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ROAD TEXTURE AND TIRE NOISE

J.-F. Hamet, P. Klein

INRETS, 25 av. F. Mitterrand, F69675, Bron, France

Tel.: +33(0)472142402 / Fax: +33(0)472376837 / Email: hamet@inrets.fr

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ABSTRACT

The research project presented here addresses the influence of road texture profile on tire noise. It is deemed more appropriate, when seeking for correlation between road profile and tire noise spectra, to 'envelope' the road profile before evaluating its spectrum. Two approaches are taken to tackle the problem. A static approach based on evaluating the contact between two plane surfaces. A dynamic approach based on a rolling tire model. Since the latter enables the evaluation of tire noise from any given road texture profile, it is also used to get a better grasp of the phenomena. Only the fundamentals of the processes are presented: experiments will be performed in the coming years. The static approach is worked in the PREDIT project "Relation between road texture and the tire noise" [1]. The partners are: INRETS, LCPC, ENPC, MICROdB, Gerland Routes, Colas S.A. The dynamic approach is developed in the frame of the European project SI.R.U.US. The partners are Autostrade (it), CRR (be), Pavimental (it), INRETS (fr), SACER (fr), Argex (be), LNEC (pt).

1 - INTRODUCTION

Although some 20 years elapsed since the basics of the road texture influence on tire noise were given [2] the principles for designing low noise surfaces remain mostly qualitative [3]. Correlation between measured road texture and noise spectra continue to be sought and new relations to be proposed [4], still disregarding porous pavements. Attempts to correlate texture and noise on these pavements proved unsuccessful [5]. It is though that the problem could be linked to the tire surface not taking the exact shape of the road profile on high texture roads, and that this could be worked out by considering an enveloped profile [6]. The road surface stiffness may also play a role in the process [7, 8]. Its importance remains however a debated matter.

The problematic presented in this paper relates to the evaluation of the road texture profile contribution to the tire noise generation at medium and low frequencies. The research work is engaged through two projects: the French PREDIT project "Relation between road texture and tire noise" whose objectives are the understanding of the phenomena at stake, and the European project SI.R.U.US. (Silent Road for Urban and extra urban Use) whose objectives are the development and the implementation of low noise surfaces.

2 - THE ROAD TEXTURE PROFILE

It is acknowledged that the road texture profile plays a fundamental role in the tire road noise generation. The same is true for the tire tread pattern. It can be intuitively reckoned that tires with 'aggressive' tread patterns rolling on rather smooth road surfaces, will generate a tire road noise somewhat independently of the road texture profile, while tires with non 'aggressive' tread patterns rolling on highly textured roads, will generate a tire road noise almost independently of their tread patterns. This must be kept in mind when evaluating the road texture influence on tire noise: below a certain road texture level, the influence of the tire pattern becomes predominant. Treadless tires are considered in the theoretical part and will be included in the experimental part.

The texture profile considered in this research is two dimensional; it corresponds to the standard measurements performed along a line in the rolling direction. It is reckoned that the low frequency noise is associated to the tire vibrations induced by the scrolling of the road profile under the tire [9]. At high frequencies, the noise is rather associated to air pumping phenomena whose effects are reduced by leaks between the tire and road. Thus, an increase of the road texture level at large wavelengths results in an increase of the tire noise at low frequencies while an increase of the road texture level at small wavelengths results in a decrease of the tire noise at high frequencies [2]. The concept of most of the low noise surfaces is based on these considerations: small maximum chip size aggregates for the rolling surface, high porosity for the structure [10].

The characterisation of the road surface texture as regard low frequency noise generation, i.e. tire vibrations, is not as simple as it may seem: taking abruptly the spectrum of the measured profile gives as much weight to the ridges as it does to the valleys. No difference is made in particular between two mirror profiles. The profiles schematised Fig. 1 would correspond to an alert band mark painting (left graph) and a cobblestone type pavement (right graph). The first is considered more aggressive and noisy, than the second.

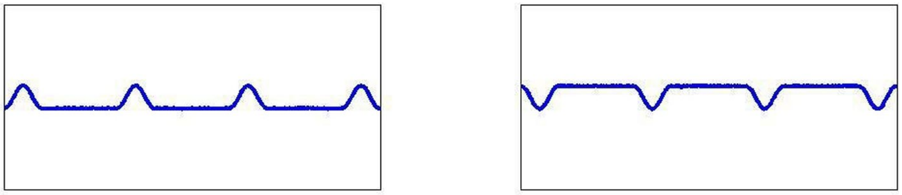


Figure 1: Illustration of two mirror images of a road profile.

On a texture spectrum basis they are identical. This means that tire noise predictions based on the road spectrum [4], [11], [12] would wrongly conclude that both pavements are acoustically identical. The other way around, comparison between the noise and road spectra would as wrongly conclude that tire noise does not depend on road texture, since two identical road spectra result in two different noise spectra

2.1 - The static envelopment process

It is believed that this may be part of the problems encountered with porous pavements, which show pronounced dips. Beyond some depth, the tire vibrations are no more affected by a further depth increase, while the texture level still is.

A possibility to take this into account is to "envelope" the road profile before evaluating the spectrum. A simple smoothing of the data has been suggested [6] but does not seem to have given entire satisfaction to its authors. It seems that the envelopment should somewhat reflect the actual deformation of the tread gum in the contact zone. Various models will be considered and their efficiency tested. The one presently evaluated in the PREDIT project depicts the gum as a semi infinite elastic foundation indented by the rigid road profile. At equilibrium, the road surface reaction forces balance the tire inflation pressure over the considered area. The basis was first tested by Clapp who studied truck tires and came out with correlations similar to Descornet and Sandberg's [13].

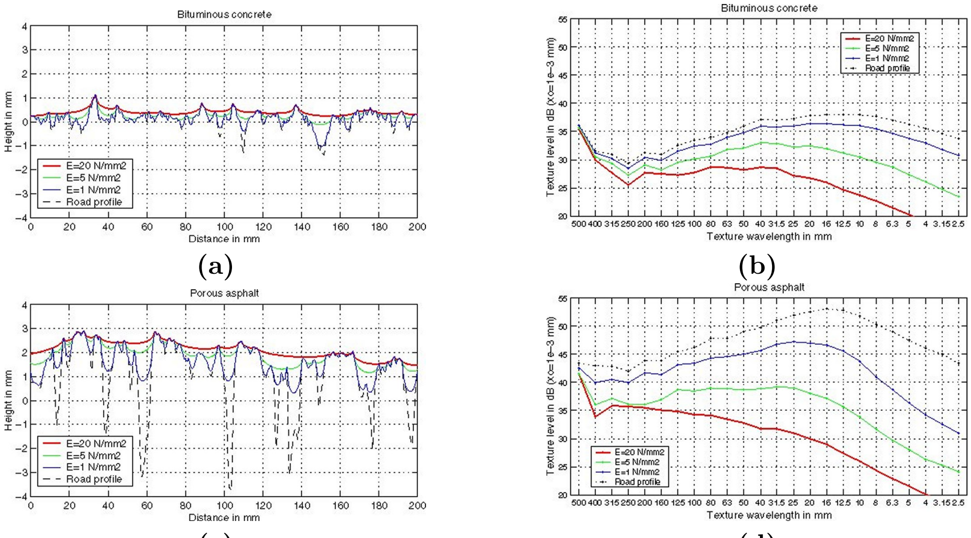
Given the inflation pressure, the envelopment depends on the modulus of elasticity of the elastic foundation. This is illustrated Fig. 2 for two road pavements: a bituminous concrete and a porous asphalt. As expected, the spectrum of the porous asphalt is more sensitive to the envelopment.

The envelopment process is the "theoretical" part of the work which, for the rest, is empirical and similar to [2]: it amounts to seeking after correlations between measured tire noise spectra and enveloped road profile spectra, using as large a data set as possible. The value for the modulus of elasticity is to be determined empirically as being the one giving the best correlation.

Sound pressure measurements will be performed on various types of surfaces using two methods: an on board method (microphone positions close to one of the rolling tires of a vehicle) and the classical pass by method (microphone positions fixed with respect to the ground). The on board method is better suited for this research, on the other hand, the pass by method is presently the official standard. This experimental part will cover the next two years.

2.2 - Tire road interaction: the rolling process

Rolling models exist which predict the tire noise from the road texture profile. It is thought that they can be an efficient complementary tool for texture noise relation studies, whether for seeking correlation or for getting a better grasp of the phenomena. A finite element rolling model has been used for instance in the European TINO project [14]. Here, an analytical model developed in the frame of the SI.R.U.US. project is used.



(a) **(b)**

(c) **(d)**

Figure 2: Envelopment of two road profiles together with their corresponding spectra.

The model is based on Kropp's work [15]. It can give as output acoustic pressure (or power) with as input the road texture profile and the rolling speed. Although validations have been performed in laboratory conditions [15, 16], validations in real conditions remain to be done.

The model can be used to evaluate correlations between measured road texture spectra and calculated acoustic spectra. An illustration is given Fig. 3 (top part) for a treadless tire rolling at 80 km/h. The road profile ”input” is not enveloped, the acoustic ”output” is the power radiated by the tire. The spectra are 1/3 octave quantities. Since the model does not consider air pumping noise, only positive correlations are obtained (a texture level increase produces a noise level increase). A high correlation does not imply necessarily a strong effect. The latter is characterised by the slope relating the sound level increase Δ_{sound} to the texture level increase Δ_{texture}. It is illustrated Fig. 3 (bottom graph).

It appears that the medium and low frequency tire noise at 80 km/h, which results here from the tire vibrations, is mainly related to the texture profile in the bands 8 c/m to 20 c/m (125 mm to 50 mm wavelength). This general trend is in agreement with [2].

The model can be also used to get a better grasp of the phenomena at stake. It consists actually of three sub-models:

- the tire itself (vibration behaviour),
- the tire road mechanical interaction,.
- the acoustic radiation of the tire including the horn effect.

The tire is characterised by its Green's function $G\left(\underline{x}\backslash\underline{\xi}, t\backslash\tau\right)$ giving at time t the tread displacement $z_{tread}\left(\underline{x}, t\right)$ produced at point $\underline{x}$ by the pressure $F^{'}\left(\underline{\xi}, \tau\right)$ which was applied at time τ at point $\underline{\xi}$

$$z_{tread}\left(\underline{x}, t\right) = \int\int\int F^{'}\left(\underline{\xi}, \tau\right) G\left(\underline{x}\backslash\underline{\xi}, t\backslash\tau\right) d\underline{\xi} d\tau$$

The model is linear and three dimensional.

Due to the non linearity of the contact, the interaction must be worked out in the time domain, not in the frequency domain as it is usual in acoustics. The mechanical interaction between the tire and the road is performed through the tread gum, modelled here by a local stiffness s_e. A contact pressure is generated when the gum is compressed:

$$F^{'}\left(\underline{x}, t\right) = s_e \Delta h\left(\underline{x}, t\right) H\left(\Delta h < 0\right)$$

where

$$\Delta h\left(\underline{x}, t\right) = h_{tread}\left(\underline{x}, t\right) - h_{road}\left(\underline{x}, t\right)$$

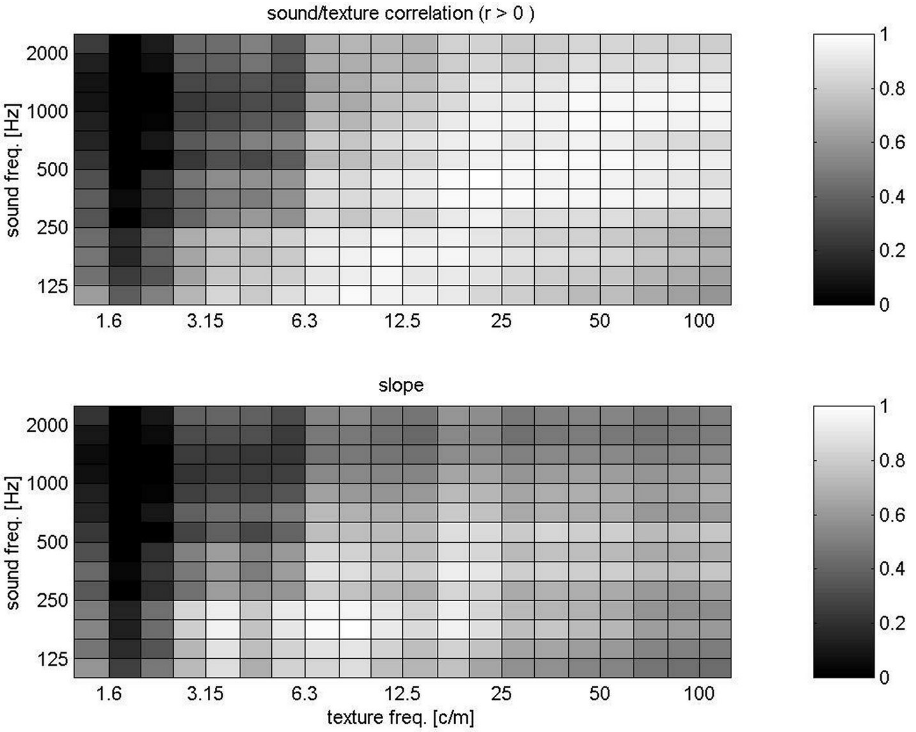


Figure 3: Sound texture correlation evaluated using the rolling model (speed: 80 km/h) Top: correlation between sound power and road texture 1/3 octave levels Bottom: associated slope $\Delta_{\text{sound}} = \text{slope} \times \Delta_{\text{texture}}$.

is the relative position of the tire and road surfaces; H is the step function ($H(x) = 1$ if $x > 0$, $H(x) = 0$ otherwise). The model is three dimensional. The road surface profiles considered in this research are however measured along a line $h_{road} \equiv h_{road}(x,t)$. Following [15] it is therefore assumed a uniform pressure distribution over the part of the treadband width which is in contact with the road. The Green's function is zero for $\tau < t$, the tread displacement at time t is thus evaluated from the known past forces, and is itself used to evaluate the force at time t.

The tire radiation including the horn effect is modelled in two dimensions. Kropp suggests a correction function to take into account the finite width or the tire when evaluating the radiated acoustic pressure. Acoustical absorption of the road can also be introduced, but only in an elementary way. These items are tackled in the frame of the PREDIT project and are presented in other Internoise papers [17, 18, 19]

The interaction process

$$F^{'} = s_e \Delta h H \left(\Delta h < 0\right)$$

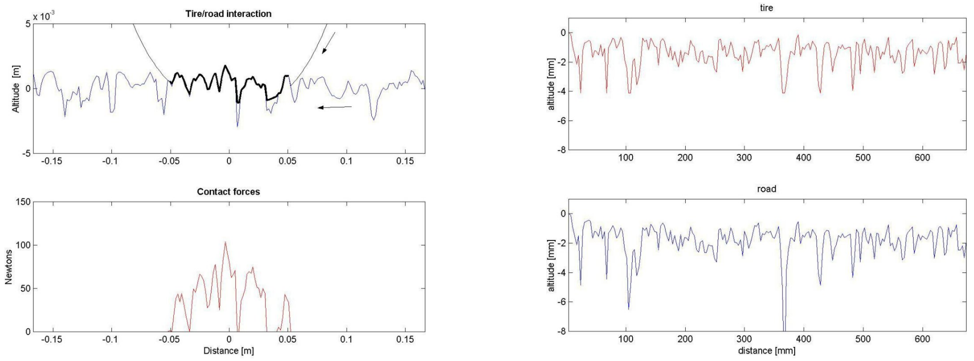
is non linear with respect to the road surface profile. One must not therefore expect a perfect correlation between road profile and noise. The road stiffness influence can be included in the s_e term

2.3 - The dynamic envelopment process

In the static envelopment process, the elastic medium is taken flat and "pressed" over the whole road profile length. Given two opposite tire and road elements; their interaction force is single valued.

In the rolling process, the envelopment of the profile by the tire occurs over a finite length (the contact length) and this contact length moves forward as the tire rotates (Fig. 4 "tire road interaction"). The interaction between two opposite tire and road elements varies as they pass through the contact zone: the force tends to be minimum at the entrance and exit, maximum at the centre of the contact zone (Fig. 4 "contact forces"). The finite length of the contact zone also creates a high pass filtering effect: the large wavelength of the road profile are not "detected" by the rolling tire.

The use the rolling model to envelop the road profile is thus not straightforward, various ways can be taken. In a first phase, the enveloped profile will be simply determined from the value of the contact force at the centre of the contact zone $z_{env}(x) = F^{'}(x_c, x/v)/s_e$ where v is the rolling speed. An illustration is given Fig. 4 ("tire") to be compared to the original profile ("road" on the same figure).



(a) **(b)**

Figure 4: Rolling process; left tire/road interaction at a given instant (geometry & forces); upper right: enveloped road profile – lower right: original road profile.

The results given here were evaluated for a speed of 80 km/h. Preliminary work would tend to show that the interaction is almost independent of speed, but this remains to be checked more thoroughly. Similarly to the static envelopment process, the dynamic envelopment depends on a parameter: the stiffness of the tread gum. This stiffness is determined experimentally on the considered tire.

3 - CONCLUSION

A static and a dynamic approach are considered for evaluating the envelopment of a road profile as seen by a tire. It is expected that using an enveloped road profile will improve the correlations between road texture profile and tire noise and enable to incorporate porous pavements, disregarded up till now in this type of studies. The dynamic approach based on a rolling tire model can also be used for simulations.

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