

Rolling noise is produced by the vibration of the wheels, rails and sleepers. This vibration is induced by the combined 'roughness' of the wheel and rail surfaces, the wavelengths of interest ranging from around 5mm up to 200mm. This noise generation process (see **Figure 1**), is described by the TWINS model for rolling noise, which was established for European railways by the author in the 1990s and has become the de facto standard.

Within Track21, aspects of the model related to the track are being refined. As part of the research, a reduced scale model track is being built which will allow acoustic testing and enable improved calculation models to be developed and validated.

One aspect that is being investigated is the effect on the sound radiation from the rail of the proximity of ballast and sleepers. Ballast is an acoustic absorbent which, according to our measurements, absorbs around half of the sound that is incident on it. It is therefore commonly held that slab track is much noisier than ballasted track because this absorbing surface is missing. In reality, although slab tracks are indeed usually somewhat noisier than ballasted track, this is only part of the explanation. A more significant effect is the use on slab track of soft rail fasteners which result in low decay rates of vibration along the rail. The further the vibration travels along the rail, the greater the noise radiation.

The track decay rate has become acknowledged as a major parameter in railway noise; it is specified for example in the TSI-Noise that the decay rate must exceed a certain limit for a track to be suitable for vehicle emission measurements. In order to reduce environmental noise, the track decay rate should be increased. Stiff rail pads could be used but these

> ***'Wheel-rail interaction is also responsible for vibration of the track at lower frequencies'***

have other less desirable effects. Therefore, in recent years, rail dampers (or 'absorbers') have been developed to increase the decay rate. They have been shown to have potential to achieve noise reductions of 3-6 dB, depending on the track to which they are fitted.

The importance of surface roughness for noise generation has led to an investigation of typical wheel and rail roughness levels in the UK. To complement established rail roughness measurement methods, a device to measure wheel roughness has been developed

Figure 2: Wheel roughness measurement device developed at ISVR

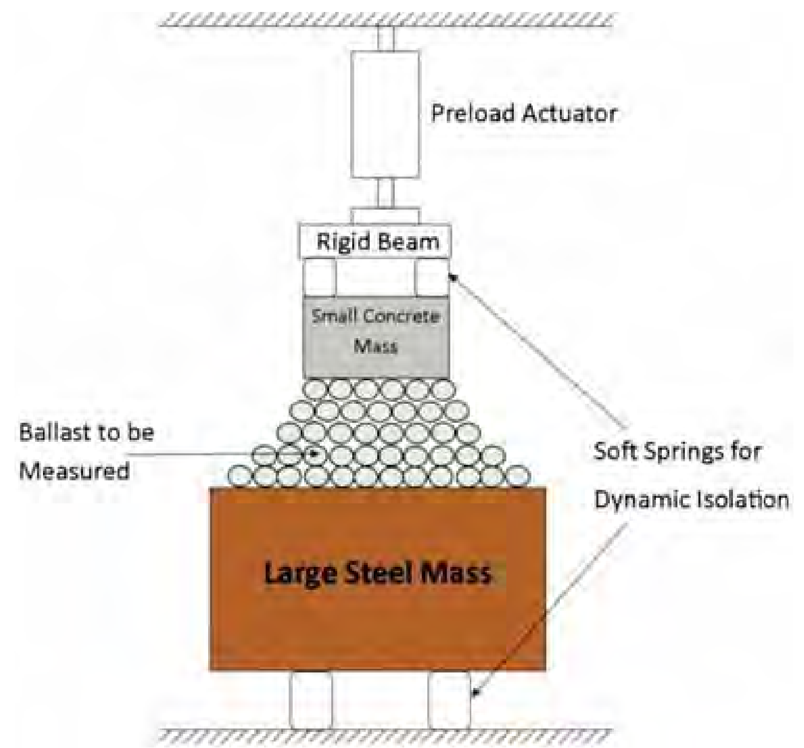

Figure 3: Test rig for measurement of ballast dynamic stiffness

(see **Figure 2**, page 30). As well as 'acoustic' roughness, it determines the out-of-roundness of a wheel and the corresponding longer wavelength irregularities of relevance for ground vibration.

Ballast dynamic stiffness

The dynamic stiffness of the ballast layer affects the transmission of vibration into the ground and into structures such as bridges, as well as the vibration of the track itself which affects the radiated noise. This dynamic stiffness is known to depend strongly on preload and excitation frequency. In order to measure this stiffness, a full scale laboratory test rig is being constructed (see **Figure 3**). The ballast layer is contained between a concrete block representing the sleeper and a large seismic mass. The rig allows a range of realistic preloads to be applied and the dynamic stiffness to be determined for frequencies up to about 1 kHz using a separate vibration excitation. The rig will be used to measure the stiffness of new and aged ballast and to study the effects of ballast grading, etc. It will be possible to measure the dynamic material characteristics of other track and sub-base configurations and components using the same apparatus including rail pads and under sleeper pads, etc.

In parallel with this work, tests are under way within Track21 to determine the degradation of ballast under repeated loading of up to three million load cycles applied through a full size sleeper. By measuring the modes of vibration of this sleeper when located in the ballast, it is possible to extract the ballast stiffness and damping at selected frequencies. This will allow any changes in ballast stiffness caused by ballast degradation to be detected. In addition, the project will study different ballast formulations and concepts such as the use of fibre reinforcements or glued ballast. The effects of these on the stiffness, and therefore on ground vibration, will be determined.

In order to interpret these results in terms of ground vibration and noise, numerical models will be used to study the propagation of vibration into the ground. The Wavenumber Finite Element and Boundary Element (WFEBE) method is particularly well suited to this as it can take advantage of the constant geometry and properties of the track in the axial direction. Wavenumber elements assume invariance of the geometry and material properties in the axial direction. The cross-section is modelled using a 2D mesh, but the 3D vibration response to forces is obtained.

The use of a combined finite element/ boundary element approach is also more efficient than conventional finite element methods, as it can avoid the need in such an approach to model a large domain to prevent wave reflection at false boundaries. In the WFEBE approach, finite elements are used to model the inhomogeneous mechanical properties and geometry of the track, ballast and formation while boundary elements are used to model the ground, achieving an infinite medium for wave propagation. The approach is demonstrated in **Figure 4**. Layered ground can also be considered in the approach.

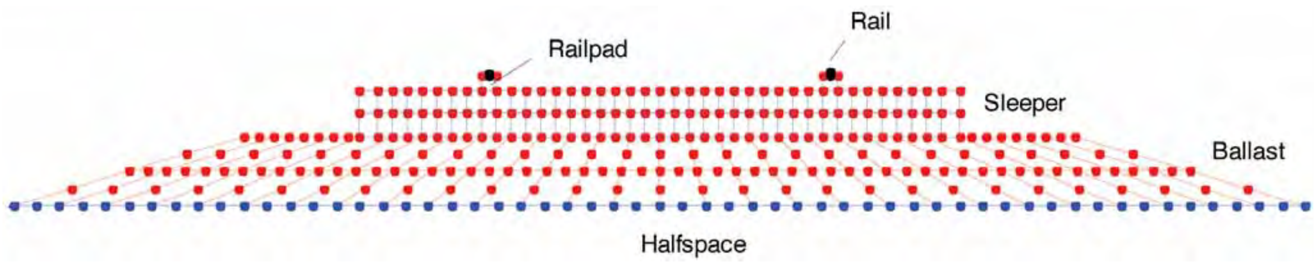

Figure 4: Wavenumber finite element/boundary element mesh of a track on a half-space ground

BIOGRAPHY

David Thompson is Professor of Railway Noise and Vibration at the Institute of Sound and Vibration Research, University of Southampton, UK. He previously worked for British Rail Research and TNO in the Netherlands. His research covers most aspects of railway noise and vibration. David has written over 100 journal papers; his book on Railway Noise and Vibration was published by Elsevier in 2008.

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ACOUTRAIN: simplifying and improving the acoustic certification process of new rolling stock

Railway noise is an environmental issue that significantly affects the population living along railway lines. It not only causes annoyance but may also have a negative effect on the health of citizens. Thus for some time politicians and policy-makers in Europe have recognised that environmental noise has to be reduced. At the same time, a strong growth in traffic volume is foreseen for the rail sector in Europe in the coming years. The highly sensitive noise situation along many strategic railway lines could impede this important development. One solution to compensate for the noise increase due to traffic growth is to limit the noise emission of each train.

In 2006, the TSI Noise (Technical Specifications for Interoperability) came into force, introducing limiting values in noise emission for the certification of new or upgraded rolling stock. By gradually lowering the limiting values in the TSI Noise, the supply industry is put under pressure to develop quieter products. Today, vehicles are assessed according to established standards for field measurements. This can be a very costly and time consuming process which includes measurements of stationary noise, starting noise, pass-by noise as well as interior noise in the driver's cab. The pass-by noise measurement, as it is specified in the TSI Noise, can be particularly expensive due to the fact that a specific low-noise reference track is required. The relatively high demands on track quality and maintenance mean such reference tracks are hard to access.

The excessive time and cost of the TSI Noise certification process may lead to a reduced and delayed effectiveness of the legislation which could even hamper the introduction of innovative solutions.

ACOUTRAIN[1] is a research project co-funded by the European Commission with the goal of simplifying and improving the acoustic certification process of new rolling stock. It began in October 2011 and is already starting to deliver results.

Virtual testing in TSI NOI

The concept of virtual testing, replacing all or part of the tests by computations, has gained acceptance in other fields, such as crash testing or fatigue. Certification based on virtual testing is used in areas where full scale tests are highly impractical or even impossible, for example when assessing an aircraft fuselage for its capability to withstand aerodynamic loads. The main goal of ACOUTRAIN is to develop a quicker and simpler acoustic certification process by introducing some elements of virtual testing, while ensuring a sufficient degree of reliability and accuracy.

By introducing the possibility to replace part of the noise testing with certain elements of simulation, the updated certification process to be developed within ACOUTRAIN will support the railway industry to comply with the noise limits in a timely manner. Such updated procedures are expected to reduce costs and speed-up time-to-market for new, quieter vehicles, resulting in a strengthening of the competitiveness of the European railway sector.

In a virtual test in the TSI Noise, as proposed by ACOUTRAIN, the limiting values and indicators are retained as they are currently defined but some aspects of testing will be replaced by simulations. For instance, this means that a pass-by noise measurement is simulated considering parameters such as operating conditions, speed, and receiver positions as found in the TSI Noise today. To perform a pass-by noise simulation the vehicle under assessment is defined in a specific software tool. This vehicle definition basically consists in the vehicle geometry and the sound power spectra of individual sound sources that contribute to the acoustic emission of the vehicle. The characteristics of the single sources can be assessed with laboratory measurements,

Testing of a converter mock-up at the KTH acoustics lab

numerical models or a combination. The tool takes physical effects like wave propagation, ground reflection and the Doppler Effect into account. Many manufacturers already have their own tools for this type of computation but a common tool is also being developed within ACOUTRAIN.

A key foundation for acoustical simulation models of vehicle noise is accurate source descriptors. For this reason a substantial effort within the project is devoted to developing and enhancing existing procedures to

> ***'A key foundation for acoustical simulation models of vehicle noise is accurate source descriptors'***

characterise noise sources relevant for rail vehicles. For certain sources, mathematical models can be applied to characterise the source – like the well-established TWINS code for rolling noise[2]. For other sources enhanced test procedures are needed, focusing on increasing the accuracy of the source power estimation. One complicating factor is that source characterisation is typically carried out in a lab environment neglecting the integration effect present when the source is assembled in the vehicle. In addition, industrial testing facilities do not always comply with the conditions stipulated in the applicable ISO standards.

The simplified evaluation method within TSI NOI

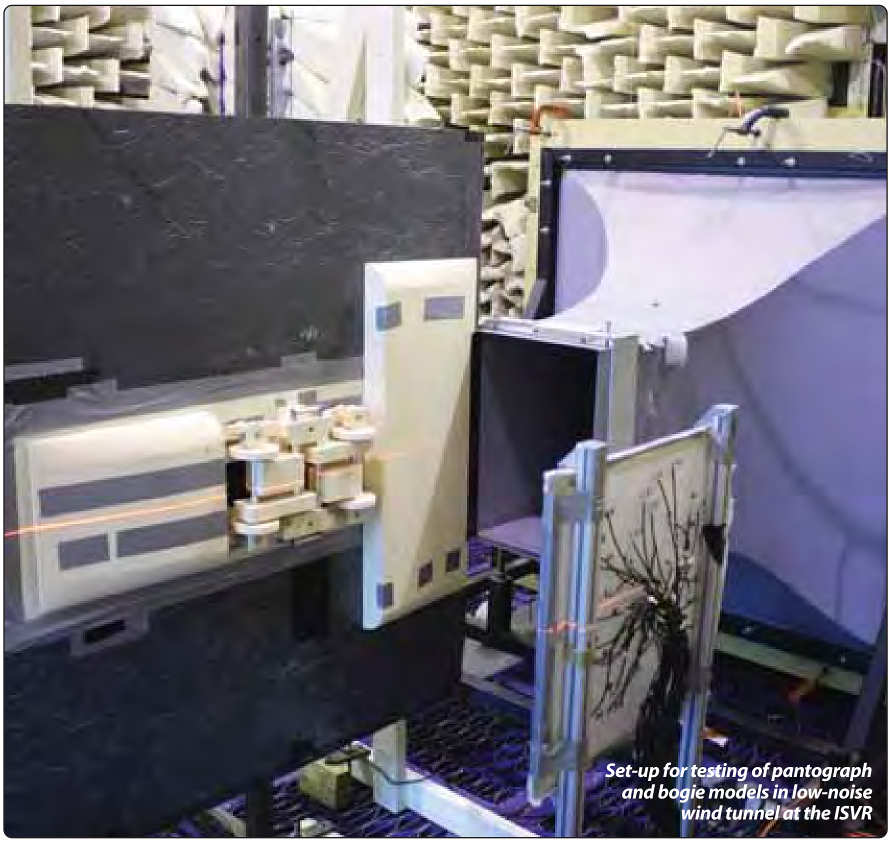
The last TSI Noise revision (2011/229/EU) already introduced some flexibility in the certification process in specific cases:

- Vehicle families: variants of a vehicle type are very often produced to satisfy different requirements of end-users; this results in several similar vehicle types belonging to the same vehicle family
- Different formation of multiple units: multiple units are often produced with different combinations of powered and unpowered vehicles
- Retrofitted vehicles: it should be demonstrated that noise levels are not increased if a component is replaced on a vehicle (for instance an HVAC unit).

A so-called 'simplified evaluation method' is allowed for these cases, but further clarifications on the process to be applied were needed: ACOUTRAIN has proposed some procedures to be applied in this framework.

A number of different application cases have been selected, corresponding to the most common cases where a simplified method will be useful:

- Modification of number of axles
- Modification of the maximum speed

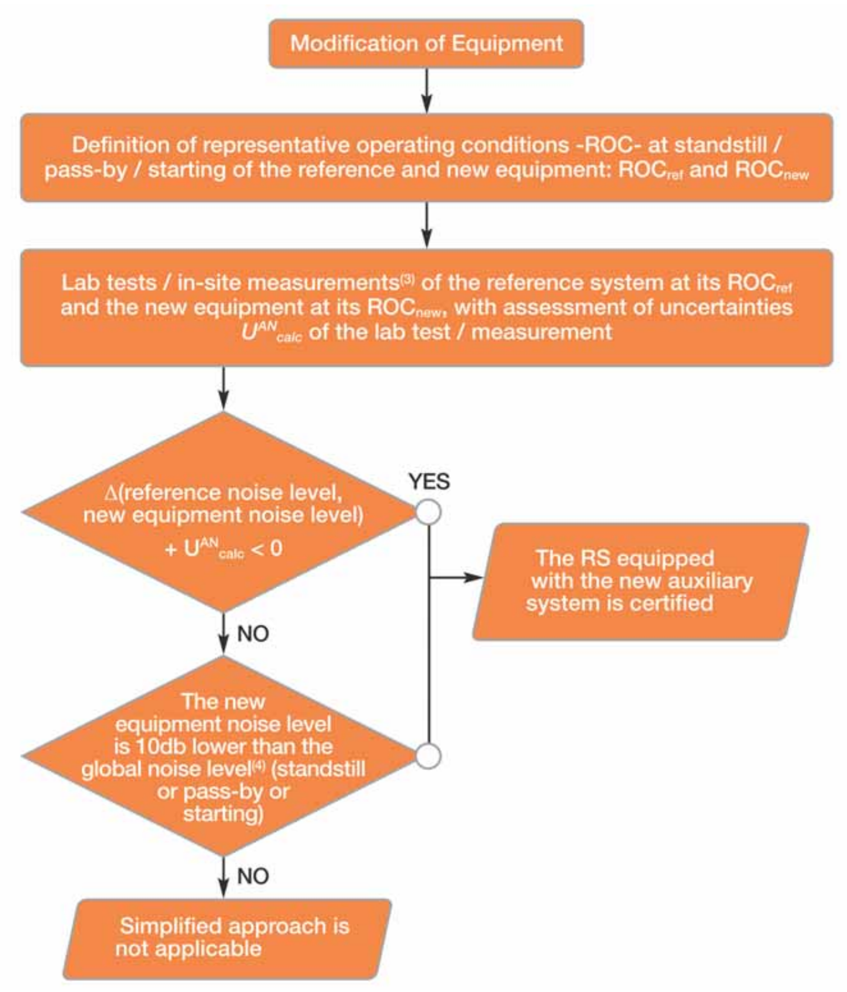


Set-up for testing of pantograph and bogie models in low-noise wind tunnel at the ISVR

- Modification of the wheels
- Modification of the brake system
- Different formations of multiple single cars (add or remove a single car)
- Selection of the worst case within a family of vehicles
- Modification of equipment (traction equipment or auxiliary system) or its installation.

These cases do not represent an exhaustive selection of what could be encountered when applying the TSI Noise; the type of rolling stock to which the method is applicable has to be specified case by case.

The procedures that could be used as a simplified method have been described with dedicated flowcharts by ACOUTRAIN in a document that is foreseen to be included in the TSI Noise application guide. The flowcharts define the limits of application of a simplified approach in each of the cases aforementioned and give a procedure to check if noise levels (for stationary and/or pass-by running condition) are lower or equivalent to the noise levels of a reference vehicle (already certified as TSI Noise compliant). For example, for the case of a modification of an equipment or its installation, **Flowchart 1** proposes a simplified approach to check that there would be no effect (no change in the noise level) or a positive effect (decrease of the noise level) on the stationary, pass-by or starting noise so that the train equipped with the new equipment is automatically certified. The reference equipment corresponds to the equipment on a reference vehicle, i.e. a vehicle already certified.



Flowchart 1: Modification of equipment for installation

For all the flowcharts, it is considered that the proposed methodologies can only manage one modification at a time. Of course, positive effects (reduction of noise level) can be considered as cumulative and in this case several modifications can be handled. In addition, indications are given to justify their reliability, considering either previous experience or analytical justifications.

Towards virtual certification

A long-term goal of ACOUTRAIN is to provide the foundation for the introduction of increased virtual testing in the TSI NOI. Virtual testing in the acoustic field is less common than other fields, but models for calculating the pass-by sound levels based on sound power inputs of the relevant sources are already available and extensively used as a decision support tool during the design phase of new rail vehicles.

However, for such models to complement real testing within a certification process, the tools themselves, as well as the methods to assign acoustic source strengths, must be thoroughly scrutinised and a rigorous tool validation and verification procedure must be in place. Such procedures are being addressed within the ACOUTRAIN project, including a procedure to deal with uncertainties. Uncertainties in the input data must be controlled and monitored, and limits for the variability in the sound levels calculated should be determined by the tool based on the input uncertainties.

It will take time to introduce virtual testing into the TSI NOI procedure and for it to gain wide acceptance but it has great potential to achieve significant cost and time savings in the certification of new, quieter railway vehicles.

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1. www.acoutrain.eu
2. D.J. Thompson, B. Hemsworth and N. Vincent. Experimental validation of the TWINS prediction program, Part 1: Method. Journal of Sound and Vibration 191, 123-135, 1996

BIOGRAPHY

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Dr. Ulf Orrenius works as a Senior Specialist at Bombardier Transportation in the Acoustics and Vibration Department. Ulf is an ACOUTRAIN Technical Leader.

Innovations for 'quiet tracks'

Finding an answer to the nuisance of rail noise is becoming critical – especially with the increasing shift of freight haulage from rail to road. Vossloh has therefore developed a lineup of innovative measures for lowering and preventing rail-traffic noise – and presented them at InnoTrans 2012.

Presented at InnoTrans 2012: Vossloh's innovative 'quiet tracks' solutions.

The main cause of rail traffic noise is wheels rolling over rails – so-called wheel-rail noise. As a train passes, vibrations and structure-borne noise are generated by the moving load, the roughness of the wheels and rails and by local variations in the firmness of the rail-sleeper system. Vossloh has developed innovative technologies for this that substantially reduce structure-borne and secondary airborne noise. The innovations are a result of synergies within the Vossloh Group and can be combined with each other, tailored to individual requirements.

Among Vossloh's contributors towards cutting structure-borne noise is the innovative *cellentic*®, developed by **Vossloh Fastening Systems**. It is used as a rail pad or elastic pad on many Vossloh rail fastening systems, for example the local transport solutions for slab tracks, the system DFF 300 UTS and DFF Metro and for several fastening systems for ballast tracks.

Thanks to its closed-pored structure, this highly elastic microcellular *cellentic*® of ethylene propylene diene monomer (EPDM) elastomer limits efficiently and lastingly the discharge of vibrations into the substructure and thus sustainably optimises the permanent way. The consequence is less structure-borne noise. With its specific physical properties, *cellentic*® is highly resistant to chemical attack. This also explains the outstanding resistance to temperature, ageing and weather of the material as well as its outstanding stability.

Another new noise suppression product from **Vossloh Fastening Systems** presents a new kind of rail web damper for minimising secondary airborne sound. The solid plastic rail web damper is injected with heavy metal to prevent the relatively lightweight rail webs from vibrating.

Also included in the 'quiet track' portfolio is the noise-suppressing switch from **Vossloh Cogifer**. The harmonious interplay of specially engineered frogs and highly elastic rail fastening systems causes the wheel to stay on the same level when negotiating the crossing. Noisy and wear-inducing bumping and banging are thus significantly reduced. To ensure noise reduction by five to eight decibels, extensive reference measurements together with the Technical University of Munich were carried out.

The final touch to the lineup of innovative measures is acoustic grinding. For the first time at InnoTrans, **Vossloh Rail Services** showcased its new generation modular grinding train – HSG-2. The innovative technique high-speed grinding (HSG) gets to the root of noise emissions. Potential sources such as slip waves and surface corrugations are effectively combated by grinding 0.1mm of material from the rail surface – with a high working speed of 80km/h. So the maintenance of rail surface smoothness comes along with the reduction of noise emissions. Extensive tests on the impact of HSG on noise emissions underscore its important role in on-going noise reduction and therefore it presents an effective alternative to grinding processes approved and used until now. High-speed grinding demonstrably satisfies the specifications of EN ISO 3095 and TSI Noise. In Germany, the total length of rail network to undergo HSG-2 maintenance has almost doubled to 7,000km – true to the motto of 'rolling stock care and noise control'. Quieter tracks not only reduce decibels but they also decimate costs caused by wear and tear.

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