

Stud Noise Auralization

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ABSTRACT

During the winter special winter tires are used to prevent the car from slipping and the grip can be improved by using studded tires. Studded tires are known to cause higher noise levels and noise that is perceived as more annoying than non-studded tires. The objective was to model the interaction between the stud pattern and the stud/tire response (i.e. sound) caused by the excitation of the studs, and to make the result audible. In this study the interior airborne noise caused by the studs was auralized using a combination of recordings, modeling and filtering.

The proposed stud auralization model makes it possible to evaluate the influence of the stud pattern and the stud/tire response at any desired speed. The noise caused by the studs is determined by the stud/tire responses when studs hit the pavement, the stud pattern and the speed of the tire. The stud patterns and the stud/tire responses were measured for 5 different studded tires. Auralizations were created for all combinations of stud patterns and responses at two different speeds. A listening test was conducted to assess the annoyance of the stud noise auralizations.

From the listening test it was found that no single stud pattern or stud/tire response always performed best. There were large variations between the two auralized speeds. This implies that a stud pattern cannot be developed without taking the response of the tire into account. Auralizations must also be done and evaluated at different speeds.

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INTRODUCTION

When a product's sound quality, or the annoyance caused by the sound from the product, is evaluated listening tests are essential. The overall sound from a product can often easily be recorded, while the sound of a subpart or a subsystem of the product can be difficult to record separately. Over the years unwanted noise sources have, for example, been covered with sheets of lead to mask the unwanted sources. Near-field recordings have also been used to record the desired sound sources. If there are several sound sources or the sound source is distributed several recordings can be combined into an auralization of the desired source(s). Since the recordings are done in the near-field and the listening position normally is somewhere else a transfer function is required to simulate the sound in the preferred position.

In some cases it is not possible to separate the desired sound from the remaining sounds with near-field recordings, or the product might still not exist as a physical product. In these cases it would be helpful to have a method to create auralizations from either simulations and/or simple models. The demands on the quality of the auralizations will depend

on the application. Sometimes a rough auralization without details might be enough, such as a sound sketch [1], while at other times the auralization must be indistinguishable from a real recording.

In this study the interior airborne stud noise from studded winter tires was auralized using a combination of recording, modeling and filtering. The proposed stud auralization model makes it possible to evaluate the influence of the stud pattern (stud distribution) and the radiated noise from the tire due to the stud/road interaction at any desired speed.

Background

Both the internal and the external noise from a car can be divided into three main groups; wind turbulence noise, powertrain noise and noise from the tire/road interaction. For the interior noise a fourth noise source is noise from mechanical devices such as ventilation fans and power windows. The external noise is dominated by the powertrain noise at low speeds while the tire/road noise will dominate for higher speeds. For passenger cars the tire/road noise will dominate the external noise at such low speeds as 15-30 km/h depending on running conditions [2]. The level of the

powertrain noise remains rather constant as the speed increases; the engine noise mainly depends on the engine load and engine speed [2]. However, the characteristics of the powertrain noise changes with running condition while the main characteristics of the tire road noise is less depending on running condition even though the level increases with increasing speed.

During the winter special winter tires (also called snow tires) are used to prevent the car from slipping. The grip can be further improved on icy roads using studded tires. Studded winter tires are known to cause both higher noise levels and noise that is perceived as more annoying than non-studded winter tires and summer tires. On bare roads (asphalt or concrete) the studded winter tires have been reported to produce higher external noise levels than non-studded winter tires [3, 4, 5]. In the study by Sandberg and Ejsmont [5] 103 different summer and winter tires (studded and non-studded) were measured. On average the studded winter tires were about 2 dBA louder than summer tires and about 3 dBA louder than the non-studded winter tires [5]. The difference in noise level between the noisiest and most quiet tire was some 10 dBA and if the studded tires were excluded the range was reduced to some 8 dBA.

The noise emitted from a studded winter tire depends both on the tread pattern and the stud pattern. If the pattern of the tread or studs is periodic, a noise with distinct tonal components is radiated. By distributing the studs as randomly as possible around the tire circumference the tire manufacturers try to reduce the tonal components in the tire/road noise. This cannot be done completely at random since the possible stud positions are limited by the tread pattern. However, the number of possible stud positions is higher than the maximum allowed number of studs on one tire. The impact and release of tread blocks and studs on the road causes vibrations of the tire belt and sidewalls. The vibrations radiate sounds that can be amplified by the geometry of tire and road resulting in far-field noise. The tread and stud patterns together with the speed of the tire determine the timing of the forces acting between the tire and the road, which further determines the forcing frequencies. The response in the tire will determine which frequencies (resonances) easily radiate noise. The interaction between the speed, stud pattern and tire response (radiated sound) are illustrated in Figure 1.

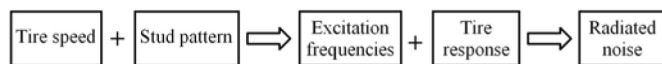


Figure 1. Illustration of the how the interaction between the speed, stud pattern and tire responses determine the radiated stud pattern sound.

The interaction between the tread pattern and tire responses can be investigated by manufacturing tires without studs that are run in test rigs and/or on roads. The effect of speed and other running conditions can easily be tested and the external as well as internal noise from the tire can be

investigated without the influence of the studs. However, the interaction between the studs and the tire cannot be investigated in the same way without the effect of the tread pattern. One way to overcome this problem is to use slick tires but since the response of the slick tire is different from the real winter tire and that even a slick tire causes substantial tire/road noise the use of slick tires is inappropriate. Therefore it would be of main interest to have a method to evaluate noise properties of different stud and tread patterns without having to manufacture a number of prototype tires.

In this paper a novel method to investigate and evaluate the interaction between the stud pattern and tire response is developed. The approach uses a combination of measurements of stud/tire responses and modeling based on the stud distribution around the circumference of the tire. The stud/tire response is the sound that is radiated from the tire as a stud hits the road. The objective of this paper was to model the interaction between the stud pattern and the structural response in the tire caused by the excitation of the studs, and to make the result audible. The aim was to create sound sketches that can be listened to and from that compare different combinations of stud patterns and stud/tire responses. A second aim was to investigate the importance of the stud pattern and the stud/tire response for the radiated noise.

METHOD OF EXPERIMENT

As mentioned, the noise caused by the studs in the tire is determined by two main factors; 1) the stud/tire response (radiated noise from the tire) when a stud hits the road pavement and 2) the repetition of these responses in time depending on the distance between the studs (stud pattern) and the speed of the tire (i.e. the speed of the vehicle).

In this study the interaction between the stud pattern and stud/tire responses were investigated without the influence of any other sound sources normally associated with rolling tires, as for example noise from the tread pattern. The method consists of four steps:

- Stud pattern measurements (or modeling)
- Stud/tire response measurements (or modeling)
- Auralization
- Listening test

In this study both measured stud patterns and measured stud/tire responses have been used. It is possible to use modeled patterns and responses to evaluate non existing patterns and tire designs. The stud pattern and the sound (stud/tire responses) when the studs were excited were measured for 5 different studded winter tires. The tires were from different manufacturers and/or of different models but all tires had the dimension 205/55R16 and the inflation pressure was 2.5 bar.

Stud Pattern Measurements

The positions of the studs for 5 tires were measured both along the circumference and in the lateral direction. In the lateral direction the studs were subdivided into 8 sections. Many studded winter tires have the studs grouped in 8 lines, known as stud lines, which can be observed in the track that a slipping tire produces in for example ice. In [Figure 2](#) a typical stud distribution for a winter tire is shown, and each stud line is shown by a grey line. All studded winter tires have the studs grouped near both sides of the tire belt due to regulations.

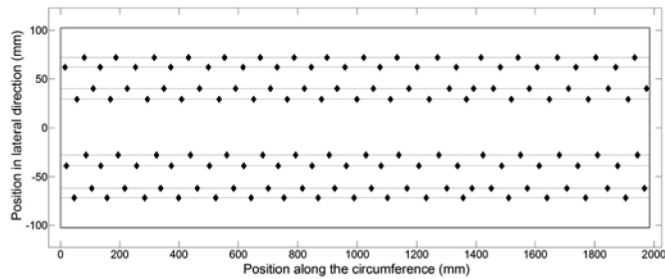


Figure 2. A typical stud distribution for a studded winter tire, the studs are arranged in 8 stud lines. Each stud position is shown by a diamond and the stud lines are shown by grey lines.

For two of the tires the studs are arranged in 8 stud lines, for two tires in 16 stud lines and for one tire in 14 stud lines. The number of studs and stud lines for the different stud patterns (i.e. tires) are summarized in [Table 1](#). For the tires with more than 8 stud lines the studs have been combined into 8 sections, see [Figure 3](#). All measured stud patterns are shown in [Figure 4](#).

Table 1. Number of studs and stud lines for the different measured stud patterns.

	Number of studs	Number of stud lines
Stud pattern 1	124	14
Stud pattern 2	130	8
Stud pattern 3	130	8
Stud pattern 4	128	16
Stud pattern 5	128	16

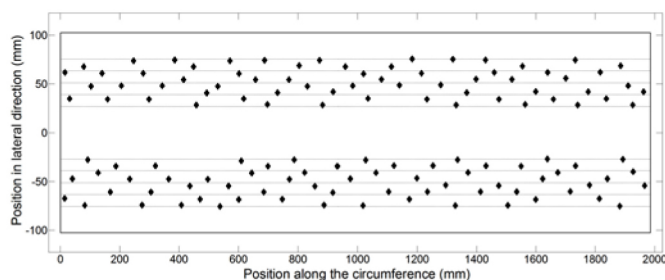


Figure 3. For two of the investigated tires the studs are positioned in 16 stud lines and for one tire in 14 stud lines that were grouped into 8 stud sections.

Stud/Tire Response Measurements

The response (noise) owing to a stud hitting the road was simulated by exciting the stud with an impact hammer (Brüel & Kjær 8202) with a steel tip. The radiated noise was measured and the procedure was repeated for a number of carefully selected studs on each tire. For each tire 8 studs were selected for the excitation. For each stud section a stud that was as close as possible to the middle of the section was selected, see [Figure 3](#). The reason to excite several studs was that the stud/tire response will depend on the actual position of the stud in the lateral direction.

The radiated sound from the tire belt and sidewall was recorded as the stud was hit by the impact hammer. The recordings were done using a free-field microphone (Brüel & Kjær 4190) positioned 0.5 m from the centre of the rim, see [Figure 5](#). All measurements were done in an anechoic chamber to ensure that no disturbing noise was recorded. Each stud was hit by the impact hammer 12 times to get a variability in the responses later used for the auralizations, in an effort to reduce the modulation which will otherwise be created due to that same stud response is repeated a number of times for each revolution of the tire. In [Figure 6](#) a typical stud/tire response is shown.

Both the time signal of the force and sound (stud/tire response) were recorded with Brüel&Kjær LAN XI interface (3050-B-6/0) along with Brüel&Kjær PULSE software. All analyses were done in MATLAB.

Auralization

The time signal of the far-field noise for a tire was calculated by adding stud/tire responses (time signals) according to the stud pattern and speed. The time between the studs hitting the pavement was calculated from the tire speed and the distance between the studs. For each stud a stud/tire response from the corresponding stud line was randomly selected and placed in chronological order according to the calculated time. The final time signal was achieved by summing all stud/tire responses for a number of tire revolutions according to the superposition principle, as shown in [Figure 7](#).

Based on the measured stud patterns and stud/tire responses auralizations were created for all combinations of stud patterns and tire responses, in total 25 combinations, see [Table 2](#). The auralizations were made for two different speeds, 50 and 80 km/h. In total 50 auralizations of the noise caused by the stud impacts against a smooth road surface were created. The reason for using different speeds is that the frequency characteristics of the excitation (caused by the stud pattern) changes with speed while the responses in the tire remains almost constant. By analysing different speeds the interaction between the excitation and response can be investigated more completely.