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RAILWAY NOISE SOURCES. AN OVERVIEW OF RECENT APPROACHES IN IDENTIFICATION, MODELLING AND REDUCTION POTENTIALS

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ABSTRACT

Understanding the physics and relative importance of railway noise sources is important, particularly in view of global railway noise reduction. An overview of recent developments in source knowledge, either through experimental identification or from modeling will be presented. Different levels of accuracy in source description will appear from different classes of models identified from their purposes. A review of the state of the art in source modeling will show that significant potential exists for reduction of rolling noise, both from an excitation and response point of view. Progress has still to be made in aerodynamic noise modeling, and research should also focus on other sources (fan noise, wheel squeal or braking noise).

1 - INTRODUCTION

Tighter environmental requirements for railways, and separation of railway operators and infrastructure owners made a better understanding of noise sources on trains and track important. The reasons are that reduction at source is the most efficient one, and because responsibilities for noise reduction will soon have to be shared between operators and infrastructure managers.

At the same time, progress has been made in identification methods of noise sources for railways. They will be presented in the first part of this paper. A focus will be made in the second part on the different categories of models for noise sources on trains, with an increasing degree of complexity. The different sources of noise on train and track will then be reviewed with an emphasis on existing models to explain the noise production and reduction potentials taken from these models.

2 - GLOBAL TRENDS IN IDENTIFICATION

Source identification on trains have for some time gone further than simply measuring pass-by levels with a single microphone: more sophisticated methods have proved useful and will be reviewed. They involve either a range of similar sensors (arrays) or a combination of sensors of different types.

2.1 - Acoustic arrays

The use of acoustic arrays was introduced more than 10 years ago, made operational among others by Barsikow, and special features for dealing with highly non stationary signals addressed e.g. by Poisson [1]. Recently, Japanese results presented identification of sources on upper parts of Shinkansen trains, above noise barriers [2], and detailed investigations using arrays were carried out on various sources on TGV and ICE high speed trainsets [3].

A difficult subject scarcely addressed was the quantitative calculation of sources from array measurements. Pallas [4] produced a quantification of noise sources on TGV and ICE high speed trains within the frame of "Deufrako" research project, but this process involved much human expertise. The same difficulty arose when building a quantitative model of sources in the following project Deufrako K2.

An attempt to use some sort of parametric model in terms of sources, for acoustic antenna measurements was carried with the "SDM" method (Source Density Modeling) in which sources were directly modeled as monopoles [3]. Such methods, working satisfactorily in simple cases (loud speaker on board a train), must still be proved to be operational in complex real situations.
Source reconstruction for array measurements is an issue for further development in the railway domain in the near future.

2.2 - Combined noise and vibration measurements

Rolling noise research carried out at ERRI, including the development of the TWINS model [5] led to quantifying wheel and track contributions to noise as calculated by the model.
For TWINS validation, techniques involving simultaneous measurements of pass-by noise and track vibration were used, in conjunction with vibration of the rotating wheels. The ability to actually calculate wheel and rail contribution to railway noise was driven further to the idea of directly measuring these contributions. This was investigated by Dittrich [6] using a silent vehicle as a reference within the fame of the METARAIL E.U. sponsored research project. This work is being taken further within the 5 th FP. STAIRRS project. The most likely practical output, in terms of assessing the contributions of wheel and rail will probably be a mix of calculation and measurement, potentially based on the principles of the TWINS model.

2.3 - Intensimetry, special devices and processing

Intensimetry, as it is a sensitive measurement technique, appears to have been scarcely used in source identification. Some example may be found in internal projects from railways either for characterizing noise from ventilation systems for stationary locomotives, or pass-by measurement on Japanese Shinkansen [2].
In another field, for on board identification of aerodynamic sources, the behavior of special probes, with respect to a turbulent environment, was assessed in order to be able to track aerodynamic sources on high speed train TGV [3], in intercoach and bogie cavity regions. Coherent output power (COP) techniques enabled characterization of radiating energy from measurements both inside the cavity and at its edge.

2.4 - Data fusion and model building

Especially for the practical case of identifying sources of aerodynamic noise from a number of different techniques (e.g. acoustic arrays, microphones on board the train or combination of microphone and accelerometers to separate aerodynamic noise from rolling noise), the development of regression techniques that could help the localization and quantification of sources from different measurement techniques would be a significant progress in measurement processing.
To summarize, identification techniques tend to use a range of sensors, sometimes of different nature, or even simultaneous, but different, measurement techniques. The challenge is to merge all these data to obtain a single but much more significant result. Another important issue would be to couple identification methods with numerical models.

3 - MODEL CLASSES FOR RAILWAY NOISE SOURCES

During the past decades several model developments were undertaken with respect to railway noise sources. It appears that 3 categories of models can be identified both from model complexity and potential use:

- Models for predicting railway noise level in the environment. It will be shown that the simplest source modeling is sufficient in many of these applications.
- "Intermediate source models" on a train or vehicle, which will identify the acoustic radiation characteristic of the main source on the vehicle. They help assessing global noise reduction potential on the vehicle.
- Detailed models for each individual source type. They help understanding the mechanism of noise production, producing noise source reduction concepts and predicting efficiency of these concepts.

3.1 - Models for noise prediction in environment (medium to long range)

The first series of models to be considered in a category are those used for railway noise prediction in environment. Such models (e.g. MITHRAFER in France, Schall 03 in Germany the Dutch model in the Netherlands, "Calculation of Railway Noise" in the UK) should implement capacity to predict noise from railway traffic, given a series of various trains types and traffic schedules, over long range in terms of distance, at least over a 24 hour period, or in terms of longer term indicators, incorporating different meteorological conditions. The prominent versatility of these models should be in terms of traffic and topography, to represent various practical situations along railway lines. They need to be coupled with accurate topographical description of the sites, including buildings to be able to model noise reflections. When compared to noise measurements, models such as MITHRAFER have shown an ability to predict day-time L_{Aeq} up to 400-500 m within 2-3 dB(A) accuracy.

In terms of complexity, the noise source description in such models needs to incorporate the right features to be able to predict day or night-time L_{Aeq}, for various propagation conditions. Some uncertainty may arise from:

- meteorological conditions (variation for different conditions were shown to range up to 5 dB(A) in terms of long time averages and $+\ 3 - 10$ dB(A) with defined gradients profiles) which are mostly conventionally taken into account,
- ground absorption which can vary over the propagation range and cannot be accurately measured for all paths of even one site.

For these reasons, as requirements for longer distance calculation emerge, and as propagation parameters may vary quite significantly over the calculation time period and distance, the number of sources on a train should be limited, provided the basic following requirements of the sources are fulfilled:

- ability to predict noise up to $400 - 500$ m, with given or conventional meteorological conditions,
- ability, in conjunction with the incorporated barrier model (including noise reflection on non $-$ absorptive barrier), to accurately predict (error less than 2 dB(A)) the noise barrier insertion loss at receivers.

For example, these requirements were shown to be met with a two level source for high speed train noise in MITHRAFER (0.8 m above rail for lower frequencies and rail level at higher frequencies).

These source positions were shown to be adapted to prediction of noise from high speed trains in various configurations (different TGV types) up to 300 km/h and distances to $400 - 500$ m.

For prediction of noise from trains at speeds where rolling noise is not dominant with respect to fan noise from engines (up to $50 - 60$ km/h), the latter should be modeled, including fan and gear noise. It will be shown later that very few data is available.

Recently, the need of a more thorough account of meteorological conditions in propagation has suggested the use of parabolic equations in propagation [7]. Irrespective of the implementation strategy of such methods, and the calculation capacity they would require, it is clear that again that the train + barrier system should be modeled rather simply but efficiently (a set of reduced primary, plus possibly reflected sources on barrier) in order to implement practically affordable boundary conditions to the propagation module. The size of the mesh around the train would also limit the complexity of the source representation.

As a conclusion, for propagation calculations up to $400 - 500$ m, source models should rather be of global nature (1 to 3 vertical levels over the train height), but should be targeted at providing a proper representation of the whole train's global emission, in conjunction with the acoustic barrier potentially used.

3.2 - Intermediate models

The previously described models could benefit from more sophisticated models, where noise sources on a train set are more accurately described. These models could serve as closer distance (10 m $-$ 100 m) calculations, providing the means for a deeper understanding of barrier efficiency, or assessing the global noise reduction potential on a defined train set, by a combination of reductions on single sources. It is hence desirable to build relatively detailed and versatile models of sources on train sets, that could simulate the global effect of single or combined source modifications. A first example of such a development was the "Prohv" program, developed by Barsikow. A more detailed and versatile implementation was recently carried out with the MAT2S development, within the frame of the "Deufrako K2" German-French cooperation [10].

An interesting feature of this model, although it was developed for high-speed application is that any train set can be modeled as a combination of vehicles, which are themselves defined as a combination of parametrizable sources located in space. Parametric variation, both in train composition and source noise reduction can then be calculated.

3.3 - Detailed models (relevant to a particular source type)

These models, unlike the previous ones, involve an internal modeling of the physics of the sources. They are usually the result of dedicated important research programmes, and their complexity prevents them

being incorporated directly into more global models. An example is the TWINS model for rolling noise [5]. Its precision enabled successful prediction of noise reduction potential of various concepts for both wheel, and rail in the frame of SILENT FREIGHT and SILENT TRACK projects.
As a conclusion, it can be seen that the first two model classes involve averaged or purely descriptive source modeling, whereas physics of vibration and sound generation are included in the third class. Each class can also be viewed as a simplification of the following one. Models of the third class will differ with the source type, and a review of the main sources and the recent advances in their reduction potential will be carried out in the following part of this paper.

4 - SOURCES AND REDUCTION POTENTIALS

4.1 - Rolling noise

A comprehensive programme of modeling rolling noise leading to the TWINS model [5] was carried out, leading to developments for refined modeling and/or reduction concepts, essentially through the SILENT FREIGHT and SILENT TRACK E-U sponsored projects. A number of papers will present in detail the results obtained in these projects in a dedicated session of this conference. The reduction potential for rolling noise come essentially from two origins:

- Reducing the "excitation" (micro-defects named "roughness") on wheel by application of disk brakes (expensive) or implementation of composite brake blocks (under development), and rail (grinding). The potential of reduction of such solutions is 5−10 dB(A) depending on the track quality and maintenance in terms of track roughness. Modeling wheel and track roughness growth is still an important open problem.
- Reducing response and radiation of wheels and rail
  It appeared that for freight traffic, track noise would be dominant over wheel noise by 5 − 10 dB(A) Solutions should in a first instance deal with track. In this respect, a reduction of 4 − 6 dB(A) can be expected from track modifications (absorbers or new track systems), whereas in conjunction with solutions on wheels, a total reduction of 6 − 8 dB(A) was reached [8]. However, care should be taken in terms of compatibility of type solutions on wheels where type is applied for other mechanical reasons.

Shrouds and low barrier close to the track, for international operation, could only demonstrate lower efficiency (3 dB(A)) due to gauge limitations.

4.2 - Aerodynamic noise

Pantograph noise
Sources on pantograph (vortex shedding) were experimentally well characterized and empirical solutions leading to up to a 5 dB(A) noise reduction, were recently proven [3]. However, when the pantograph is situated in a cavity the contribution of the latter should not be neglected.
Cavity noises
They are frequently encountered in bogie regions, intercoach gaps . . . etc. For the latter, partial masking of the cavity proved successful. In many cases models for such applications still have to be developed (in railway applications, cavities are "open"). The most promising reduction concepts are shrouds or possibly flow control.
Significant effort in modeling aeroacoustic phenomena were carried out [9]:

- dedicated models for simple geometries were developed (backward and facing steps),
- a more comprehensive approach coupling LES (Large Eddy Simulation) with acoustic propagation is in progress.

4.3 - Fan noise

Apart from direct measurement of acoustic intensity of ventilation systems, no modeling of fan noise, as applied to railway engines, seems to be available. This subject remains an issue, since in many applications the exhaust ducts are situated above the top of barriers.

4.4 - Braking noise, wheel squeal noise in curves and during braking

Very little published material is available about squeal noise during braking. Squeal noise in curves is an important problem for urban systems and is being investigated in an E.U. sponsored project dedicated to this field of applications. Operational solutions in service (Nantes − F) involve water sprinkling on the curve before tram passes by.

4.5 - Noise from bridges

Noise can come from steel bridges. SEA modeling coupled with TWINS proved efficient [11] as a modeling technique. Noise reductions up to 5 dB(A) were obtained by treatments on bridges.

In conclusion, whereas rolling noise is well understood and modeled, aerodynamic noise is still much more complex to model. Efforts should also be made towards better understanding of braking noise and fan noise.

5 - CONCLUSION

Global trends in source identification are to use an increasing number of sensors, even of different nature (arrays and/or combination of microphone and rail measurements).

Coherent interpretation of all these measurements still needs some methodology to be developed in order to help build coherent quantitative models for sources.

The requirements for source description accuracy in different types of models were shown to differ significantly with the category of model identified. Among all sources, rolling noise, bridge noise, and to a lesser extent, aerodynamic noise, have been the subject of extensive modeling leading to significant reduction potentials. Similar efforts in terms of modeling should also pave the way for similar reduction of so called "secondary sources" such as fan noise or wheel squeal noise.

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