



HAL
open science

Evaluation of tire road noise from road texture profiles using INRETS rolling tire model: Evaluation from a profile measured by the LCPC

J. F. Hamet, P. Klein

► **To cite this version:**

J. F. Hamet, P. Klein. Evaluation of tire road noise from road texture profiles using INRETS rolling tire model: Evaluation from a profile measured by the LCPC. 2004, 18p. hal-00546115

HAL Id: hal-00546115

<https://hal.science/hal-00546115>

Submitted on 13 Dec 2010

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



*INSTITUT NATIONAL DE RECHERCHE
SUR LES TRANSPORTS ET LEUR SECURITE*

JF Hamet
Ph. Klein

Evaluation of tire road noise from road texture profiles using INRETS rolling tire model

Evaluation from a profile measured by the LCPC

LTE 0424
October 2004

The authors :

Jean-François Hamet
Directeur de Recherche au Laboratoire Transports et Environnement
25, avenue François Mitterrand – Case 24, 69675 Bron cedex
hamet@inrets.fr

Philippe Klein
Chargé de Recherche au Laboratoire Transports et Environnement
25, avenue François Mitterrand – Case 24, 69675 Bron cedex
klein@inrets.fr

Bibliographic notice

1 Research department (1 st author) Laboratoire Transports et Environnement (LTE)		2 Project N° SILVIA (silent roads)	3 INRETS
4 Title Evaluation of tire road noise from road texture profiles using INRETS rolling tire model			
5 Sub-title Evaluation from a profile measured by the LCPC		6 Language Engl	
7 Author(s) JF Hamet Ph. Klein		8 Ext. collaboration	
9 Name, address, financing, co-editor		10 N° contract, conv. GRD2/2000/30202	
		11 Date of publication October 2004	
12 Comments This report is an INRETS-LTE edition of the SILVIA-INRETS-011-WP2 report dated 08/08/2003			
13 Summary Part of INRETS contribution in the SILVIA project is to perform tire noise estimations using models. This needs measured road profiles as input data. The data format of the recordings, the sampling rate... are generally different from one system to another, which may create difficulties for running the models. It was thus agreed that INRETS would check his routines using one texture data sample of each measurement system used in the project. This report addresses the LCPC texture data format and INRETS rolling tire model.			
14 Keywords tire road noise, road texture, measurement, modelling		15 Distribution PUBLIC INRETS/RR/04-538-ENG	
16 Number of pages 18	17 Price	18 Confidential until	19 Bibliography

Fiche bibliographique

1 UR (1 ^{er} auteur) Laboratoire Transports et Environnement (LTE)		2 Projet n° SILVIA (silent roads)	3 INRETS
4 Titre Evaluation of tire road noise from road texture profiles using INRETS rolling tire model			
5 Sous-titre Evaluation from a profile measured by the LCPC		6 Langue Engl	
7 Auteur(s) JF Hamet Ph. Klein		8 Rattachement ext.	
9 Nom adresse financeur, co-éditeur		10 N° contrat, conv. GRD2/2000/30202	
		11 Date de publication October 2004	
12 Remarques Ce rapport est l'édition INRETS-LTE du rapport SILVIA-INRETS-011-WP2 publié le 08/08/2003			
13 Résumé Une des contributions de l'INRETS au projet SILVIA est d'effectuer des estimations du bruit de contact pneumatique chaussée à l'aide de modèles. L'une des données d'entrée de ces modèles est le profil de texture de la chaussée. Le format des enregistrements, le pas d'échantillonnage... diffère en général d'un système à l'autre. Il a donc été convenu que l'INRETS vérifierait la compatibilité de ses algorithmes avec les différents formats en effectuant une évaluation à partir d'un fichier texture de chaque système utilisé dans le projet. Ce rapport concerne le format du système de mesure du LCPC et le modèle INRETS du pneumatique en roulage.			
14 Mots-clés Bruit pneumatique chaussée, profil de texture, mesure, modélisation		15 Diffusion libre INRETS/RR/04-538-ENG	
16 Nombres de pages 18	17 Prix	18 Confidentiel jusqu'au	19 Bibliographie

Contents

1	Road texture recordings	5
2	Texture profile preprocessing	7
2.1	Rolling model requirements	7
2.2	Slope and offset correction	7
2.3	Unevenness correction	7
2.4	End to end connection	8
3	Rolling tire process and noise evaluation	11
3.1	Loading	11
3.2	Rolling	11
3.3	Vibration noise power	13
4	Conclusion	17
	Bibliography	18

1 – Road texture recordings

LCPC texture profiles are given in *.pro files organized in three parts.

- The first part is an information zone:

```
V2
PM2D1
X+
0.000000000E+0
12001
100.000000000E+0
Plage du capteur / à définir
rayon de pointe de stylet / à définir
```

- The central part contains the profile readings:

```
.
-1471.000000
-1435.000000
-1381.000000
-1212.000000
999999.000000
999999.000000
-1008.000000
-991.000000
-955.000000
-970.000000
.
```

À 999999.000000 value indicates a drop-out.

- The third part is a comment zone:

```
*
Zone de commentaire
Mode de mesure IN SITU;
Mode de mesure : ;
Nom du projet : Piste M2;
Opérateur : PM;
Date et heure : 26/07/01 14:01:30;
Nom de la tâche : piste_lepc;
Nom de l'action : piste;
Type de l'action : Mode VOL;
Pas selon l'axe X (en  $\mu\text{m}$ ) : 100;
Pas selon l'axe Y (en  $\mu\text{m}$ ) : 0;
Vitesse selon l'axe X (en mm/s) : 3.50;
Vitesse selon l'axe Y (en mm/s) : 0.00;
X0 (en m) : 0;
Y0 (en m) : 0;
Z0 (en m) : 137626;
Nombre de points selon X : 12001;
Nombre de points selon Y : 1;
Mode Vol selon l'axe X;
Commentaire <utilisateur> sur l'action : Piste M2 axe2;
Commentaire <utilisateur> sur la tâche : Aucun;
1 piste Invalidité : 01
*
```

The separation of the readings is $\Delta x = 100\mu\text{m}$, the altitudes are in μm . Each file corresponds to a length 1.2 m.

Two sets were given by LCPC : a set of 20 profiles PM2Dnn.pro (nn=100, 200,..., 2000)

and a set of 5 profiles `PM2Gmm.pro` (`mm=100, 200, ..., 500`). Only the PM2D profiles are analyzed in this report.

Drop out correction The interpolation of drop-outs is made as indicated in the ISO working draft TS 13476-4 [1]: extrapolation from extreme values, interpolation for the rest.

2 – Texture profile preprocessing

2.1 Rolling model requirements

- The rolling model which is used evaluates the contact forces for a fixed altitude of the wheel hub; it does not take into account the car suspension. It is therefore necessary to correct an eventual slope or unevenness of the road profile
- The rolling is performed over several tire rotations¹. The elementary profiles are 1.2 m long. A processing has to be devised to reach the desired length (see §2.4 below).

2.2 Slope and offset correction

The ISO working draft TS 13476-4 [1] suggests a technique for slope and offset suppression (it has been applied in [2]). Another possibility is to use a fitting by a polynomial of order 1. The fitting procedure is used here with a routine available in Matlab. The resulting profiles are drawn Fig 2.1. Some profiles show pronounced unevenness (n°14 and n°20 in particular).

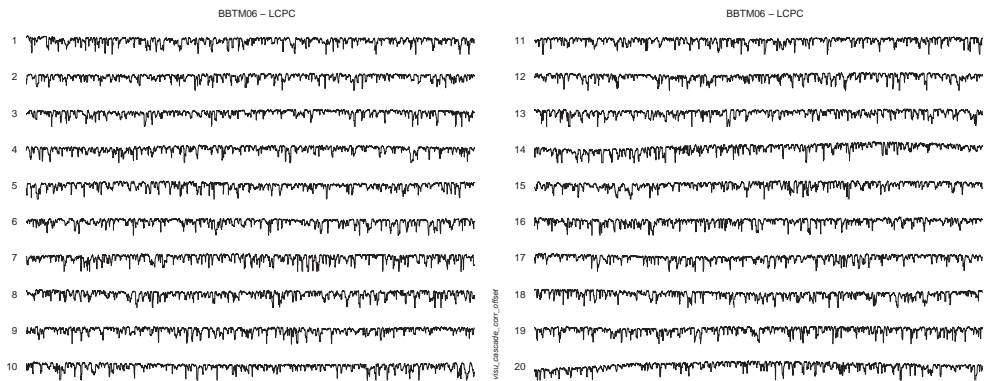


Figure 2.1: 'PM2D' : slope and offset corrected profiles

2.3 Unevenness correction

The unevenness is corrected using a low pass filtering with a 1 m^{-1} cut off frequency. The filtering is performed by taking the FFT of the signal, setting to zero the components below 1 m^{-1} and taking the IFFT. The filtered profiles are drawn Fig 2.2, the correction appears efficient.

¹the tire perimeter is 1.97 m

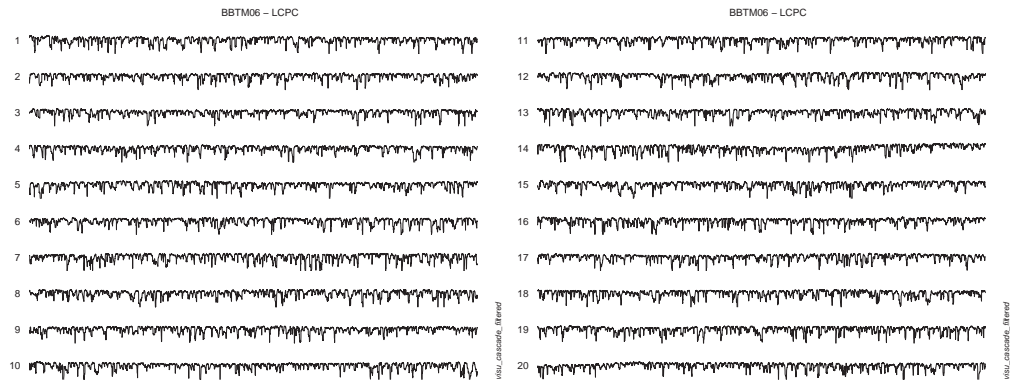


Figure 2.2: 'PM2D' : unevenness corrected profiles

2.4 End to end connection

As mentioned above, the rolling is performed over several tire rotations (up to five) which needs some 10 m length for the profile. At least two types of processing can be thought of:

- **Rolling on individual profiles:** each elementary profile is replicated to reach the desired length. The rolling process is performed on this *replicated* profile and the resulting noise evaluated. The road surface noise can then be taken as being the average of the individual noise results.
- **Rolling on successive profiles:** the elementary profiles are connected end to end, one after the other, to reach the desired length. The rolling process is performed and the rolling noise evaluated.

The evaluations are made here using the end-to-end process. The profiles are taken in the order of the file names: PM2D100-PM2D200-PM2D300,...

An implicit assumption is that connecting one profile to the other does not create strong discontinuities². This is checked visually: the last 5 cm of one profile and the first 5 cm of the next are drawn Fig 2.3 (the horizontal and vertical scales are the same). The connections do not appear to show larger discontinuities than the rest of the profiles, no global offset (similar to a step) is observed from one end to another.

²the same problem arises when a single profile is replicated

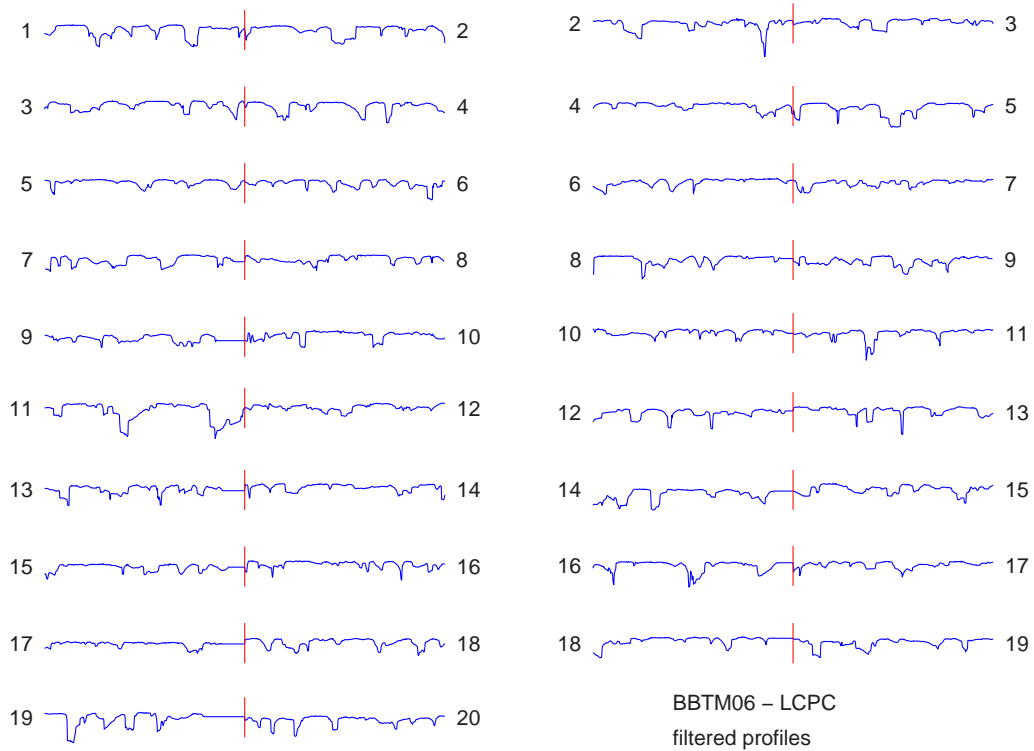


Figure 2.3: 'PM2D' : connected 'end to end' filtered profiles. Only the 5 cm before and after the connection are shown

Texture profile spectra 1/3 octave texture spectra are compared Fig 2.4:

- **individuals:** 1/3 octave spectra of the individual profiles.
- **average:** average of the individual spectra
- **end-to-end:** spectrum of the 20 connected profiles.

The dispersion between the individual spectra is rather large at low frequencies (more than 20 dB below 10m^{-1}). The spectrum level of the end-to-end profile is slightly higher than the average spectrum level in the mid and low frequencies (up to 5 dB at 5m^{-1}). The differences at $\lambda = 80\text{mm}$ and $\lambda = 5\text{mm}$ ($f = 12.5\text{ m}^{-1}$ and $f = 200\text{ m}^{-1}$), domains where the correlation between texture and noise levels is taken to be highest [3], are small; estimations using statistical models (e.g. [4] p31 or [5] p414) would give similar noise levels.

Rolling on two sections The rolling is performed on two sections corresponding to the first and the second half of the end-to-end profile.

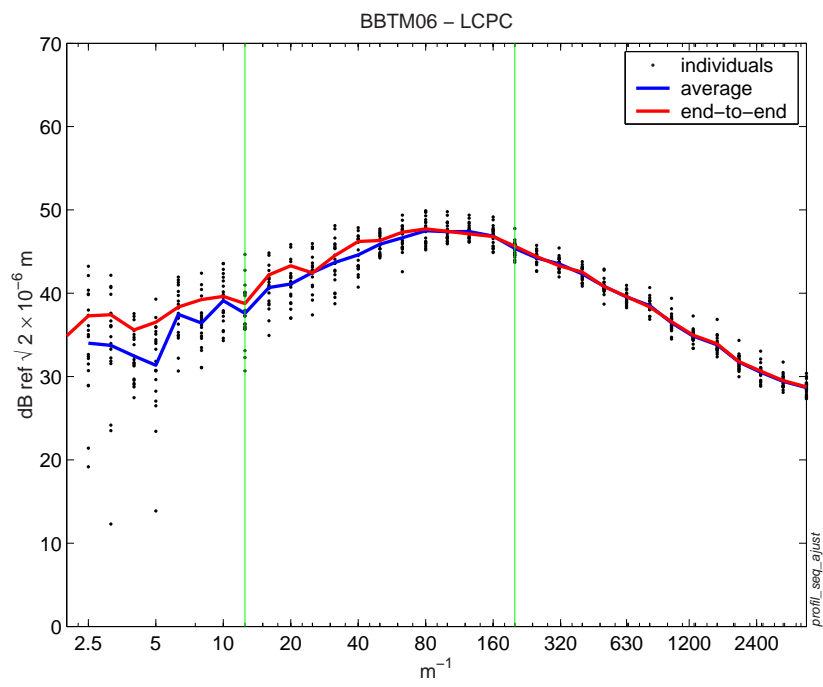


Figure 2.4: 'PM2D' : profile spectra

3 – Rolling tire process and noise evaluation

The tire belt is modelled as a thin orthotropic plate under tension (effect of the internal pressure in the tire cavity) resting on an elastic bedding (effect of the enclosed air volume and of the sidewalls). The tire gum is modelled as independent springs. This model was first suggested by Kropp [6] [7]. The rolling process is performed in the time domain [8]. The contact force is assumed to be constant over the contact width b^1 . The spatial resolution used for numerical evaluations, $\Delta x = 1.9$ mm corresponds to taking 1024 points on the perimeter. Space and time resolutions are linked through the rolling speed: $V = \Delta x / \Delta t$.

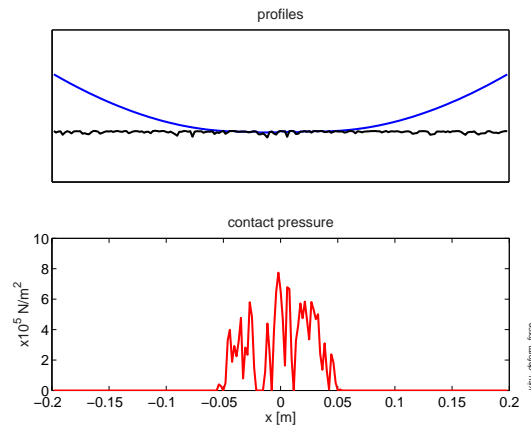


Figure 3.1: rolling model: profiles and contact pressure at one instant

The tire gum used for the computations has a rather high stiffness constant : $s_g = 417 \text{ MN/m}^3$ (for a 12 mm gum thickness, the equivalent Young's modulus would be about 5 MN/m^2).

The contact is at times non linear: parts of the road profile within the contact zone are not in contact with the tire gum.

3.1 Loading

The tire is gradually pressed on the road profile. At each time step the contact forces are evaluated. The loading process is stopped when the resultant of the contact forces (the hub force) balances in a permanent way the nominal loading force (within the required tolerance).

3.2 Rolling

Once the equilibrium reached, the hub position is fixed and the rolling process starts. The road profile is made of 10 individual profiles 1.2 m length, the total length is 12 m, the tire has a perimeter of 1.973 m so that there is no repetition of the road profile over up to

¹ b is lower than the tire width

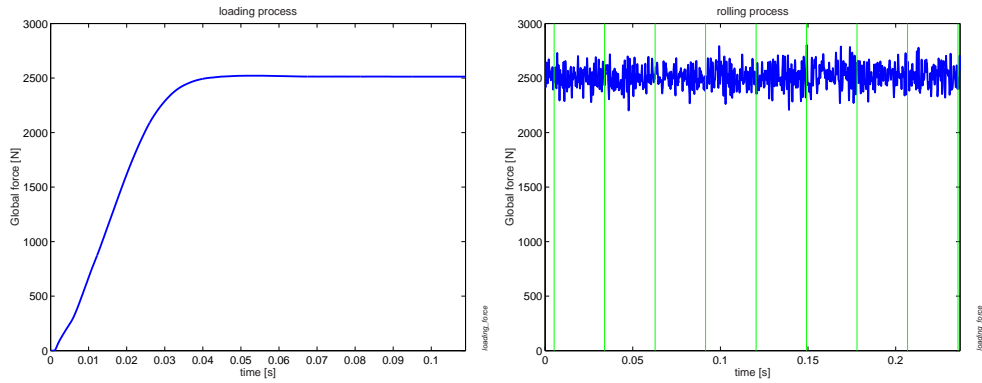


Figure 3.2: Hub force - left: loading process - right: rolling process

5 tire revolutions². The illustration given Fig. 3.2 (right) is the time evolution of the hub force during 5 tire revolutions at a rolling speed of 150 km/h. The vertical lines indicate the end-to-end connections between successive profiles³.

Contact pressure The first 10 ms of the time evolution of the contact pressure at the center of the contact zone, $F''(0, t)$, is drawn Fig. 3.3. Moments of zero pressure, i.e. of no contact at the centre, can be seen.

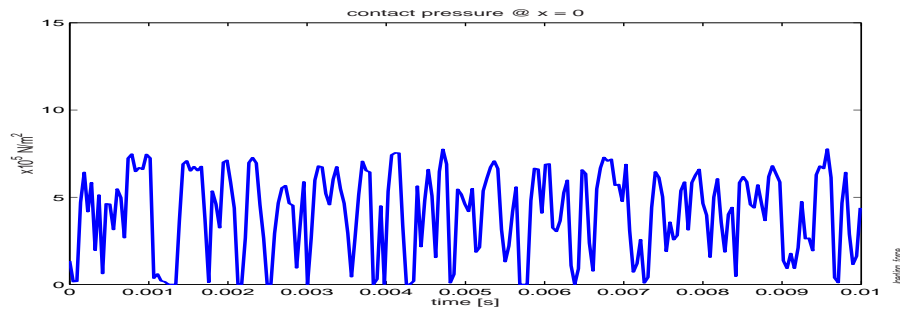


Figure 3.3: contact force at the center of the contact zone

The quantity $z_e(x) = F''(0, x/V)/s_g$ can be compared to the actual profile to get a visual estimation of the parts of the profile in contact with the tire:

- When the contact between the tire and the profile is complete i.e. when the tire envelopes totally the profile in the contact zone (this occurs for smooth textures or/and soft tire gums⁴), $z_e(x)$ is locally equal⁵ to the profile $z(x)$.
- When the contact is incomplete, the contact pressure is no more proportional to the profile, the quantity $z_e(x)$ is related to the profile only where a contact occurs, elsewhere it is equal to zero. This does not correspond to an actual deformation of a tire gum so that $z_e(x)$ cannot be considered as an enveloped profile.

²Evaluations with the rolling model are made on 3 to 5 tire revolutions depending on the rolling speed

³The center of the contact zone is initially positioned at half a tire perimeter distance ($l_x/2$) from the beginning of the road profile. The first connection occurs at $1.2 m - l_x/2$

⁴cf. for instance the evaluation made on the a1a1fm profile with a soft gum : SILVIA_INRETS_007

⁵ $z_e(x) - z(x)$ is a slowly varying function

An illustration is given Fig 3.4 (left graph) where the measured profile and $z_e(x)$ are compared⁶.

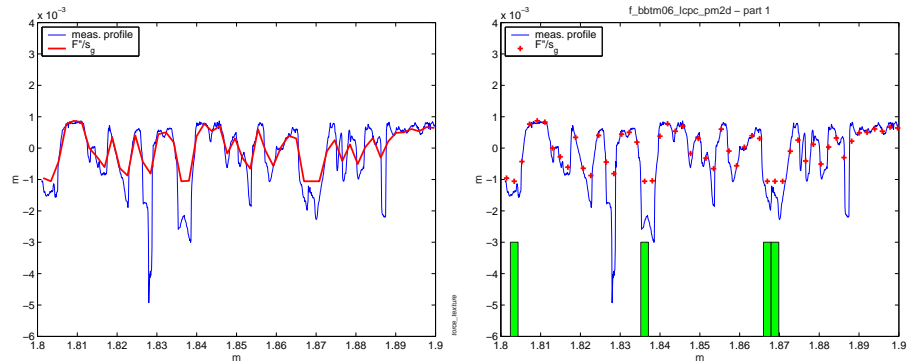


Figure 3.4: contact force and road profile (the vertical bars indicate the positions of no contact)

The figure is however misleading: one expects quite a few non-contact zones while there are actually four of these (indicated by the vertical bars on the right figure). The reason is that the road profile is given with a $\Delta x_{road} = 0.1$ mm while the calculations are made with a $\Delta x_{tire} = 1.9$ mm: each calculation step involves 19 profiles readings. A zero contact can be obtained in the computation only if the profile "dip" is larger than 1.9 mm. This may be better seen on the right part of the figure where the z_e values are indicated by a + mark. This aspect was not seen in the previous report relating to the TRL texture profile [2], probably due to the dips being rather large.

Recall An enveloped profile, as input for hybrid models relating texture and noise, should be evaluated using the static approach [9].

The contact forces, evaluated with the rolling model, can be used for hybrid models relating contact forces to noise⁷.

3.3 Vibration noise power

The rolling model implemented by INRETS addresses the vibration noise only. The road surface is perfectly reflecting. The evaluations are performed here in term of noise power levels (the whole tire radiation):

- noise power/ speed regressions in 1/3 octave bands : Fig 3.6. The levels are dB(A) weighted.
- vibration noise power spectra at 50, 90 and 130 km/h : Fig 3.7.
- slopes (in dB/decade) : Fig 3.8
- global noise power as function of speed evaluated when rolling on the first 10 profiles and the last 10 profiles : Fig 3.9.

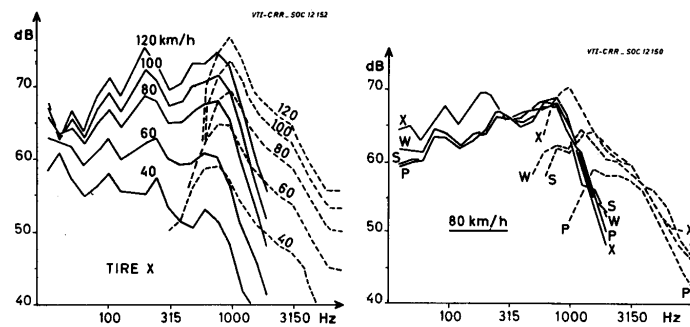
⁶ $z_e(x)$ is evaluated at a speed of 150 km/h, it is offset on the illustration so that the higher values correspond to the measured profile.

⁷The results could be compared to those obtained using the contact forces from the static envelopment

Comments⁸:

The noise radiation due to tire vibrations is seen to be maximum around 1 kHz and to decrease sharply at higher frequencies⁹(Fig 3.7). The peaky shape depends on the tire gum stiffness used¹⁰. This is in agreement with interpretation given by Sandberg and Descornet in 1980 [10]: from regression analysis between measured noise and texture spectra they came to the conclusion that "tire/road noise is the superposition of two independently generated spectra". Their estimations are reproduced Figure 3.5 (the levels are not A weighted). Their interpretation was that there was "a strong argument for identifying the LF noise generating mechanism with radially excited vibrations" [3]. (See also [11] for tire road noise evaluations using the rolling model).

The noise evolution with speed amounts to some 30 dB(A)/decade (Figure 3.9); this is commonly observed on pass-by noise measurements. The rate increases with frequency with however a dip around the 250 hz, 315 Hz 1/3 octave bandwidth (Figure 3.8); this trend has been observed on on-board measurements results, although the local minimum was rather in the 500 Hz frequency range¹¹



Differentiation of noise spectra into LF and HF components

Fig. 14 : Tire X at different speeds

Fig. 15 : All tires at 80 km/h

Figure 3.5: Differentiation of noise spectra into low frequency and high frequency components (from [10]). Note: the spectra are not A weighted)

⁸This is an addition to the original report

⁹the low frequency noise levels are strongly affected by the A weighting

¹⁰The same peak shape is obtained on other profiles when using the same gum stiffness (417 N/m³ while a "rounded" peak shape is obtained using a lower gum stiffness (65 N/m³)

¹¹INRETS on board measurement in the SIRUUS project, not published

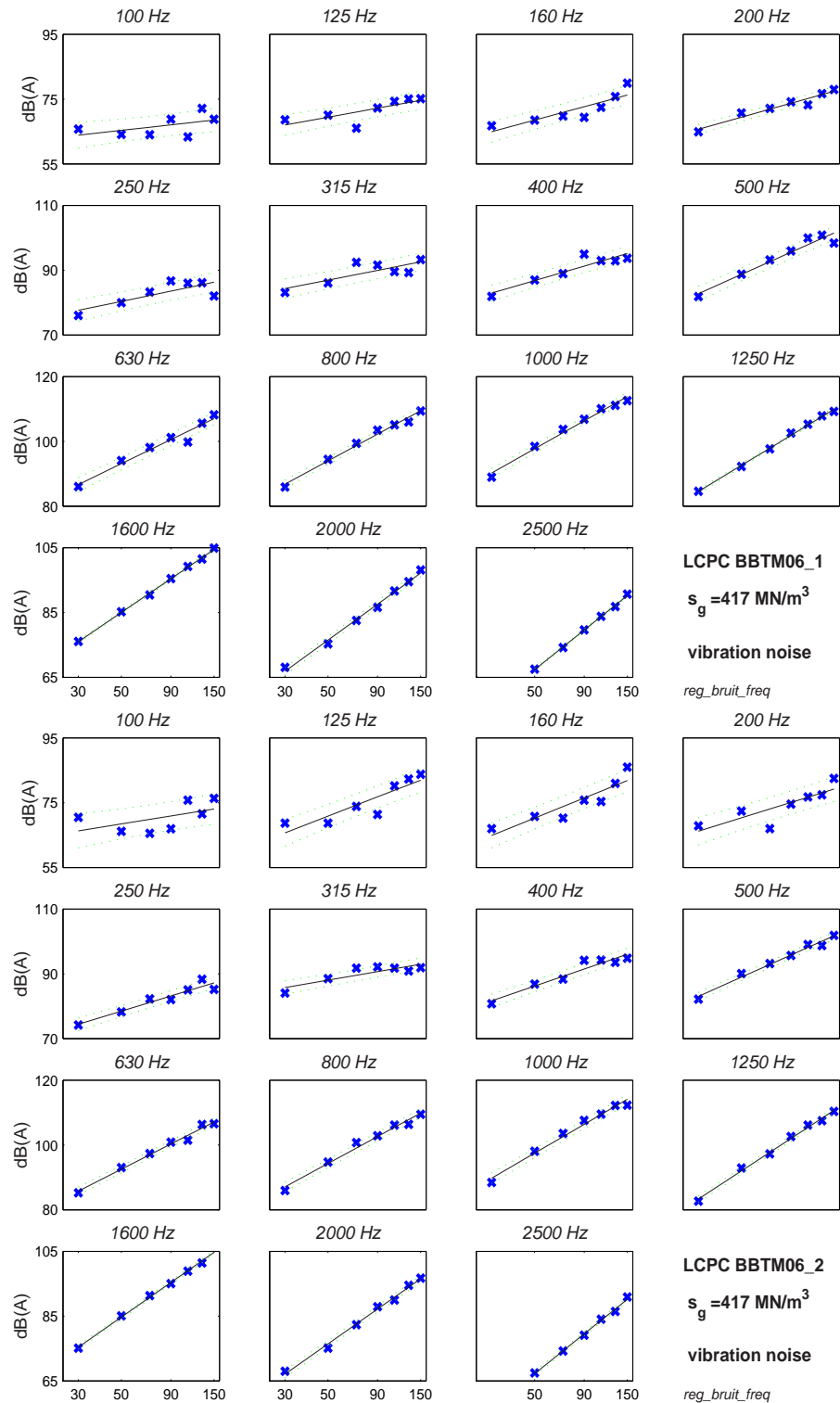


Figure 3.6: vibration noise on **BBTM06** first half(top) and second half (bottom) : regressions on power levels

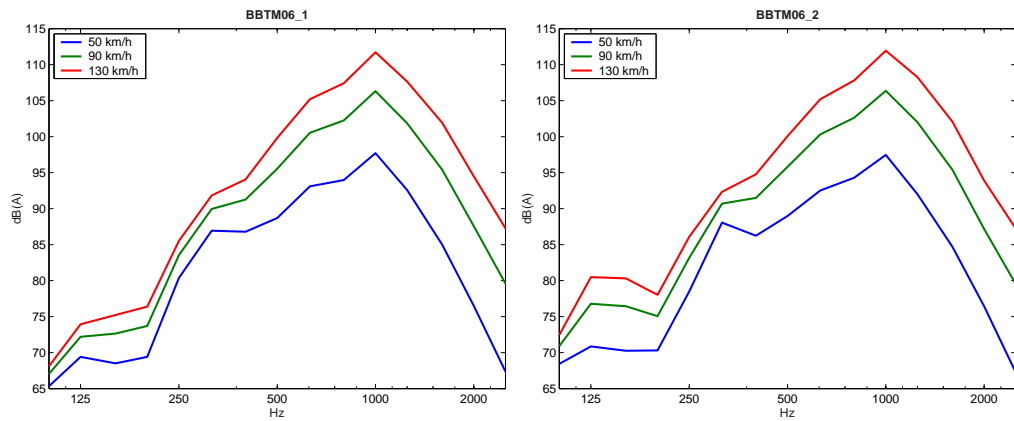


Figure 3.7: vibration noise on **BBTM06** first half and second half : power spectra

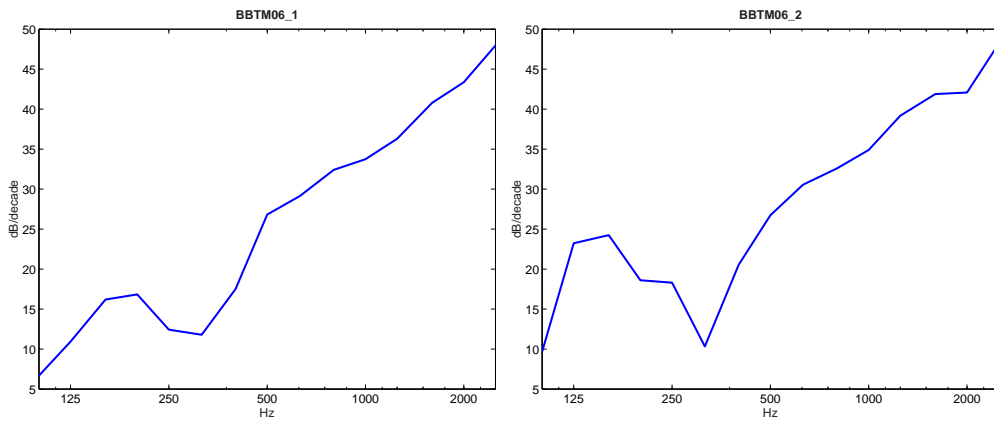


Figure 3.8: vibration noise on **BBTM06** first half and second half : slopes

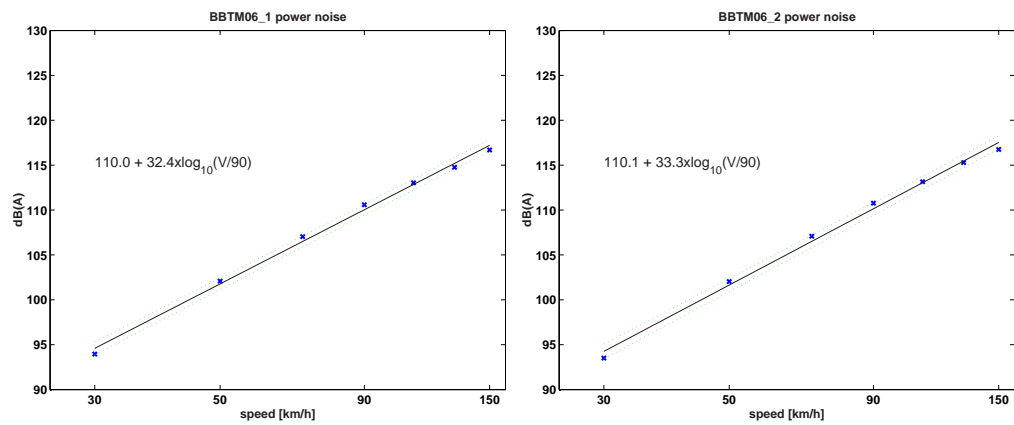


Figure 3.9: vibration noise on **BBTM06** first half and second half : global power noise

4 – Conclusion

The LCPC texture files do not raise major difficulties to be used as input data for the INRETS rolling tire model: the unevenness of each elementary profile 1.2 m long is first corrected, the profiles are then connected end to end leading to a 24 m long profile. Noise power evaluations are made over the first and the second half; they give slightly different results at low frequencies, with no consequence on the global noise values.

The evaluated noise spectra indicate that the vibration induced tire noise radiate mainly in the low frequency domain (up to about 1 kHz). This corroborates interpretations of experimental results given by Descornet and Sandberg in 1980. The evolution of vibration induced tire noise is found to be around some 30 dB(A)/decade which agrees with experimental results.

Bibliography

- [1] ISO-TS-13473-4. Characterization of pavement texture using surface profiles. part 4: Spectral analysis of texture profiles. Technical report, 2000.
- [2] J-F. Hamet and Philippe Klein. Road texture profiles - trl data format. Technical Report SILVIA-INRETS-010-WP2, INRETS, 2003.
- [3] G. Descornet and U. Sandberg. Road surface influence on tire/road noise. part 2. In *Inter-Noise 80.*, volume 1, pages 267–272, Miami, 1980. Proceedings of the 1980 International Conference on Noise Control Engineering.
- [4] G. Descornet, B. Faure, J-F. Hamet, X. Kestemont, M. Luminari, L. Quaresma, and D. Sandulli. Traffic noise and road surfaces: state of the art. Technical report, 2000.
- [5] Ulf Sandberg and Jerzy A. Ejsmont. *Tyre/road noise reference book*. Informex, 2002.
- [6] W. Kropp. *Ein Model zur Beschreibung des Rollgeräusches eines unprofilieren Gürtelreifens auf rauher Strassenoberfläche*. Phd, T. U. Berlin, 1992.
- [7] Wolfgang Kropp. A mathematical model of tyre noise generation. In *Engineering Foundation Conference on Vehicle-Infrastructure Interaction IV*, San Diego, 1996.
- [8] J-F. Hamet. Tire/road noise: time domain green’s function for the orthotropic plate model. *Acta Acustica*, 87:470–474, 2001.
- [9] Philippe Klein and J-F. Hamet. Envelopment procedure for tire/road contact. Technical Report SILVIA-INRETS-009-00-WP2, INRETS, 2003.
- [10] U. Sandberg and G. Descornet. Road surface influence on tire/road noise - part 1. In *Internoise*, pages 259–272, Miami, 1980.
- [11] Frédéric Wullens. *Towards an optimisation of tyre/road parameters for noise reduction*. Licentiate of engineering, Chalmers, 2002.