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An alternative close-proximity test to evaluate sound power level emitted by a rolling tyre

Nuria Campillo-Davo *, Ramon Peral-Orts, Hector Campello-Vicente, Emilio Velasco-Sanchez

Miguel Hernandez University of Elche, Avda. de la Universidad, s/n, 03202 Elche (Alicante), Spain

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The noise emission of a rolling tyre is produced by different physical mechanisms generated during the tyre-road interaction, being the main noise source of a vehicle when driving at high speeds. Diverse measurement methods can be found in the literature to assess the rolling noise emission. In that sense, the close-proximity (CPX) method allows to evaluate tyre/road sound level with at least two microphones operating in the close field of the test tyre. This paper presents a new methodology, based on the CPX method, which allows assessing the sound power level of the rolling tyre by introducing some changes in the traditional close-proximity test. The methodology (named A-CPX) has been analytically and experimentally validated, and is finally used to obtain the total tyre/road sound power level emitted by the whole set of tyres of a vehicle.

1. Introduction

Tyre/road noise is one of the main noise sources in a traffic flow. In fact, the rolling noise becomes the most important contribution to the total sound emission, higher than the engine noise in an internal combustion vehicle, when it is circulating at high speed. Previous studies demonstrated that such fact is independent even of the vehicle type. The results presented in [1] show a significant difference in the noise emitted by internal combustion engines and electric engines, especially at speeds below 50 km/h. But, above that speed, it is possible to assume the noise emitted by an electric vehicle as the noise emitted by an internal combustion engine vehicle without mechanical noise.

Different methods are collected in the literature to assess tyre/road noise, some of them are standardized methods and others are specifically designed for research purposes. Among the first group, the Coast-By (CB) method [2] is the current method for the approval of tyres, based on measurements at 7.5 m of the test vehicle when it passes with the engine switched-off and the transmission in neutral. The Close-Proximity (CPX) method [3] is much extended in the research field, and it is based on sound pressure measurements in the near field of the tyre/road interaction.

The CPX method proposes two different alternatives for measurement: the test tyre is installed in a trailer, and the trailer is towed by a vehicle; or the test tyre is directly mounted on the vehicle. The debate about benefits and drawbacks of each configuration is open. Some authors prefer to use an open trailer [4,5], whilst others choose to use a covered trailer [6–8], and some research groups install the measurement microphones on the test vehicle [9–11]. The trailer solution avoids any wind noise disturbances but sound reflections are generated inside the chamber, in contrast with the vehicle solution that may be affected by wind noise but there are no added sound reflections.

A common feature of most of the tyre/road noise studies collected in literature is the resulting magnitude. Most of them provide their results as an expression of the sound pressure level, but just a very few assess the sound power level [12–14], and mostly are used in traffic noise prediction models [15,16]. The benefit of providing the power level of a sound source is the invariability of such parameter, as it is independent of factors as environment, attenuation or distance.

The work presented in this paper defines an alternative methodology, named alternative close-proximity (A-CPX), to assess the tyre/road noise sound power level of a rolling tyre installed on a car while it is being driven on a road. The analytical and technical viability of the methodology are validated by means of a theoretical study and a series of field measurements, respectively. The results obtained with the A-CPX test are used to obtain the tyre/road sound power level of the whole vehicle, which is finally compared with other experimental results found in the literature.

* Corresponding author.
E-mail address: ncampillo@umh.es (N. Campillo-Davo).

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2. The alternative close-proximity (A-CPX) methodology

The novel A-CPX methodology has been designed for evaluating the sound power level emitted by a rolling tyre, by means of sound pressure level measurements. The methodology is based on the procedures described in the ISO 11819-2 standard [3] and also on the ISO 3744 [17]. The major difference regarding the traditional CPX method lies on the microphone locations, since in the A-CPX method these are located in further distances than in the traditional one. Such fact allows to assume that measurements are made in acoustical far field, as it will be illustrated in the next sections. The test tyre is directly boarded on the test vehicle, instead of using a trailer, in order to avoid sound reflections and to ease instrumentation setup.

The initial hypothesis is to consider the tyre as a static, omnidirectional, point source located on two reflecting planes: the road surface and the vehicle body. The power level emitted by the source is assumed to be proportional to the mean root square of the sound pressure, averaged in time and space.

An imaginary parallelepipedic surface must be defined surrounding the test tyre, which should not be installed on a drive nor steering axle, see Fig. 1. The characteristic dimension of the source, $d_{0\_A\text{-}CPX}$, is determined by the Eq. (1).

$$d_{0\_A-CPX} = \sqrt{(l_1/2)^2 + l_2^2 + l_3^2} \quad (1)$$

As the noise source is considered to be located on two reflecting planes, microphone positions will be distributed over an imaginary surface, quarter-sphere shaped. The radius of this surface should satisfy the condition expressed by the Eq. (2), in which the characteristic dimension of the source, $d_{0\_A\text{-}CPX}$, should be previously rounded to the higher integer. Likewise, it is recommended that the radius of the surface never be less than 1 m and preferably should have an integer value.

$$r_{A-CPX} > 2 \cdot d_{0\_A-CPX} \quad (2)$$

Microphone positions are distributed over the surface according to the coordinates collected in Table 1. The Fig. 2 shows a comparison of the microphone positions for the traditional CPX test, Fig. 2a, and the microphone positions for a radius of 1 m in the A-CPX, Fig. 2b. After studying different alternatives, presented in the Section 4, it is recommended to use slender structures for supporting the microphones, in order to avoid air turbulences in the surroundings of the microphones that might influence the measurements.

Fig. 1. Parallelepipedic reference surface defined for the A-CPX test.

Table 1
Microphone position coordinates.

Microphone position	x/r	y/r	z/r
A-CPX Front down	0.86	0.50	0.15
A-CPX Rear down	−0.86	0.50	0.15
A-CPX Middle	0	0.89	0.45
A-CPX Front top	0.57	0.33	0.75
A-CPX Rear top	−0.57	0.33	0.75

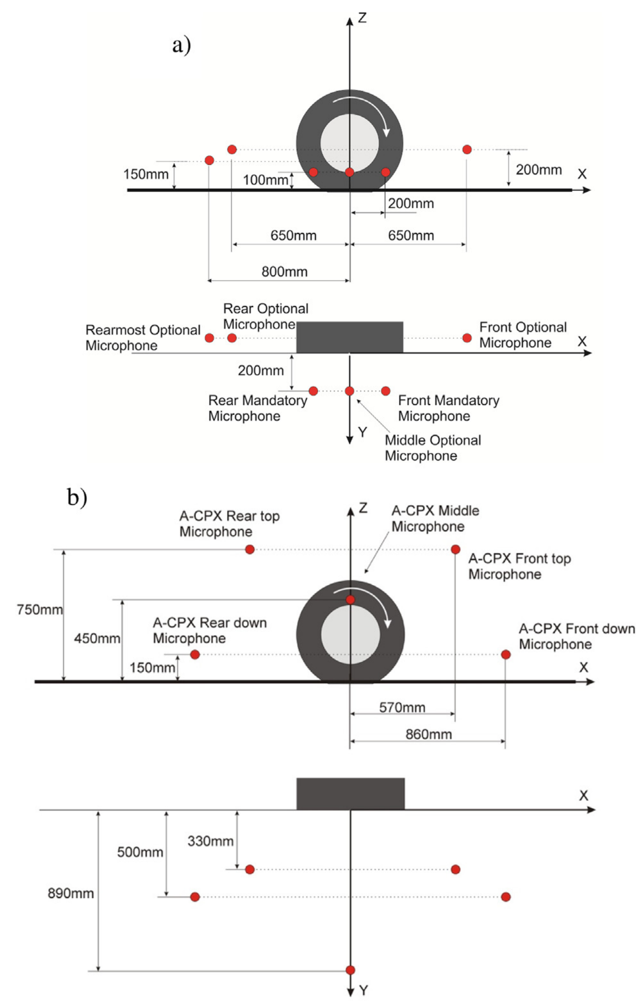

Fig. 2. Comparison of microphone positions: a) the traditional CPX test; b) the A-CPX test for a quarter-sphere surface of 1 m radius.

In an A-CPX test, the vehicle equipped with the test tyre circulates at a reference speed, over a distance of 200 m on the road surface. During the test, the microphones record the sound pressure levels generated by the tyre/road interaction. That procedure is repeated at least 3 times. The microphones are connected to a multichannel data acquisition system that will be located inside the vehicle. The sampling frequency follows the theorem of Nyquist-Shannon, defining the sampling frequency at least twice the maximum frequency of interest. Data is processed in third octave bands.

Vehicle speed is controlled during the test, using a global positioning system (GPS) boarded on the vehicle. Also weather conditions are registered, avoiding wind speeds over 5 m/s.

For the data processing, each road section of 200 m is divided into segments of 20 m. For each segment, it is calculated the equivalent sound pressure level registered by each microphone, according to the Eq. (3):