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Tyre-Road Noise Generation and Mitigation Strategies in Pavements –A Review

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Abstract:-- **The increasing vehicular traffic in urban area results in the increase of traffic related noise. Presently the traffic related noise pollution is a serious issue like all the other forms of pollution. The main sources of traffic noise generation are vehicles, tyre-road interaction and sound of wind around a moving automobile. For speed greater than 40km/hr, tyre-road noise is the major factor in noise emission. The noise reduction technique at source level is more economical than other techniques. This paper studies about different noise generation and noise amplification mechanisms in pavements, and different measures to reduce the tyre-road noise in pavements. The noise reduction techniques for the concrete and asphalt pavements are discussed in detail.**

Keywords: Low Noise Pavements, Noise Pollution, Noise Reduction, Tyre-Road Noise.

I. INTRODUCTION

With the increase in urban traffic, noise generated by traffic is also increased and became a serious environmental issue. Hence the road traffic noise reduction is a critical issue, especially in cities [1]. These noises created by road traffic leads to many health issues and is even a threat to the countries' economies. The industrial, transportation and social activities may also lead to noise pollution. The major causes of noise pollution are related to road and railway transport [2]. At present, the studies indicate that the transportation related noise produced is not just an annoyance, but has a wide range of harmful health, social, and economic effects like all the other forms of pollution [3], [4]. The major portion of urban population gets exposed to high traffic noise that severely affect their standard of living [5]. With the every twice increase in traffic, normally a 3 decibel (dB (A)) noise addition is estimated [6]. The key sources of traffic noise generation are vehicles, tyre-road interaction and sound of wind around a moving automobile [7], [8], [9]. At a speed higher than 40 km/h, tyre-road interaction is the superior source of road noise pollution [10]
Noise pollution will simultaneously affect the human psychology as well as the body, especially injurious to the nervous system and cardiovascular system. Researches indicate that the intellectual development of children with continued exposure to noisy environment is 20% less than in the quiet environment [11].

At present, the main three noise reduction techniques are, low-noise pavements, traffic control and countermeasures like roadside barriers and enclosures to minimize the noise. Among these the low-noise pavements are most effective because the noise minimization techniques at the source level is more economical than any other methods such as treatments on buildings or on a propagation path like noise barriers [12]. The tyre-pavement noise production is highly influenced by the surface texture of pavements. The surface texture affects the vibrations of tyres as well as the aerodynamic processes that occur between the tyres and the pavement surface which cause noise emission [13].The sound-wall is the technique which is commonly used around the globe due to its simple function. But they are very costly to construct and maintain [14], [15]. In some cases the sound-wall technique is not practical, mainly in hilly and urban areas due to space constrains [16]. The air and road temperatures significantly influence the tyre-road noise emission. The influence of temperature on tyre-road noise emission depends on the tyre and road combinations [17].
In the tyre-road noise generation, pavement surface profile also plays an important role. The influence of tyre becomes dominant, when it is below a particular road texture level [18]. The relationship between noise and speed on different pavement surfaces is found to be different. Consistently low values which is about 66 dBA was given by rock asphalt and sand-asphalt surfaces [19]. Poro-elastic material and asphalt rubber material also helped to lower the noise levels [20]. A low noise pavement surface is based on two factors which are the high porosity of the structure and the small maximum chip size aggregates for rolling surface [18]. At low frequencies, the increase in road texture level at large wavelength leads to the increase in tyre-road noise, whereas at high frequencies the increase in road texture level at small wavelength leads to the decrease tyre-road noise [21]. The different factors influencing tyre-road are schematically represented in fig: 1.

Section 2 and 3 deals with the generation and amplification of tyre-road noise respectively. The different methods to

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reduce tyre-road noise are discussed in section 4 and concluded in section 5.

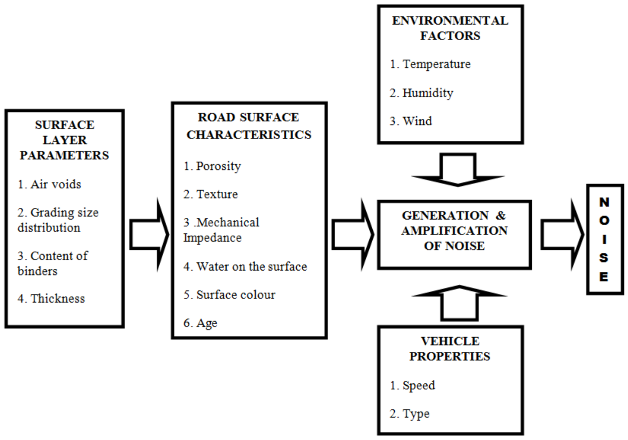

Fig. 1. Major influencing factors on tyre road noise [1]

2. GENERATION OF TYRE ROAD NOISE IN PAVEMENTS

2.1. Thread impact

The thread block of the tyre turns along with the tyre [22]. Due to the impact of tyre tread pattern on the pavement surface texture a mechanical vibration is generated [12].These vibrations are generated in the lateral zones of the tire, at the point of contact between the tyre tread and road surface due to the interaction forces between them [1]. The vibrations generated travels through the nearby structures as elastic waves and vibrates the surrounding air producing noise [23]. The phenomenon of thread impact is comparable to hitting the pavement with a rubber hammer [22]. Depending on the speed of the vehicle and its weight, the tire vibrations produce noise of low frequency approximately below 1000 Hz [1].

2.2 Air pumping

The trapped air present in the tread grooves of the tyre knock around the rubber body walls and resonates. This trapped air gets compressed and decompressed frequently [1]. An aerodynamically created sound is produced due to this air compression and air pumping effect. The sound, thus produced is similar to the sound produced by clapping hands [22]. The intensity of the sound produced is high if the size of the tread grooves is lesser than the wavelength [1].

2.3 Stick-Slip effect

The "Stick-Slip" effect is produced due to the sticking (adhere) and slipping (slide) of the tyre over the pavement [12]. These actions will take place very quickly and can produce both noise and vibrations [22]. The "stick-slip" effect can cause squeaks and squeals, similar to a sneaker on a basketball court. This "stick-slip" effect will commonly generate high-frequency noise [24].

2.4 Stick-Snap effect

The "Stick-Snap" effect is also known as the suction pad effect [12]. An addition force is developed at the point of contact between the tyre and the pavement surface [22]. As the tyre leaves the pavement surface suddenly in the rear of the tyre-pavement contact area, it generates radial vibrations [12]. This noise is similar to that produced when a suction cup is pulled off from a surface [24].

3. AMPLIFICATION OF TYRE ROAD NOISE GENERATED

3.1 Horn effect

The noise produced gets enhanced due to the geometrical features of the tyre and the pavement surface. The portion of the entry and exit of the contact area of the tyre and the pavement is much similar to a horn, which amplifies the noise generated by air pumping and treads vibrations [24]. This acoustical horn effect created due to the geometrical features of the tyre and the pavement will lead to significant amplification in the ahead and back directions and distortion of some frequencies [12]. The horn effect boosts the noise produced in the area where the tire touches the pavement and where it loses the contact with the pavement. The horn effect is increased with the increase in the angle between the pavement and the tyre edge tangent line [1].

3.2 Helmholtz resonance effect

The Helmholtz resonance effect is produced due to the up and down vibration of air, which enter into the wedge like a portion where the tyre touches pavement. This results in the amplification of some specific frequencies depending on the geometrical features of the tyre and the pavement [12]. The Helmholtz resonance effect is much alike to the sound produced when a whistle is blown across an open bottle [22].

3.3 Pipe resonance effect

The tread pattern of tyres consists of grooves or channels which will act like organ pipes generating channel or pipe resonance effect. The vibration of air in these grooves of the tyre gets amplified just as the resonant vibration of air in organ pipes gets amplified [24]. The noise produced elsewhere gets amplified within these pipes [12].

3.4 Cavity resonance effect

During the excitation of the tyre, the air inside the tyre also gets exited [22]. The Cavity resonance is also

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known as “the balloon” effect, which is generated when the tyre is kicked. Since the air present inside the vehicle amplifies this frequency, the noise produced due to this effect is high inside the vehicle [12].

4. LOW NOISE PAVEMENTS

4.1. Low noise concrete pavements

4.1.1 Pavements with transverse tining

Transverse tining can be described as a texture which is generated by a single pass of an artificial turf or burlap drag, which is followed by mechanically operated transverse texturing equipment [25]. Longitudinal as well as transverse is used along with skew or wave pattern [26]. In North America, transverse tining is commonly used texture on high speed roads and highways. Tining is created with the help of a mechanical device consisting of a tining head which moves laterally across the width of the pavement. Hand rake is used for smaller areas. Skewing of tines was found to be effective in reducing the tire-pavement interaction noise [25].

4.1.2 Diamond ground pavements

Diamond grinding can be defined as a texturing technique which can be effectively used for newly placed concrete and existing concrete pavements [26]. The diamond ground pavements will provide better riding quality, safety, enhanced service life, reduced rehabilitation costs and low surface noise. [27]. It is also used for the better water drainage of the concrete pavement surface [13]. Diamond grinding consists of longitudinal, continuous, and line-type texture which contains corrugations with evenly spaced ridges. [27] It is created by a series of saw blades which are equipped with a drive shaft over the concrete pavements. Depth of grinding varies from 3 to 5 mm. The spacing of the blades as well as the concrete composition affects the reduction of noise emission. Concrete pavement surfaces with diamond grinding having a very low spacer width produce lowest noise emission [13].

4.1.3 Portland cement porous pavement (PCPP)

Portland cement porous pavement (PCPP) is a type of quiet pavements. Since there are a large number of voids in the material, porous concrete material can lower the noise. [16]. Since it is a type of pervious material having high amount of macropores, the PCPP has high drainage and can recharge groundwater to supply water resources [28]. As the sound wave gets into the material, the air movement will be restricted or blocked as it meets the solid walls of these void space. The high absorption coefficient was found to be in porous concrete with a maximum aggregate size of 9.5 mm. The characteristics of the mix and the thickness of the specimen are the factors which affect the absorption coefficient peak. A specimen with thickness of 80 mm was found to have optimum absorption. Porous cement concrete can effectively reduce the tyre-road noise around 4 to 8 dB [16]. Since the current pervious pavement technology is not at all well developed, it can be applied only to light load conditions such as sidewalks, driveways, parking lots or residential streets [29]

4.1.4 Exposed Aggregate Concrete Pavement

Exposed aggregate concrete pavement is used for new construction, and renovation or reconstruction of cement concrete pavements [30]. Because of the random convex surface of the aggregate of the exposed concrete pavement, sound waves and pressure waves will dissipate on their own in the space below the tread, 7dB lesser than the ordinary concrete pavement noise. The formation of water film on the surface of this pavement is very difficult and hence even in the rainy season it exhibits a high skid resistance. By treating the surface of exposed aggregate concrete pavement, rough road can form diffuse, eliminate or mitigate the diffuse reflection [31].

4.1.5 Asphalt Overlay Low Noise Pavement

Asphalt overlay low noise pavement is a type of pavement structure type which can reduce the tyre-road noise. Porous asphalt pavement, also known as permeable pavements are the ordinary asphalt or cement concrete pavement or other paved pavement layer having a high porous layer of asphalt mixture [32]. The surface voids’ sound absorption is the noise reduction mechanism of this pavement [33].

4.2 Low noise Asphalt pavements

4.2.1 Porous asphalt pavements

Porous asphalt pavement is considered as one of the major low noise pavement which has a relatively high air void ratio in the range of 15% and 20% [34]. Porous asphalt pavements are constructed by lowering the quantity of smaller aggregates which are used for pavement construction in such a way that the pavement cannot be tightly compacted [22]. Single porous layer and double porous layer are commonly used. The two layer porous asphalt pavement is found to be highly effective in the reduction of noise in pavements. It is very complex to construct a double layer porous pavement due to the bonding of the two layers [12]. These pavements can reduce the tyre-pavement interaction noise above 1000Hz. Porosity of the pavement will help to reduce the strength of the air pumping source mechanism by preventing air compression and also reduce the enhancement potential of the horn, organ pipe, and Helmholtz resonator mechanisms [22]. Studies show that porous asphalt pavement exhibits less rutting increase than dense graded [12]. The porous pavement can lower the traffic noise by absorption of sound. Average

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noise reduction of around 3 to 4 dB can be achieved with the help of porous asphalt pavements [35].

4.2.2 Gap graded thin overlays with small aggregate

Gap graded size aggregates are used in order to attain the porosity so that the finished pavement will achieve porosity that can handle water and grit particles. For 6mm top size, graded aggregate of less material in 2-4mm size is used and for 10mm top size, graded aggregate of less material in 4-6mm size is used. The thickness of the overlay depends on the size of aggregate which is in the range of 15 to 25mm [31]. Thin overlays over flexible pavements are cost effective, but on composite pavements they are not due to the greater deterioration prior to overlay and the condition may not be favorable for thin overlays [36]. The less porosity of the material will help to reduce high frequency noise. As compared to dense graded asphalt, the noise reduction in pavement with gap graded thin overlays with small aggregates is 3dB [31].

4.2.3 Texturing for reduced noise

As stated by the acoustics principle, the decrease of noise depends on pore distribution, interconnected pore content, pore shape and pore size in the tire-pavement contact patch. The surface texture of impervious asphalt pavements will make the noise level higher at lesser frequencies [37]. Negative texture having characteristic lengths lower than 10mm will help to reduce the noise. Any other texture size and texture type rather than this may increase the noise significantly. The 3mm depth of local texture will help to attain the noise reduction effects. The pavement texture for asphalt pavements depend on the pavement material used. By the selection of size, shape, size distribution of aggregates we can attain the control of texture. The sealants or alternate techniques which are used to lower the texture will smoothen the pavement surface at the microtexture level, which will lead to an increase in tyre-road interaction noise [22].

4.2.4 Poro-elastic pavement

Poro-elastic pavement is a mix that consists of 20% to 40% of air voids and is composed of rubber, generally from scrap tyres [12]. The mechanical elasticity can help to lower the effect of mechanical sources on noise production. Acoustically porous pavement can lower the aerodynamic sources, reflections and acoustical enhancement mechanisms [22]. Porous elastic road surfaces (PERS) as a low-noise pavement was introduced by Nilsson. Poro-elastic pavement consists of rubber granulate combined with urethane. Nilsson & Zetterling had studied the noise reduction factors of PERS, with the help of measured noise data of moving automobiles. These pavements will help to reduce the noise approximately up to 10 dB or greater [38]

5. CONCLUSIONS

The major portion of traffic related noise is contributed by tyre-road noise. The main sources and reduction measures of tyre-road noise was studied and the following conclusions are drawn.

1. The noise reduction techniques at the source level is more economical and effective.
2. Surface layer parameters, road surface characteristics, environmental factors and the properties of vehicles will affect the noise generation and amplification mechanism in pavements.
3. With the increase in porosity of concrete as well as asphalt pavements, the tyre-road noise emission can be reduced. By using different texturing techniques such as diamond grinding can effectively reduce the noise emission.

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