Road impedance optimisation
using an efficient two–dimensional model for the tyre radiation

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Introduction

Because of the reduction of engine and exhaust system emissions, the noise generated at the tyre / road interface is now the main contribution to the overall vehicle noise for driving speeds as low as 50 km/h for light vehicles. In order to reduce the noise emission, numerical tools are needed which could describe accurately the mechanisms of the noise generation and radiation at the tyre / road interface.

The work presented in this paper participates to this effort by proposing a model which describes the sound radiation of a tyre above an arbitrary impedance plane. Based on the equivalent sources method, this model is numerically efficient and allows to perform the parametrical studies addressed to the design of optimal acoustic properties of the road surface.

Model description

The model presented in this paper results from the combination of two independent models, one for the tyre radiation and one for the ground effects.

The model for the tyre radiation over an acoustically rigid surface was originally developed by Kropp and is presented in [1]. It assimilates the tyre to an infinite cylinder and uses the fields from a two–dimensional multipole and its image to simulate a rigid surface. The problem is expressed using the equivalent sources approach, which means that the amplitudes of the multipoles are tuned to fulfill a prescribed velocity boundary condition given on the tyre surface. Results shown in the aforementioned reference proved that this tool is accurate in the domain of validity of the two–dimensional simplifications, namely at frequencies above 600 Hz.

To include the influence of ground effects on the tyre radiation, this model is coupled to an integral equation alternate approach as presented in [2]. In a two–dimensional geometry, equivalent sources are placed directly at the ground surface to control the value of the acoustic impedance. In this case, the source strengths are adjusted to fulfill a prescribed impedance value on a small portion of ground. By doing so, discontinuities in the impedance distribution are handled. Calculations obtained with this model correspond well with solutions proposed by other authors and with measurements over homogeneous or inhomogeneous surfaces [2].

Hence, the resulting model comprises a multipole source placed at the tyre centre, its mirror image source, and a series of monopole sources placed on the ground surface. The key point of the present approach lies in the fact that the amplitudes of all sources are such that the two boundary conditions, that on the tyre surface and that on the ground surface, are simultaneously fulfilled. For this, an original iterative method is proposed.

Iterative process

One approach to solve this problem could consist in inverting one large matrix which contains all sources' contributions. Numerically speaking, matrix inversions are more demanding than matrix multiplications. Therefore, the approach proposed here consists in computing approximate solutions to the problem and correct them in an effortless iteration.

First, the amplitude of the multipole sources are calculated to fulfill the velocity boundary condition on the tyre surface. Given this incident field, the amplitudes of the ground sources are calculated according to the desired impedance value. As a consequence, additional multipoles are needed to correct the tyre velocity distribution, which also leads to a change in the ground impedance. Successive amplitudes are calculated in this way until the two boundary conditions are simultaneously fulfilled. The final source strengths are the sum of all successive strengths calculated during the iteration.

Numerically speaking, at the end of the iteration, the boundary errors are at most equal to a treshold value fixed by the user. An example of the evolution of the boundary error along the iteration is presented in Figure 1. The tyre is placed 0.8 cm above a surface, the

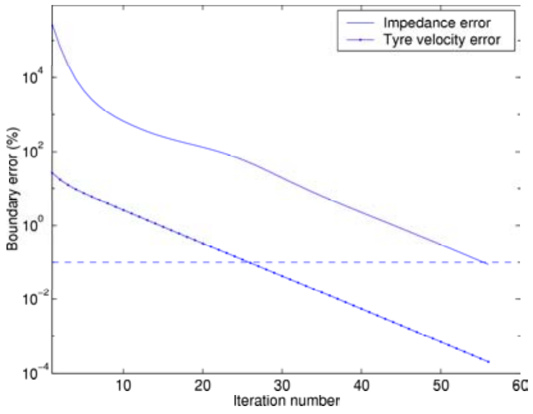

Figure 1: Evolution of the boundary error along the iteration. f=420 Hz, $Z_n = 625 - 3178j$. (From [3])

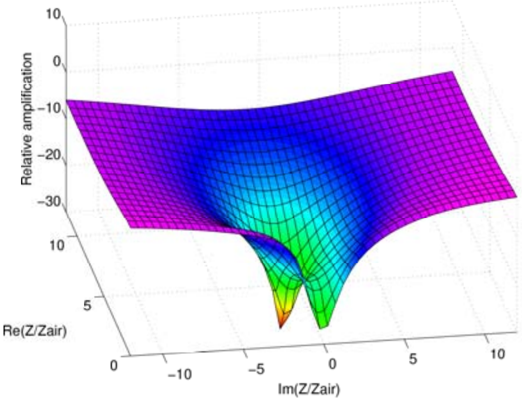

Figure 2: Relative horn amplification due to an impedance surface compared to a rigid surface. f=500 Hz. d_s=0.05 m. (From [3])

impedance of which corresponds to an absorption of 0.09 for plane waves under normal incidence at this frequency.

In this figure, the two boundary errors, after some fluctuations, decrease with the same rate, uniformily. This means that the process is stable and that an arbitrary accuracy can be achieved in the fulfillement of the boundary conditions. This typical situation is also found at other frequencies and for other values of the ground impedance.

The iteration is numerically effortless because it implies only matrix multiplications and, as a result, the computational time is mainly governed by the inversion of the initial matrices. The efficiency of this technique becomes even more evident when the effect of the impedance plane on the field radiated by the tyre is is strong.

Optimisation of the road acoustical impedance

To obtain reliable optimisation results, the model has to give accurate predictions of the sound field radiated by the tyre over impedance surfaces.

This is assessed by comparisons of horn effect amplifications over impedance surfaces measured with a real tyre on one hand and predicted with the present model on the other hand. Results shown in [3] prove the model to be accurate in the case of homogeneous and inhomogeneous impedance surfaces, at frequencies above 600 Hz.

Therefore the model seems adapted to perform the parametrical studies necessary to design the optimum acoustical road properties. For this, the value of the ground impedance is varied and the resulting horn amplification is calculated and compared to the case when the road is acoustically rigid. The optimum value of the road is the one giving the maximum reduction of the horn amplification. Figures 2, 3 and 4 show few examples of optimisation performed at several frequencies and for several distances d_s between the noise source and the contact point between the tyre and the road [1].

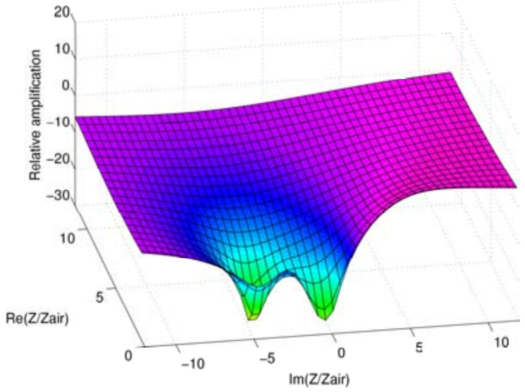

Figure 3: Relative horn amplification due to an impedance surface compared to a rigid surface. f=1000 Hz. d_s=0.05 m. (From [3])

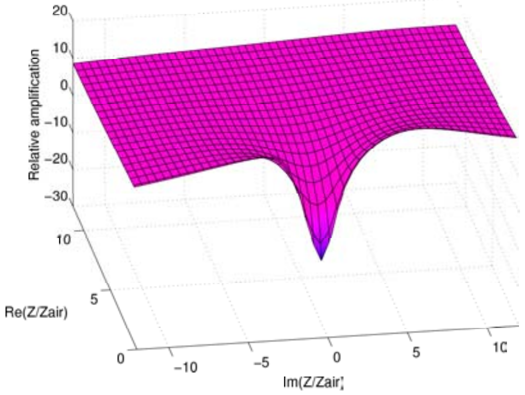

Figure 4: Relative horn amplification due to an impedance surface compared to a rigid surface. f=1000 Hz. d_s=0.1 m. (From [3])

The main result of these calculations is that the model is able to predict physical value of the road impedance, besides zero impedance which is a trivial result. However, in some cases, an impedance surface may yield an increase of the horn amplification, as shown in Figure 4. This observation, confirmed by other measurements presented in [3], has not been clarified. Finally, these results show that the exact value of the optimum impedance is very sensitive to the exact geometry of the tyre / road interface.

References

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