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Study of Tire-Pavement Noise Generation Mechanism using a Two-Wheeler

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ABSTRACT

The major objective of this study was to understand and quantify the interaction of tire-pavement noise when a two-wheeler traversed along different types of pavement sections. This involved designing a fixture to record the noise at source based on the On-Board Sound Intensity (OBSI)-like method, which was mounted on to a two-wheeler. Field noise measurements were recorded on asphalt and cement concrete pavements for varying speeds. The spectral analysis of tire-pavement noise collected by the setup displayed the influence of tread impact to be one of the major sources of noise generation. The first peak frequency in the spectral region, where the tire-pavement noise was dominant was found to be proportional to velocity of the vehicle and distance between the adjacent treads. In addition, harmonics proportional to the peak frequency were also observed in both types of pavement sections. The influence of pavement texture as a noise source appeared to exhibit a wide band spectrum while the influence of aerodynamic effects and pavement properties was less obvious, but needs further investigation. Nonetheless, this study is first-of-its-kind in the world in that a two-wheeler was used to evaluate tire-pavement noise characteristics whose results were comparable to the commonly used automotive (four-wheeler) OBSI setup. It is also envisioned that the two-wheeler setup developed in this study can be comfortably utilized in road locations that do not have enough space to accommodate larger vehicles as well.

Keywords: Two-wheeler noise measurement setup, On-Board Sound Intensity, Tire-Pavement Noise, Tire treads, Spectral analysis, asphalt concrete, cement concrete
I-INCE Classification of Subject Number: 11, 72

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1. INTRODUCTION

Traffic noise is the combined outcome of the vehicle drive train noise, interaction between the tire and the pavement, and the aerodynamic effects attributed to the vehicular motion. Globally, it has been recognized that tire-pavement interaction noise is a significant contributor to the overall traffic noise (1). Hence, there have been numerous efforts to understand the mechanism of tire-pavement noise generation and its subsequent mitigation by adopting changes in the tire and pavement design. Extensive discussion on the studies carried out using cars and trailers have been reported elsewhere (2, 3) in which it was observed that tire-pavement noise is typically characterized by three major sources: (a) tire dimensions and materials properties; (b) pavement type, texture, and other pavement-related properties; (c) air surrounding the pavement and tire, and its interaction with these elements during vehicular motion.

Different methods have been developed to record and/or characterize tire-pavement noise of which Statistical Pass-By (SPB) (4, 5, 6), Close Proximity (CPX) (7, 8), and On-Board Sound Intensity (OBSI) (9) methods are popular. Standardized procedures are available to carry out these tests and measure noise depending on the problem. In India, a few attempts have been made to characterize tire-pavement noise by developing CPX-like trailers (11, 12), wherein the isolation chambers were designed to run with a car / mini-truck as parent vehicles. But, it is interesting to note that from the perspective of roads and convenience of their utilization in the country, two-wheelers are the major class of vehicles traversing the pavements across the region. Therefore, influence of the two-wheeler in tire-pavement noise regime in the overall traffic noise needs to quantified. It is noteworthy that there have been no attempts to characterize noise in this setting, and hence a need to study the mechanism of noise generation and characterization is deemed necessary.

Based on the studies on cars and trailers in the past (13), it has been found that OBSI method is effective for measurement of noise at source as against other methods such as CPX and SPB methods. Thus, this study focused on the measurement of tire-pavement noise generated, as a two-wheeler traversed a pavement section. Since there was a very high chance of capturing the influence of noise due to engine of the vehicle as well as other vehicles passing the study vehicle, a system similar to the OBSI method was adopted in order to measure only the tire-pavement noise. Although OBSI is sophisticated and robust, the current designs are compatible with cars and not two-wheelers, and hence, there was a need to align the setup to follow the path of the two-wheeler. The scope of the effort included design of a OBSI test setup to measure tire-pavement noise using a two-wheeler, and subsequently analyzed to identify the major source of noise generation.

2. DESCRIPTION OF THE TEST SETUP

The OBSI test procedure and setup on two-wheeler developed in this study had at least a pair of microphones to act as leading and trailing sensors, which were mounted on a fixture and connected to the two-wheeler. The fixture has been designed in accordance with AASHTO 76:2013 (9) guidelines, which specifies the distance of the microphones to be at 100 mm and 75 mm from the tire and the pavement surface respectively, and the longitudinal distance between the microphones to be 210 mm. The dimensions of the fixture schematic designed and fabricated for the purpose, are shown in Figure 1. The fixture was fabricated by cutting and welding 3 mm thick mild steel solid square sections and mild steel bars of diameter 10 mm, and the final setup is as shown in Figure 2a. A pair of PCB Electronics microphones (Model 378B02, sensitivity

= ±0.20 dB) were mounted on to the fixture, as shown in Figure 2b. This setup was in turn clamped to the two-wheeler below the exhaust pipe as shown in Figures 2c and 2d. Note that the two-wheeler used for testing purposes had a capacity of 150 cc. Further, the microphones were connected to a 16-channel Data Acquisition System (DAQ), which had a precision to work offline and collect samples at 25.6 kilosamples/s. This OBSI test setup was used in the field to acquire tire-pavement noise data.

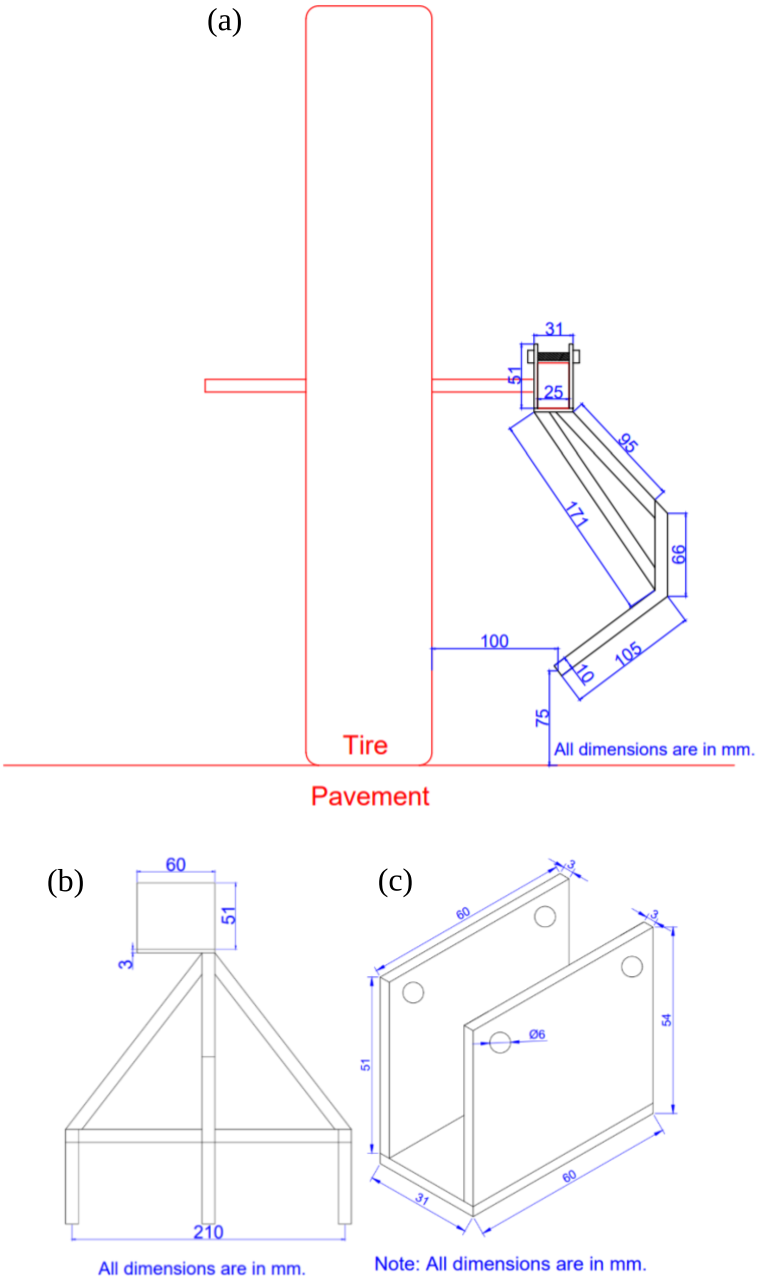

Figure 1: Details of the OBSI fixture schematics viewed from the rear end of the vehicle: (a) Section view, (b) Longitudinal view, and (c) Isometric view of the clamp

Figure 2: OBSI actual test setup: (a) Fabricated fixture, (b) Microphones mounted on the fixture, (c) Fixture connected to the two-wheeler (rear view), and (d) Longitudinal view

3. DESCRIPTION OF THE TEST RUNS

The tire-pavement noise measurements using the developed OBSI-like fixture for a two-wheeler was carried out on stretches of asphalt concrete and cement concrete pavements. The pavement sections were selected such that the tests could be conducted at average speeds of 30, 40, 50, and 60 km/h without encountering any turnings and curves. The time for testing was chosen such that the influence of extraneous noise and interruptions from the adjacent traffic was minimum, thereby avoiding the need for braking. The data acquisition system during each test was started once the vehicle was accelerated to the required speed and then maintained for the duration until the desired stretch was covered, after which the acquisition was stopped. This cycle of testing was repeated for three trials on each type of pavement and at each speed. The noise measurements using the microphones were recorded between time and pressure. A typical plot of time versus acoustic pressure for both asphalt and cement concrete pavement stretches is shown in Figure 3.

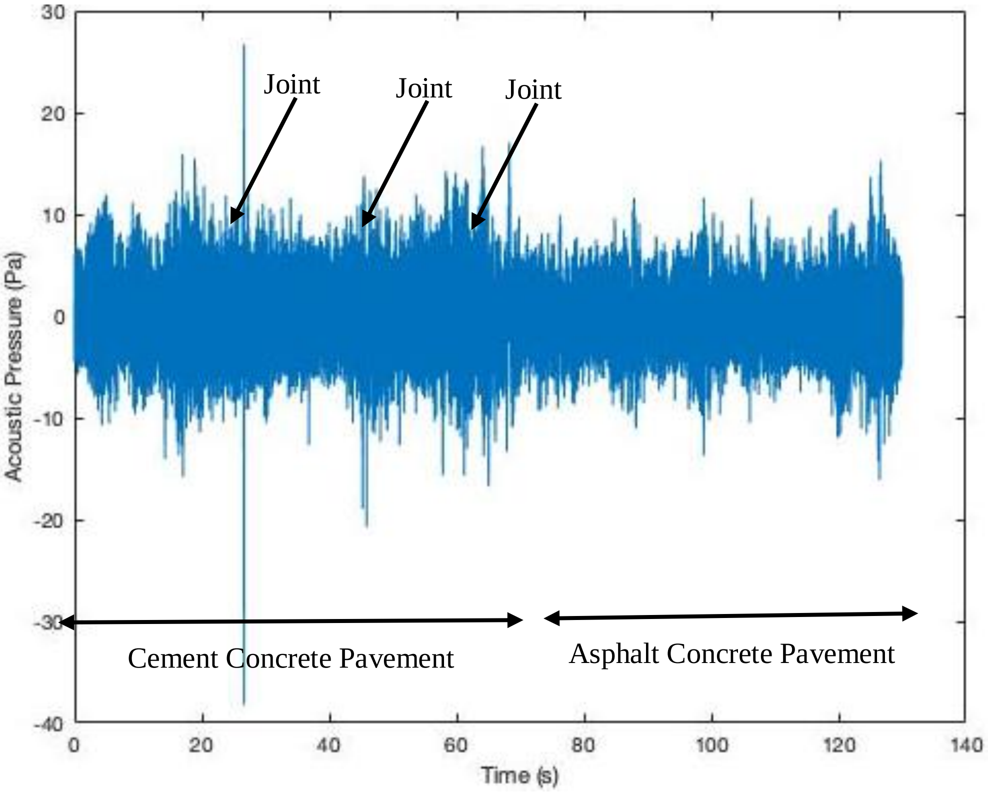

Figure 3: Noise recorded on cement concrete and asphalt concrete pavements using the microphones

4. ANALYSIS OF TIRE-PAVEMENT NOISE CHARACTERISTICS

As observed in Figure 3, the sound level in cement concrete section (104.2 dB) was found to be higher than the asphalt concrete pavement (98.9 dB). Also, the impulses observed at regular intervals in the cement concrete measurements indicated the presence of joints at frequent intervals along the pavement length. These general features invested confidence in the test setup developed for tire-pavement noise measurement. As mentioned previously, test runs were conducted at 30, 40, 50, and 60 km/h with three trials at each speed. It was observed that the tachometer reading of the vehicle at those speeds varied from 2200-6000 rpm, which correspond to a frequency range of 36-100 Hz. Furthermore, it was found that based on the spectral content of noise data, the influence of tread pattern was more pronounced at frequencies greater than 200 Hz. Hence, it was inferred that engine noise and tire-pavement noise together contribute to the overall noise level in the spectral range of 0-200 Hz. It has been reported in the literature (14) that the major sources of tire-pavement noise occur at frequencies lower than 1300 Hz. Hence, the range of 200-1300 Hz was identified as the region where tire-pavement noise was significant based on actual measurements of this study.

Figure 4 shows the tread pattern on the two-wheeler's tire having a diameter of 640 mm (D) and a wavelength of 29 mm (l). The number of treads was computed using the following Equation:

$$N_{treads} = \frac{\pi\,\mathrm{D}}{l} \ldots\ldots (1)$$

where: N_{treads} = number of treads; D = diameter of tire, mm; l = distance between adjacent treads, mm

Figure 4: Tread pattern of the two-wheeler tire used in the study

Note that N_{treads} in turn is related to the vehicle velocity (v) and was used to derive the frequency as follows:

$$f = N_{treads}\frac{w}{2\,\pi} = N_{treads}\frac{v}{2\,\pi\,\mathrm{D}/2} = \frac{v}{l} \text{ ……. (2)}$$

where: w = angular velocity of the tire, Hz; v = velocity of vehicle, m/s.

Using Equation (2), the frequency corresponding to the tread impact was calculated for various speeds and tabulated in Table 1. Based on the calculations, it was observed that the first significant peak at all speeds was similar to the calculated frequency.

Table 1: First peak frequency in the range 200-1300 Hz for asphalt and cement concrete pavements recorded at different vehicular speeds

Speed (km/h)	Trial	First peak frequency (Hz)		Calculated Frequency (Hz) (using Equation (2))
		Asphalt Concrete	Cement Concrete	
30	1	275.00	268.75	287.36
	2	281.25	268.75	
	3	281.25	275.00	
40	1	356.25	350.00	383.14
	2	362.50	356.25	
	3	356.25	362.50	
50	1	456.25	468.75	478.93
	2	450.00	462.50	
	3	450.00	456.25	
60	1	525.00	556.25	574.71
	2	550.00	543.75	
	3	531.25	525.00	

Figure 5 shows the spectrum in the range 200-1300 Hz for the noise measured at 40 km/h. The first peak in this range was mapped to the influence of tread impact and this was consistently observed in asphalt concrete (Figure 5a) and cement concrete (Figure 5b) pavements across all trials in both leading and trailing microphones. Note that the first frequency in the spectrum was a function of velocity (Equation (2)), which was observed in the noise data collected at other vehicle speeds also, as listed in Table 1. A maximum deviation of 8% was observed, which was attributed to the deviation in vehicular speed for any given trial. From observations, it was deduced that the tire tread pattern and consequently the tread impact are the major sources of tire-pavement noise for the two-wheeler used in the study. Since the difference between the leading and trailing microphones was about 2-5 dB with the former recording higher noise levels, only the results based on leading microphone data was summarized in Table 1.

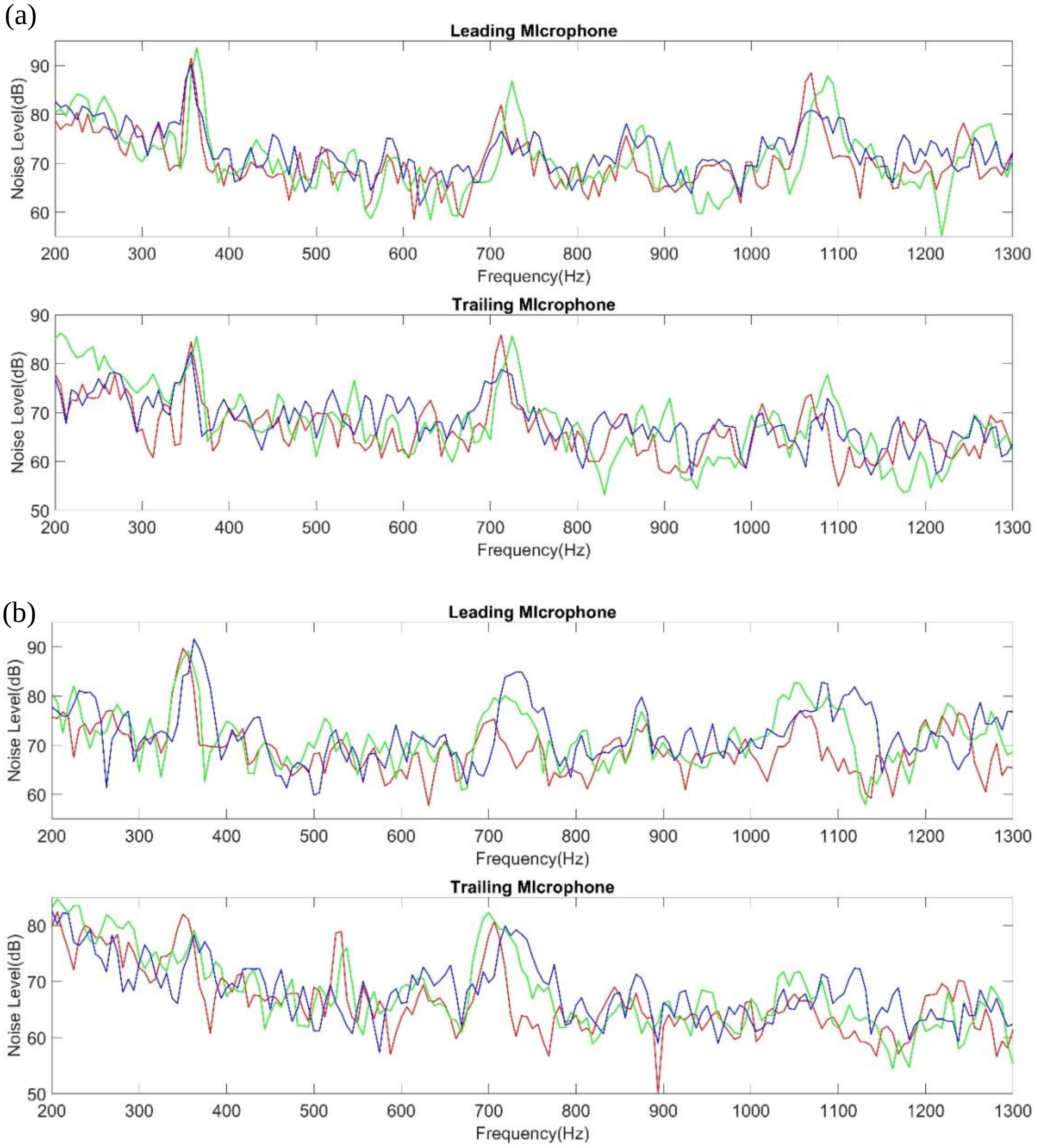

Figure 5: Leading and trailing microphones noise spectra of the noise data collected at 40 km/h on: (a) asphalt concrete, and (b) cement concrete pavements

The noise level corresponding to the frequencies reported in Table 1 was found to be similar and in some trials higher for asphalt concrete than in cement concrete sections. This aspect of the tire-pavement noise needs further validation by considering the test runs on other sections of asphalt concrete, where the surface conditions may have higher influence to the field noise measurements. This aspect is being studied in greater detail in the ongoing measurements by the authors.

Additionally, in the frequency range of interest, harmonics proportional to the tread impact frequency were observed. For the case of 40 km/h, harmonics were observed at (712.50, 1068.75, 1418.75 Hz,…), which were significant in asphalt concrete pavement and relatively less obvious in cement concrete pavement, especially, for the higher order harmonics. This indicated nonlinear behavior of the tire due to its interaction with the pavement. This nature of the spectral content was evident in all trials at all speeds of the two-wheeler, which needs further examination as well.

5. DISCUSSION AND CONCLUSIONS

The OBSI fixture to measure tire-pavement noise was designed and fabricated in-house, to study the noise behavior of two-wheeler vehicles. It was observed that in the lower end of the spectrum, the engine and tire-pavement noise along with other sources were significant contributors to the overall noise levels. For frequency range greater than 200 Hz, the peak in the spectrum corresponded to the tread pattern of the tire, indicating tread impact to be one of the major sources of tire-pavement noise. The presence of harmonics indicated a nonlinear behavior of the tire, which demands further study. The role of the texture wavelength that typically varies from 0.5-500 mm corresponding to a wideband influence could be attributed to the tire-pavement noise, though this needs further investigation by carrying out mean profile depth measurements on the pavement sections. The stick snap and stick slip mechanisms of tire-pavement noise generations along with aerodynamic effects are yet to be accounted for, if present, in the noise measurements. The study intends to build on this understanding in the future to observe the effect of tire-pressure, tread-pattern, pavement texture, and temperature among other parameters that remarkably influence noise characteristics using a two-wheeler.

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