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NOISE FROM TRAMS - SOURCE IDENTIFICATION AND EFFECTS OF NOISE MITIGATION MEASURES

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Abstract

The noise from rail and road traffic in urban areas is a major issue in many European cities. This topic is dealt with in the ongoing 6th framework EU-project "Silence" (ref TIP4-CT-2005-516288). In an urban context noise from trams is one component in the overall picture that is potentially annoying for nearby residents unless properly dealt with. The noise characteristics of a tram and a train are quite different due to the substantial difference in design and construction both on the vehicle side and on the track side. In particular, the squealing noise when running through tight curves is a well-known problem mainly associated with trams. Also, in tram networks there are often many crossings and switches, which will cause increased noise.

The T3000 low floor tram represents the state-of-the-art in its class and was delivered to the city of Brussels in October 2005. It is equipped with resilient wheels and modern traction equipment. The present work reports a detailed acoustic analysis carried out on the T3000 tram within the above mentioned EU-project "Silence". A detailed identification of acoustic sources has been made using a combination of numerical calculations, laboratory experiments and full-scale stationary and running tests with wayside microphones and onboard microphones and accelerometers. The tests have been performed both on a dedicated test track and in selected "hot spots" in the Brussels city network. Wheel-rail noise has been derived using the TWINS prediction software with measured wheel and rail roughness as input. Noise from equipment such as the traction motor, gearbox and ventilation units has been measured in laboratory and in-situ on the vehicle.

Resulting from the source ranking exercise, a global prediction model has been set up in which the benefit of applying different noise mitigation measures such as bogie covers, wheel absorbers, rail grinding, etc can be quantified.

INTRODUCTION

The recently delivered T3000 tram to STIB in Brussels is a member of the Flexity Outlook product family developed by Bombardier. It is a modern low floor design and well representative for the state-of-the art in terms of noise performance of trams today. The T3000 tram used for the current study is a 5-car unit but comes also in 7-car variants. It has resilient wheels to reduce noise and ground-borne vibrations. The wheels are prepared with fixing holes on the rim to allow additional noise absorbers to be mounted if considered necessary to reduce curve squeal noise. Bogie sides are completely covered with skirts for aesthetics and noise reasons. Traction motors and gears are mounted in compact units – one on each side of the powered bogies. Converters and HVAC systems are placed on the roof.

In a currently ongoing EU-funded project “Silence”, the T3000 tram is selected as one of the application examples. This project aims at developing an integrated system of methodologies and technologies for an efficient control of urban traffic noise. It takes a holistic treatment of all traffic noise facets: urban noise scenarios, individual noise sources (vehicles), traffic management, noise perception and annoyance. Both road and rail traffic is covered.

The present study on noise sources on the T3000 tram is part of the initial project task aiming at the establishment of a baseline situation for the selected vehicles and infrastructure. The findings from this study shall serve as a decision basis for the priorities to be made later in the project on which noise control treatments to focus on. It shall be pointed out that the finalisation of this paper was made before the closure of the baseline phase in the project, so in that sense the results presented here can be seen as slightly preliminary.

By a combination of measurements with the tram at stationary and running at different speeds it has been possible to tune the noise sources in a global calculation model to fit the measurement results.

Figure 1 – Flexity Outlook T3000 tram in the Haren depot in Brussels

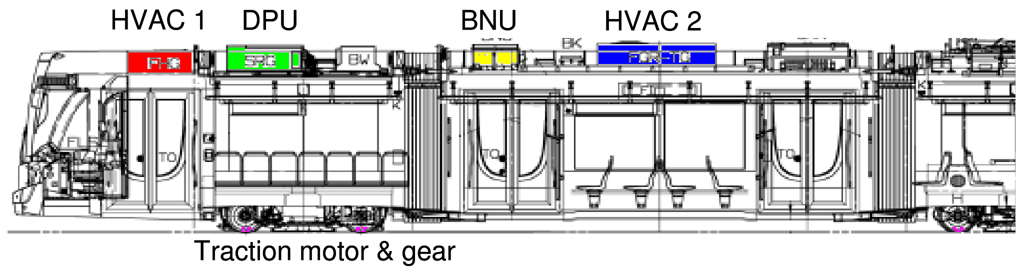

Figure 2 – Sideview layout of T3000 tram with position of acoustic sources indicated.

VEHICLE DESCRIPTION

The layout of the T3000 tram and the position of the relevant acoustic sources are shown in Figure 2. Only half the vehicle is shown due to symmetry. The equipment on the roof includes the two ventilation and air conditioning units (HVAC1 and HVAC2) – separate ones for the driver's cab and the passenger compartment. Also the converters for traction motors (DPU) and auxiliary equipment (BNU) are positioned on the roof. Noise sources in the bogie are wheel-rail, traction motor and gear.

TEST CAMPAIGN

A test campaign was carried out in Brussels October 2005. Noise emission was measured both on a test track (see Figure 3a) within the depot premises and on several locations in the city network. Roughness was measured [1], [2] on the test track and on all wheels on the tram (See Figure 3b), which is essential to identify the wheel-rail source contribution. It was found that the track was considerably rougher than the limit curve in prEN ISO3095, which is commonly used in contractual requirements. There was further a clear difference between the roughness of the powered and the trailer wheels. The reason for this is not investigated but there are several possible mechanisms.

Additionally, the exterior noise was measured at a number of chosen hot spots in the city network. These locations included curves, crossings and switches. A summary of passby noise spectra for such cases are shown in Figure 4. It is notable that there is a higher low frequency content of the noise spectra compared to the situation on the straight reference track discussed more in detail in the subsequent section. The rail roughness at these sites was not measured. The curve was selected as a hot spot due to its tight radius and the high risk of squeal. During the test campaign, however, there was no occurrence of squeal in the curve, partly due to the moist wheather conditions.

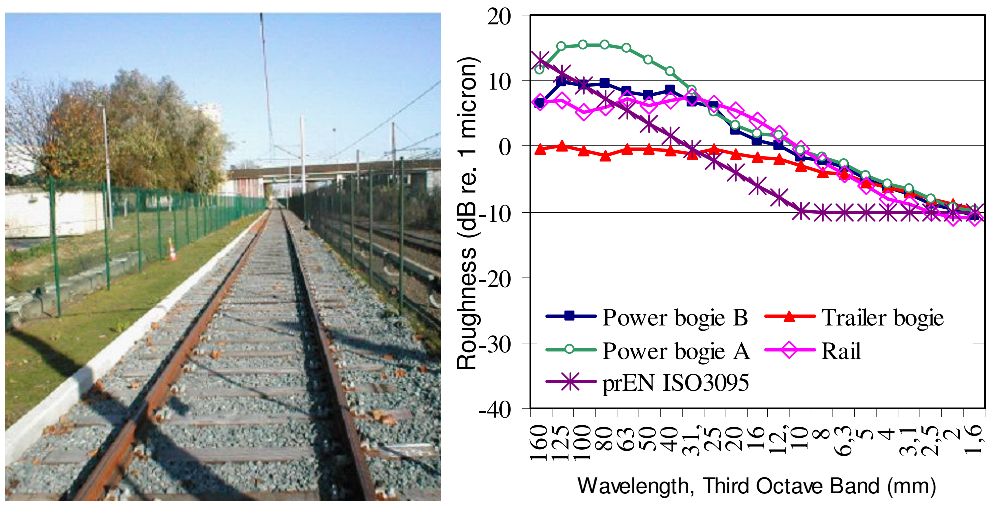

Figure 3 – (a) Test track at the Haren depot, (b) measured roughness of rail and wheels

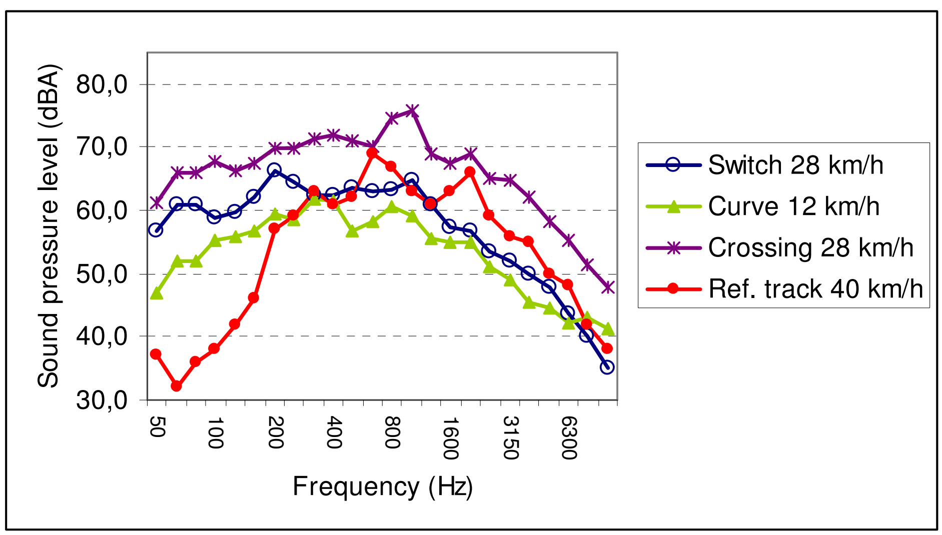

Figure 4 – Measured wayside noise spectra at hot spots and at the Haren reference track

SOURCE IDENTIFICATION

The identification of individual sources was made by tuning a global noise emission model for the vehicle to the different tests – first with the stationary tests with single sources operating and then with the running tests on straight track for which the roughness was known. The wayside noise at 7.5m distance was calculated by superposition of source contributions using an in-house software tool. The process also involved tuning the sound pressure measured in the bogies when running.

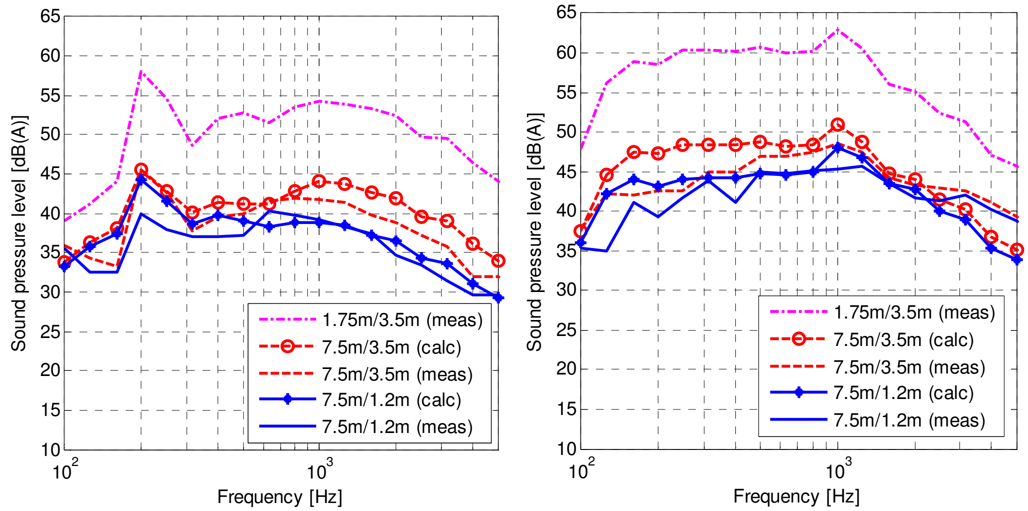

Figure 5 – Measured and calculated wayside noise spectra for stationary tram with HVAC units operating at max cooling mode. (a) Cab HVAC, (b) Passenger HVAC

Stationary tests

In the stationary tests, the two HVACs and the other systems that were able to be operated within moving the tram were characterised. Different loads for the systems were tested. A grid of nine microphones was positioned at a distance of 0.5m from the tram sidewall. A point source model including directivity was tuned to the measured sound pressure levels at these points.

The contribution from the two HVACs when running in the noisiest mode (i.e. cooling) is shown in Figure 5. The source spectra in the calculation model were tuned to give correct sound pressure spectrum at a close microphone, roughly 0.5m from the sidewall at the height of the HVAC. The overall level at 7.5m/1.2m is 58 dBA for the passenger HVAC and 53 dBA for the cab HVAC. During the passby tests the HVACs were running in the “auto mode”. The corresponding overall levels in this mode were found to be 7 dB lower, which is clear evidence that both HVACs have negligible effect on the passby noise compared to wheel-rail and traction motor noise. The noise contribution from the auxiliary converter was found to be even lower than that from the HVAC units.

Running tests

From the running tests, the wheel-rail source and the traction motor source could be quantified. As a starting point, noise spectra for the complete VEM/Flender traction unit (motor + gear) measured under load in laboratory were used. The sound power level was 94 dBA for the condition corresponding to 40 km/h and 103 dBA for 60 km/h. As seen below, these spectra fitted quite well to the measured sound pressure levels at the wayside and bogie microphones when the rolling noise was added.

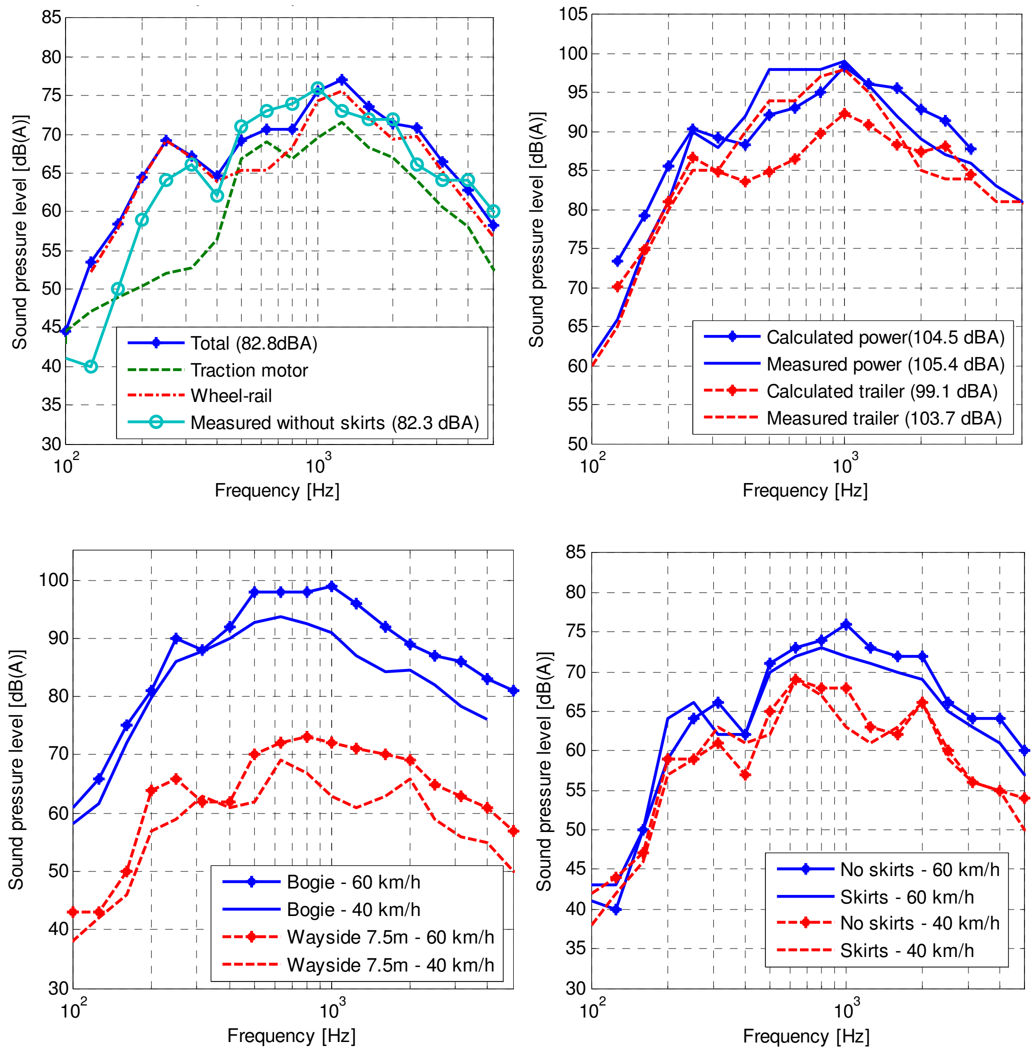

Figure 6 – Sound pressure spectra at different positions and for different running conditions. (a) wayside microphone at 7.5m, (b) bogie microphone, (c) measured SPLs for speeds 40 km/h and 60 km/h, (d) measured wayside SPLs with and without bogie skirts

The rolling noise sound power was calculated with the TWINS software [3]. It shall be noted that there was no FE-model of the specific T3000 wheel available at the time of completion of this paper so a wheel of similar dimensions had to be used in the calculations. Since the wheel contribution is typically 10-12 dB smaller than the track contribution for a tram, this is an acceptable approximation and the main conclusions are not likely to change when the anaylsis is later re-done with the actual wheel model. The vertical pad stiffness k_{vert}=500 MN/m was found to give best agreement with the measurements.

The increase of both the wayside noise and the bogie noise when the train speed changes from 40 km/h to 60 km/h is 5-6 dBA. The increase is slightly less for the trailer bogies. This corresponds to a speed dependence to the noise of 28log(v) to 34log(v), which further implies that the wheel-rail rolling noise dominates over the traction motor noise. The laboratory measurements of the complete traction unit (motor + gear) showed a very clear 50log(rpm) dependence, which is normal for self ventilated traction motors. The influence of the side skirts on the wayside noise for the two speeds 40 km/h and 60 km/h is shown in Figure 6d. The change in overall noise level was 1-2 dBA.

Microphones were placed in two bogies (one of the end power bogies and the trailer bogie in the middle) above one of the wheel axles and along the centreline. The calculation model assumes a reverberent sound field in the cavity enclosing the bogie. This model has been used with good results for conventional rail vehicles. The sound pressure inside the bogie is not used explicitly in the calculations for wayside noise emission. In the in-house prediction software the bogie noise is used to calculate the interior noise inside the tram, which is outside the scope of this work. Despite the fact that the tram bogie looks so different from a conventional train bogie it was found that the model gave surprisingly good results although the noise inside the trailer bogie was somewhat underpredicted as seen in Figure 6b. A more detailed model of the bogie cavity and the position of the sources would probably further improve this.

As mentioned before, the roughness of the test track rail was rather high as was also the roughness of the powered wheels in the end bogies. As seen in Figure 7 there were local defects, probably because the tram had undergone a long period of traction and braking tests prior to the acoustic tests, which could have contributed to the deterioration of the running treads. A 4 dB lower rolling noise was resulted from using the “ISO3095” and “trailer” roughness spectra from Figure 3b. This should be considered as a “best case” but 2 dB reduction could be realistic.

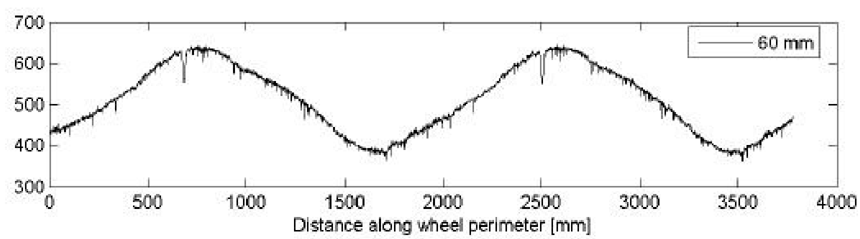

Figure 7 – Roughness samples for two revolutions around a power wheel (from [2])

NOISE MITIGATION MEASURES

The most frequent cause of annoyance by trams comes from the high pitch squealing in curves that can occur under special conditions. Such curve squeal noise was not identified during the test campaign of the T3000 tram. Nevertheless, it is neccesary for a supplier to possess a toolbox of treatments to put in place if this should occur. Although it is difficult to predict the occurrence and level of squeal noise in a deterministic way, the key parameters for the excitation mechanism are well-known: the contact point friction coefficient, the angle of attack when negotiating the curve and the damping of the wheel are a few of them. The Flexity Outlook tram family has resilient wheels, which are prepared to be fitted with additional noise dampers. This happened for the Flexity Outlook tram in Nottingham, where the installation of a wheel noise absorber design from Schrey & Veit successfully solved a problem with curve squeal.

Since the track noise dominates by some 10-12 dB over the wheel noise, it is not meaningful to reduce the noise radiation from the wheels. On the contrary, it could even be beneficial to *increase* the wheel noise if it leads to a total reduction in rolling noise. Such an effect by optimising resilient wheels has been discussed in [4]. Of course, it is always beneficial to reduce the *excitation mechanism* of the rolling noise (i.e. the roughness) by maintaining wheels and rails in a good condition.

Provided that wheels and rails are kept smooth, the self-ventilated traction motor fans will dominate the nosie emission for the higher speeds. The noise could here be lowered by reducing fan diameter and improving the inlet and outlet flow.

CONCLUSIONS

The traction motor noise and the rolling noise were found to be the two most prominent sources during the running tests, with an overweight for the rolling noise. This could in part be explained by the rather high roughness measured on wheels and rails. The roof-mounted equipment such as converters and HVAC units was of secondary importance. It is worth pointing out that the present study only deals with *exterior* noise emission. For the *interior* noise inside the tram, the roof-mounted sources play a much more important role.

In the “Silence” project, this baseline source ranking study will be used for setting the priorites for the deeper studies on noise control treatments to follow in the project.

ACKNOWLEDGEMENT

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