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TIRE/ROAD NOISE SIMULATION FOR OPTIMIZATION OF THE TREAD PATTERN

J. Ejsmont

Technical University of Gdansk, Mechanical Faculty, ul. Narutowicza 11/12, 80-952, Gdansk, Poland

Tel.: Int+48 58 347 23 47 / Fax: Int+48 58 347 26 95 / Email: jejsmont@pg.gda.pl

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ABSTRACT
There are many factors related to the tires, which are important to the level and spectral characteristics of the tire/road noise. The tread pattern is one of the most important factors in this respect. This paper deals with one aspect of the tread influence − namely tread pattern randomization which is a measure used to decrease tonality of the tire/road noise. The first part of the paper gives a short overview and comments on methods of data transformation and optimization, which have been reported in open literature. The next part is dealing with one of the possible approaches in this respect, which has been developed and successfully used by the author in designing numerous tread patterns. Noise spectra for tires having the same tread pattern segments but being differently randomized are presented.

1 - INTRODUCTION
Road traffic noise has become one of the major environmental problems of this century. Each motorized vehicle generates noise from several different sources during its operation. There are three major noise source groups. The first group is related to the power unit noise, the second group is related to the aerodynamic sources of the vehicle body and the third to the rolling of the tire on the road surface. The last one is called tire/road noise.

Many investigations show that tire/road noise starts to dominate over other sources at speeds of 20 − 55 km/h, depending of the road surface and vehicle acceleration/deceleration rate. Investigations also show that both road surface type and tire design may influence tire/road noise considerably.

Very often, in simplified studies, the tire/road noise is characterized only by the A-weighted sound pressure levels. Such characterization does not account very well for subjective noise perception. Rolling tires generate noise of a more or less periodic type and such noise may have tonal components as well as a certain degree of modulation. A typical example of a very annoying tonal noise is the noise generated by a circular saw with non-randomized teeth separation.

Old tires were manufactured with a total neglect of acoustics. They had a very simple tread pattern (often with "pockets", inducing a noise generation mechanism called "air pumping") and the tread elements were uniformly spaced. Such tires had a so called "constant pitch" of the tread. As the noise of such tires was very annoying, the tire manufacturers started to make more complicated tread patterns and to utilize the so called "tread randomization" that is to vary the sizes of consecutive tread elements in a certain "random" way. In order to make the randomization in the best possible way several methods have been used. This paper presents some of them.

2 - TREAD RANDOMIZATION BY DIFFERENT ALGORITHMS
The optimal tread randomization cannot be obtained by purely analytic means. Occasionally some special optimization algorithms are used but usually the proper randomization is accomplished by a some kind of trail-and-error method. Independent of the optimization algorithm, the computer programs for tread randomization use some rather simple methods for simulation of the tire/road interaction. It is justified to some extant by the fact that their scope is not to simulate true tire/road noise but only to "smooth" a spectrum in the region of the major tread harmonics. A signal, which is repeated synchronically with the tread pitch, is of secondary importance, while the way it is repeated is of primary concern. There are

two main problems related to such programs. Firstly, how to synthesize a reasonable time signal and, secondly, how to obtain the best sequence of the tread segments.
At first, let's assume that we have a good method for signal synthesis and we would like to find a good tread pitch sequence. In 1969, Varterasian [1] proposed a method called Mechanical Frequency Modulation (MFM) to obtain the goal − that is the noise being as similar to the white noise as possible. His method was based on a subjective observation of a spectrum calculated for the synthesized signal. An initial randomization was represented by a certain signal and in the case the spectrum of this signal was judged to be undesired, the pitch sequence was changed manually in such a way that the energy was transferred from peak(s) to "valley(s)" in the spectrum. After this the spectral analysis was repeated and new corrections were applied if necessary. The method of Varterasian was well harmonized with the level of computer science in the late sixties, but it required a very skilful human operator to make the fitting of the pitches.
Still another approach was presented by Walker [2] who proposed to use a sinusoidal modulation of the pitch around the tread circumference. Such a solution may give a good reduction in dominant tones but it also causes some audible warbling effects.
Recently, another algorithm begun to gain attention for tread pattern optimization. The so-called Genetic Algorithm (GA) is an optimization technique that simulates the process of biological evolution [3]. The following description of the GA is based on the above reference as well as [4] (due to a rather specific vocabulary the exact citation is presented):
"The basic concepts of a GA are as follows:

- *Encode design parameters into a **gene** string,*
- *Initialize **population** of candidate solutions,*
- *Loop for several **generations***
- *Evaluate the **fitness** of candidate solution*
- *Select **parent** solutions for **breeding** new candidate solution*
- ***Offsprings** are created from parents' genes with **crossover** and **mutation** operators*
- *Replace old solutions that are the least fit with the new offspring to form a new generation from the previous one.*
- *Repeat until fully **evolved** (i.e., converged) or out of analysis time"*

It is difficult to estimate if the GA is much more efficient than the simple random generation optimization. The GA optimization (at least as presented by Hoffmeister) does not, however, preserve the initial number of segments in each group. This may lead, in practice, to some variations of the overall length of the string (the circumference of the tire).
In the opinion of this author, it is not necessary to build very complicated algorithms to find the desired solution in the case of the tire tread pattern randomization. With modern and very powerful computers, it is possible to generate many random or semi-random (a random string of segments with certain restrictions imposed by the algorithm; for example no more that three segments of the same length are allowed) strings of segments and analyze them to find an optimal one. Many tests performed at the Technical University of Gdansk show that it is usually enough to test at about 1000 random strings to find a very good one (that is nearly as good as the best one for as many as 100 000 simulations). Instead of developing some very complicated optimization algorithms, it is probably more profitable to improve the methods of tread pattern representation as time signals intended for spectrum analyzes being a part of the optimization process, and also to improve the optimization criteria.
It is a matter for discussion what criterion should be used to distinguish between a "desired" and an "undesired" spectrum. For example it is possible to minimize the harmonics of the pitches or to minimize the energy contained in the wider band around them. Nowadays, it is possible also to use rather complicated algorithms related to ***Sound Quality*** techniques. Sometimes a very subjective method of listening to the synthesized noise may be utilized.

3 - METHODS OF TREAD PATTERN REPRESENTATION AS A TIME SIGNAL

The most important and not yet solved problem seems to be the proper generation of the sound pressure time history on the basis of the tread pattern. The tread pattern of most tires is composed of so called

"segments". The segments are basically elementary patterns, which are periodically spread around the tire. In order to randomize the pitch of the tread, some of them are "stretched" and some are "compressed" in longitudinal direction. This idea is explained in Fig. 1.
In the literature, different concepts of signal creation are presented. The simplest method is to generate a single unit pulse for each tread segment. Such a method was reported for example in [5]. Unfortunately, there are severe disadvantages with this solution. First of all, the shape of the unit impulse is far from being similar to the real excitation acting on the tread elements. The second problem is, that a single segment of the tread may contain many different elements and each element will in fact excite the tire when interfering with the surface. What more, the border between the segments may not have any grooves which would actually generate the noise − See Fig. 1. Thus it is much better to synchronize in some way the pulses with the existence of grooves in the tread pattern (see the lower part of Fig. 1). If such synchronization with grooves is preferred, it is possible to look separately at a single cross-section of the tire tread or to investigate several parallel cross-sections and to combine the corresponding signals together. Unfortunately, this method is not fully satisfactory since the unit pulse is not a very good representation of the real impulse caused by the tread block interaction with the surface. Some other shapes of "elementary" signals may be used instead. Another problem is related to the fact, that the tire footprint is not exactly rectangular, so the grooves in the tread hit the surface and leave the contact with the time shift depending on their lateral position.

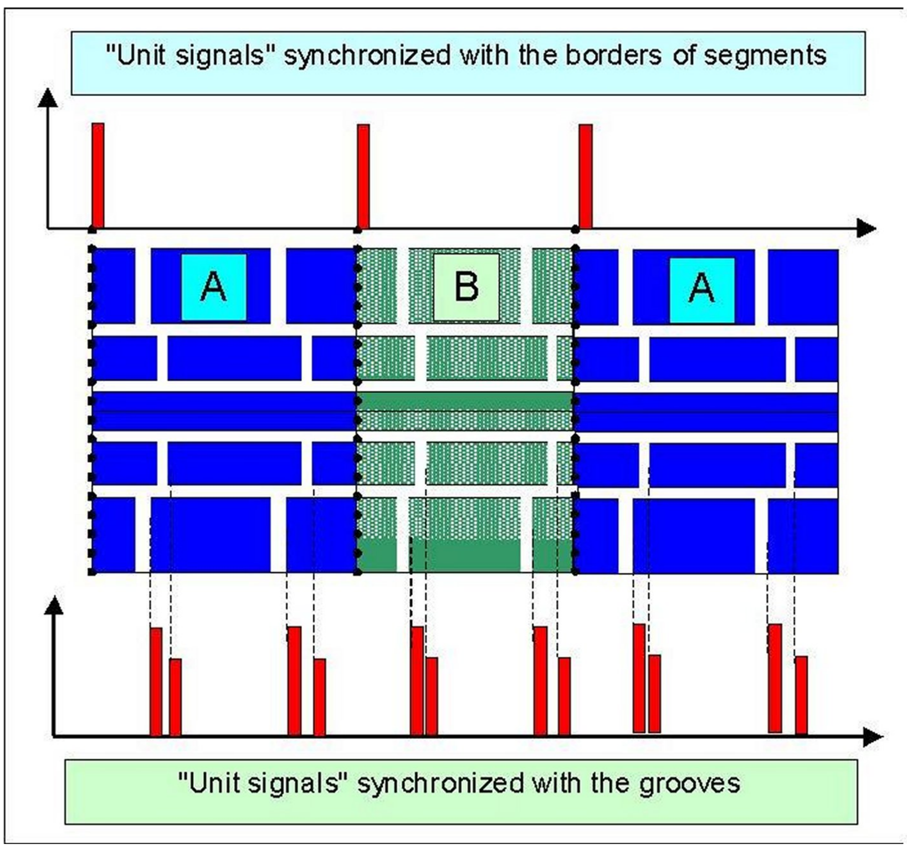

Figure 1: Segments (A and B) and two ways of their representation in the time history.

In Fig. 2 some possible representations of the "elementary" signal are presented. In addition to the "unit signal" synchronized with the edge of the tread element, rectangular and triangular signals synchronized with the element length are also shown. They are however inferior to more advanced signals based on the theoretical and experimental investigations of the tire/road noise generation mechanisms, like the example presented in Fig. 2D.
The development of computers made it possible to develop and utilize some rather complicated algorithms for simulation of noise related to the tread pattern. The inventors consider most of their algorithms as confidential because they are presently used for developing tires. In general, the algorithms analyze the tread pattern and try to synthesize the "noise" signal. Such a program has also been developed in the Technical University of Gdansk and successfully used for designing numerous tire tread patterns. The

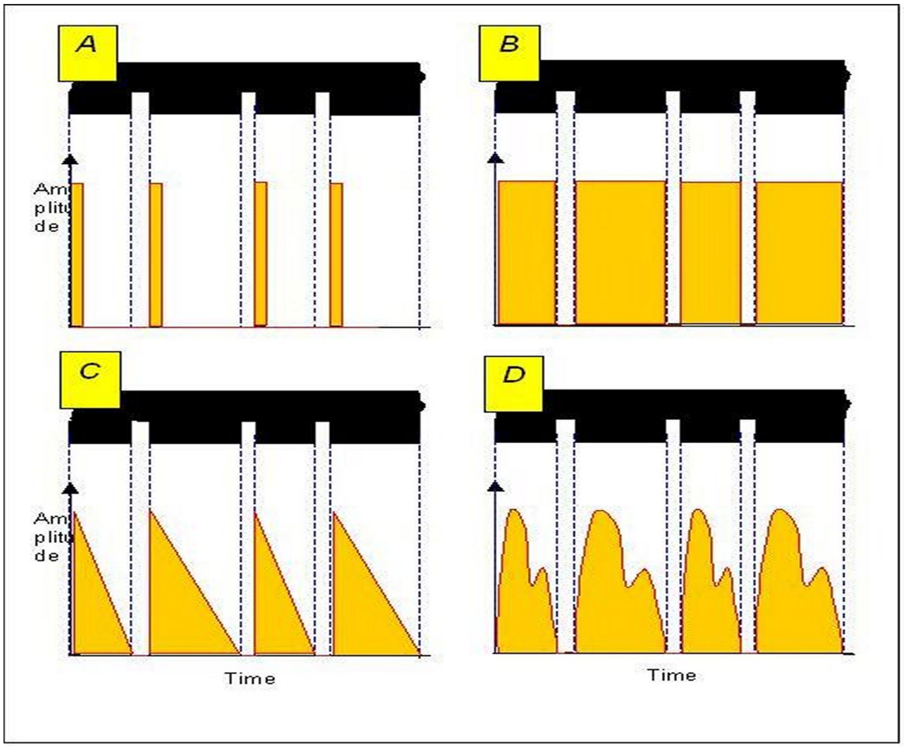

Figure 2: Various assumed shapes of elementary signals induced by the segments or elements of the tread pattern.

program accounts for the tire foot print shape and analyzes changes in the contact of rubber elements on the whole length of the trailing and leading edges − see Fig. 3. It analyzes the tread in numerous cross-sections ("circumferential slices") starting from the left and continuing to the right shoulder. For each cross-section, the intersections between the outline of the footprint and both the leading and the trailing edges are investigated. If the program recognizes that any of the intersections is passing or have just passed over the groove, a certain type of signal is generated. Signals for all cross-sections are combined (with the weighting function related to the lateral position of the cross-section). After this the signals from the leading and trailing edges are also combined and analyzed by the FFT.
The program automatically searches for the best randomization by testing numerous semi-random combinations of segments. A few different criteria may be imposed on the optimization process. The program also estimates the modulation of noise, which will appear when the tire rolls on the surface. An example of such a "modulation map" for a low level of modulation, as well as a high level, is shown in Fig. 4. The size of the rectangles represents level of a certain frequency at a certain tire angular position (two full rotations of the tire are represented on the vertical axle).

4 - CONCLUSIONS

Although it is still not possible to model the tire/surface interaction in a very precise way, the simplified models may be a useful tool in optimization of the tread patterns. Especially satisfactory results are obtained for designing the tread pattern randomization based on computer simulation accounting for the shape of the tire foot-print and analyzing the tread pattern in numerous cross-sections. Fig. 5 shows an example of the noise spectra for two tires with exactly the same tread segments but randomized in a different way. For the first tire the randomization was performed on the basis of a subjective judgement of the designer, and the second tire was designed with the use of the computer program described above. The computer simulation made it possible to considerably reduce the peaks related to the first harmonics of the tread pitches. Fig. 5 presents both spectra obtained during simulation (the two lower curves) and during drum measurements on the very smooth surface "Safety Walk" (two upper curves). As can be seen from the figure, especially in the frequency domain, the simulation is well correlated with the measurements. Further development of the models and algorithms may also help to design the layout of the grooves giving a low level of excitation to the tread elements and having de-tuned frequencies of vibration-excited noise.

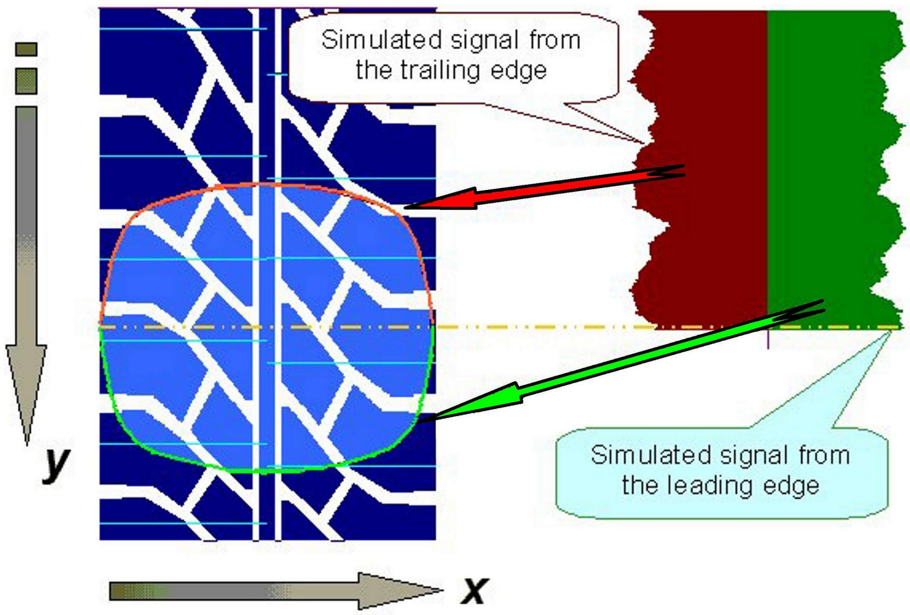

Figure 3: The principle of signal synthesis.

There are also some other methods, which may lead to improvements of the tonal characteristics of the tire/road noise. One of them is the so called "asynchronous tread randomization" patented by this author. In such randomization, the segments on the left side of the tire have a different order than the segments on the right side of the tire. Experience shows that for many tread patterns different randomization schemes on both tire sides reduce the tonality better than what may be achieved with the conventional method.

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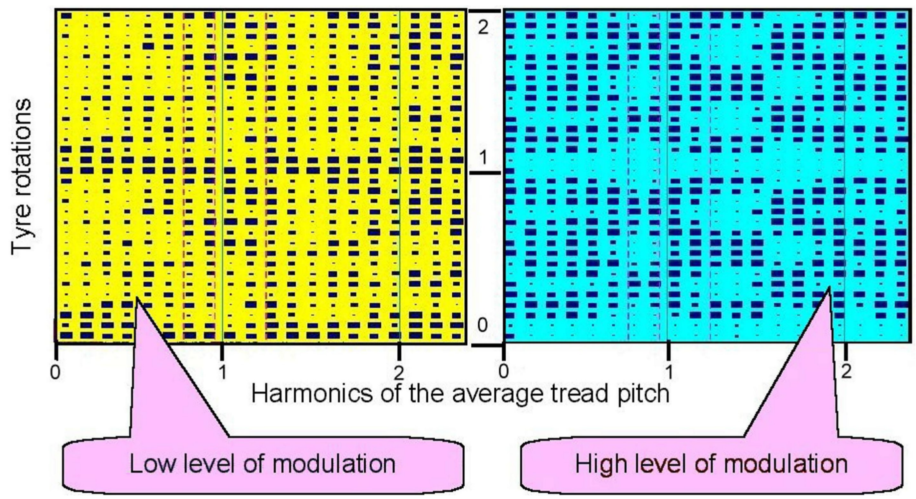

Figure 4: "Modulation map" for the certain randomization scheme of the tread pattern; the size of the rectangles is proportional to the level of a certain frequency at a certain wheel position; the periodical changes of the rectangle sizes indicate a high level of modulation.

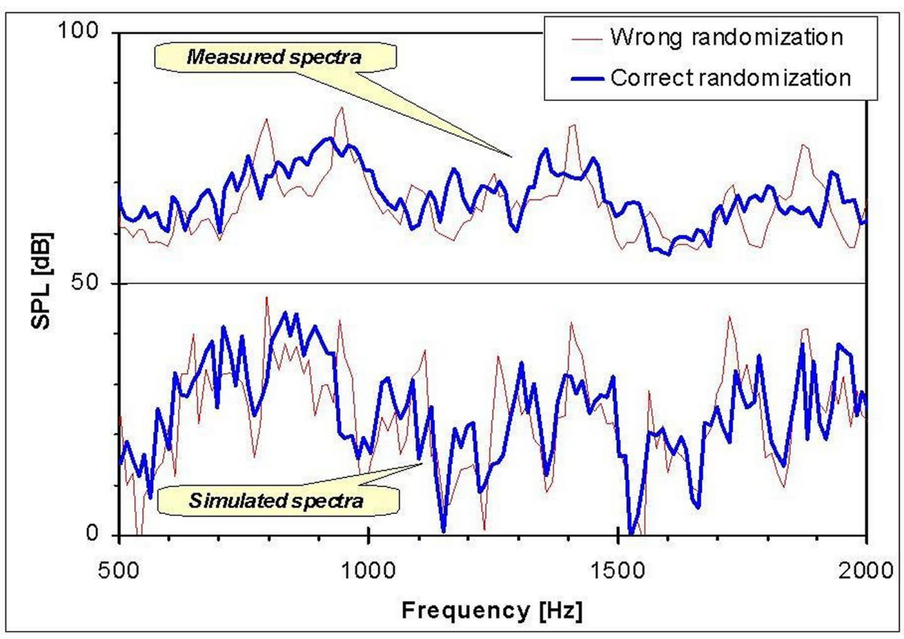

Figure 5: Comparison of narrow-band spectra (12 Hz bandwidth) for tires, which differ only in the randomization quality but having the same segments (data obtained during drum measurements on a replica road surface imitating smooth asphaltic concrete); the simulated spectra are arbitrary shifted down to facilitate a comparison with the measured spectra.