Determination of the equivalent source height of Strasbourg's tramway with a two-microphone technique

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Introduction

For noise impact studies, the knowledge of the equivalent source height of vehicles is required. The present paper focuses on the case of tramways and describes a method for the determination of this parameter. The principle of the measurement is outlined and formulated as an optimization problem. The second part deals with the experimental validation of the method, at first on a controlled source and then on the Strasbourg tramway.

Description of the method

Model of sources

In the same way as a light vehicle can be modelled by one monopolar point source [1], a model of the far field emission of a tramway can be defined as a moving rectilinear distribution of monopolar point sources. The number of sources and the spacing between sources is directly related to the bogies. Such a model is formulated elsewhere in the proceedings [2]. It is also shown in [2] that the agreement between this simple model and pass-by signatures is very good in the case of the Strasbourg tramway.

Principle of source height determination [3]

The principle exposed in this section is a generalization to several sources of the method proposed in [1] for one source. In the far field model, the tram is seen as a rectilinear distribution of point sources S_i, parallel to the ground, at height h_{s_i}, whose relative power level is known and given by the series a_i. For n sources, the acoustic pressure p_{d_j} in free field at receiver point R_j is

$$p_{d_j} = \sum_{i=1}^{n} \frac{A_s.a_i}{r_{d_{ij}}} e^{ik_0 r_{d_{ij}}} , \qquad (1)$$

with $A_s.a_i$: amplitude of the source S_i, $r_{d_{ij}}$ the distance between S_i and R_j (m), k_0 the wave number in the air (m^{-1}). The term of the atmospheric absorption is neglected here, according to the short distance of propagation. In the presence of a ground, the acoustic pressure at point R_j is the sum of the contribution of the source and its image,

$$p_{r_j} = \sum_{i=1}^{n} \left(\frac{A_s.a_i}{r_{d_{ij}}} e^{ik_0 r_{d_{ij}}} + Q_{ij} \frac{A_s.a_i}{r_{r_{ij}}} e^{ik_0 r_{r_{ij}}} \right), \qquad (2)$$

with $r_{r_{ij}}$ the distance between the image source S'_i and R_j, Q_{ij} the reflexion coefficient in spherical waves of the ground at the incidence between S_i and R_j [4]. The ground is represented as a Delany and Bazley porous absorber [5].

We can define the *excess attenuation* ΔL_j by

$$\Delta L_j = L_{ground,j} - L_{free,j} \qquad (3)$$

The previous right hand side terms are

$$L_{ground,j} = 10\log_{10}\left\langle \frac{p_{r_j}^{2}}{p_0^{2}} \right\rangle ; L_{free,j} = 10\log_{10}\left\langle \frac{p_{d_j}^{2}}{p_0^{2}} \right\rangle . \qquad (4)$$

$L_{ground,j}$ (resp. $L_{free,j}$) is the pressure level (dB) of the average of the quadratic pressure with ground (resp. in free field) at the receiver point R_j, $p_0 = 2.10^{-5}$ Pa. From (3) and (1), and if the sources are incoherent, it comes

$$\Delta L_j = L_{ground,j} - 10\log_{10}\left(\frac{A_s^2}{p_0^{2}} \sum_{i=1}^{n} \frac{a_i^{2}}{r_{d_{ij}}^2} \right). \qquad (5)$$

With 2 receiver points, it can be written

$$L_{ground,2} - L_{ground,1} = \Delta L_2 - \Delta L_1$$
$$+10\log_{10}\left(\sum_{i=1}^{n} \frac{a_i^{2}}{r_{d_{i2}}^2} \right) - 10\log_{10}\left(\sum_{i=1}^{n} \frac{a_i^{2}}{r_{d_{i1}}^2} \right). \qquad (6)$$

From simple geometrical transformations, this equation can be expressed with variables h_{s_i}, h_{r_j} and d_{ij} (parameters defined on Figure 1).

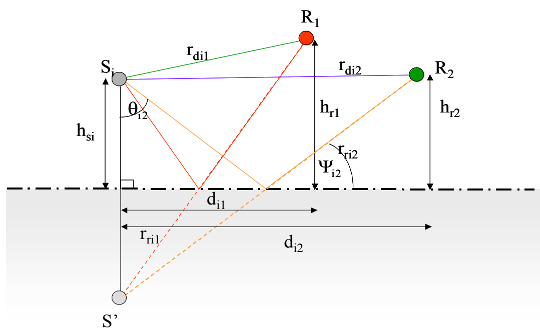

Figure 1 : Geometry of the sources S_i, and receiver points R_j

It is reasonable to assume $h_{s_i} = h_s$. With this hypothesis, the only unknown term remaining in equation (6) is the source height.

Optimization

The computation of h_s is defined as the minimization of the function F (equation (7)). F is a sum of the deviations between the measurement (*meas* in equation (7)) and the model, for each frequency f_j of the spectrum.

$$F(h_s) = \left[\begin{array}{l} \sum_j \left(L_{ground,2}(f_j, h_s) - L_{ground,1}(f_j, h_s) \right)^2_{meas} \\ - \sum_j \left(L_{ground,2}(f_j, h_s) - L_{ground,1}(f_j, h_s) \right)^2_{model} \end{array} \right]^2 \qquad (7)$$

As there is only one unknown and the precision required is around 0.01m, an exhaustive search is carried out to find the minimum of F through a range of possible values of h_s.

Validation of the method

Validation with a single controlled source

To validate the method, tests have been carried out with a single controlled source, *i.e.* a loudspeaker at specified heights ranging from 0.05 to 0.6 m. For each test $h_{r1}=h_{r2}=1$ m, $d_1=2$ m and $d_2=4$ m (cf Figure 1), over a flat and reflecting ground. The MLS technique was used for data acquisition. The frequency range was 0-20 kHz. The results are shown on Figure 2.

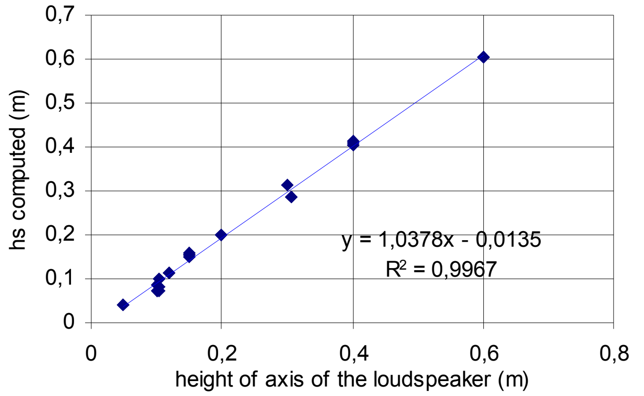

Figure 2 : validation of the measurement with a single controlled source. Comparison between specified and computed height.

The agreement between the specified height and the computed height is satisfying.

Measurement on the Strasbourg tramway

The method has been tested on the Strasbourg tramway. The experimental attenuation is computed on 0.125 s long segments centered on the peaks of the pass-by signature. A third microphone was placed very close to the railway (0.9 m) in order to get an accurate localization of the peaks.

For these measurements : $h_{r1}=h_{r2}=1.2$ m, $d_1=2.4$ m and $d_2=3.9$ m (cf Figure 1). On the chosen site, the ground is flat and reflecting. A typical curve for F (cf equation (7)) is shown on Figure 3. Over the 16 pass-by measurements recorded with speeds between 22 and 38 km/h, the optimisation procedure returns $h_s=0.02$ m in average with a standard deviation lower than 0.007 m.

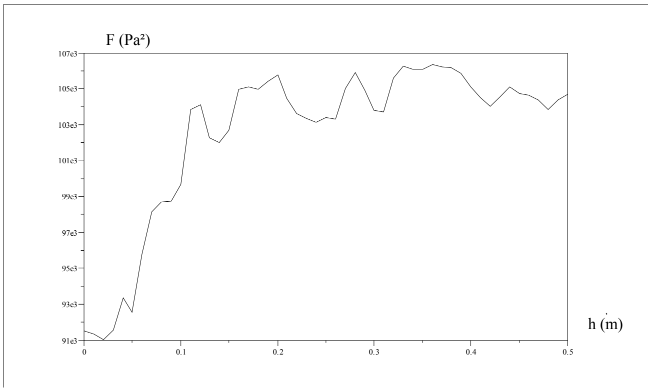

Figure 3 : Example of a typical cost function expressed in Pa² and function of the tested height (m) of the model from the ground to 1 m

Conclusion

The method outlined here gives satisfying results in configurations with single controlled source. When applied to the Strasbourg tramway, it returns values of h_S which are coherent with the expectation, insofar as the wheel-rail contact is the main noise source at the speeds of interest here.

The model presented in this paper does not take the atmospheric absorption into account. This component can easily be re-introduced in it, to extend the application field of the method. Some research is in progress concerning the optimization of the geometry of the set-up with respect to the uncertainty of measurement. It is also planned to replace the current optimisation algorithm by a more efficient one.

References

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Acknowledgements

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