A STUDY ON TIRE NOISE

A Thesis

Submitted in partial fulfillment of the requirement for the award of

degree of

MASTER'S OF ENGINEERING

IN

PRODUCTION AND INDUSTRIAL ENGINEERING

Submitted By

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CERTIFICATE

I hereby certify that the work which is being presented in this thesis entitled **"A STUDY ON TIRE NOISE"** in partial fulfillment of requirement for the award of Master's Degree in Production & Industrial Engineering submitted in Mechanical Engineering Department, Thapar University, Patiala, is an authentic record of the initial work carried out by me under the guidance **of Dr. S.P Nigam, Visiting Professor and Mr. Daljeet Singh, Assistant Professor, Mechanical Engineering Department, Thapar University, Patiala.**

The matter embodied in this report has not been submitted in part or full to any other university or institute for the award of any degree.

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This is to certify that above declaration made by the student concerned is correct to the best of our knowledge & belief.

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ABSTRACT

Today traffic noise is one the major problems related to noise pollutions. It is increasing day by day with the increase in the number of vehicles on the road. The sources of noise from a vehicle can be separated into four main areas, the engine, exhaust exit, air intake and the noise produced as a result of the tires rolling in contact with the road surface. Reductions in the levels of noise from the former sources have been significant and it is now recognized that the tire/road interaction noise is dominant for constant speeds in almost all types of driving, certainly above 40 km/h for cars. For reducing the noise generation from tires and eliminating the ill effects caused by noise pollution to environment and society, noise produced form the tire/road interaction have to be studied carefully.

Tire/road noise is produced due to some generation mechanisms i.e mechanical, aerodynamical, frictional or propagational, when tire rolls over the road surface and these generation mechanisms depend upon some of the operating conditions like vehicle speed, tread pattern type, type of road surface, condition of tire etc. In this work, different types of tire noise generation mechanisms and different kind of measurement methods are discussed briefly. More focus is on the effect of different operating parameters on tire/road noise. For this, an experimental rig is fabricated. Background noise level is estimated first and then removed with the help of shielding being done by making a wooden box, a wooden wall having a layer of an absorbing material fixed, before taking the measurement. Effect of vehicle speed, tread pattern design, road surface and tread wear on tire/road noise is examined. Three two-wheeler tires are used named as A, B, C for studying the effect of tread pattern on sound pressure level. Four different speeds are used with the help of multiple pulleys attached to the motor shaft, for determining the effect of speed variation on sound pressure level. Two road surfaces, asphalt and concrete are prepared and different conditions i.e dry, wet, oily of each of them are taken for studying the effect of road surface conditions on spl. For the whole work, two-wheeler tires are used. Close proximity method is used for taking the measurements. Measurements are taken at an angle of 45 degree to the leading edge having sound level meter (SC-310) placed at 4 inches above the level of tire/pavement contact and 8 inches away from the centre of tire. A-weighted sound pressure level

(L_{eq}) and 1-1 octave band frequency spectrum measurements are taken under the combined effect of different operating parameters.

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NOMENCLATURE

SYMBOLS	**DESCRIPTIONS**
spl	Sound pressure level
dB	Decibel
L_s	Sound level in dB
L_t	Total sound level in dB
L_{s+n}	Combined source and background sound level in dB
L_n	Background noise level in dB
L_W	Acoustic power in dB (A) (ref. 10^{-12}W)
L_p	Acoustic sound power level in dB (A)
L_i	Acoustic sound intensity level in dB (A)
f_{upper}	Upper limit frequency
f_{lower}	Lower limit frequency
c_{center}	center frequency
L_{eq}	Equivalent sound level

CHAPTER 1

INTRODUCTION

1.1 Introduction to Noise

Noise is basically defined as “unwanted sound”.

In our modern world, rapidly expanding environment one of the developing problems is that of noise. Apart from the pure annoyance factor of noise, exposure to an intense sound field over a long period of time presents the risk of permanent damage of hearing. This problem is becoming a serious concern to industrial corporations, trade unions and companies.

The main objective of this part is to discuss the concept, problems and effects of noise on human beings and environment.

The major sources of noise are:

1. Industrial noise
2. Traffic noise
3. Community noise

Now a days, the source which is affecting the most is traffic noise which is produced due the tire/road noise, engine noise and various moving parts like propeller shaft etc.

Sound is defined as any pressure variation that the ear can detect ranging from the weakest sounds to sound levels which can damage hearing.

Acoustics is the study of sound and covers all fields of sound production, sound propagation and sound reception, whether created and received by human beings or by machines and measuring instruments.

Sound can be classified as two types based on its use to mankind.

- Sound that is useful to mankind like music, speech which we use for communication,
- Sound that is not useful to mankind like the sound from an aircraft, bursting of high intensity crackers, blaring sound speakers etc. is called as Noise.

Decibel: The range of sound pressure magnitudes and sound power of sources experienced in practice is very large. Thus, logarithmic rather than linear measures are often used for sound pressure and sound power. The decibel (dB) is used to measure sound level. The dB is a logarithmic unit used to describe a ratio.

Decibel is a logarithmic unit used to describe physical values like the ratio of the signal level in terms of sound power, sound pressure, and sound intensity.

The decibel can be expressed as:- $dB = 10 \log_{10} (P / P_{ref})$

Where, p- measured sound energy

p_{ref}- reference sound energy

Decibel Addition: Since Decibels are logarithmic, they cannot simply be added. For instance, 40 dB + 40 dB is not 80 dB, it is 43 dB. Decibels can be added as follows:

$$Ls = 10 \operatorname{Log}_{10}(10L^{1/10} + 10L^{2/10} + 10L^{3/10} + ...)$$

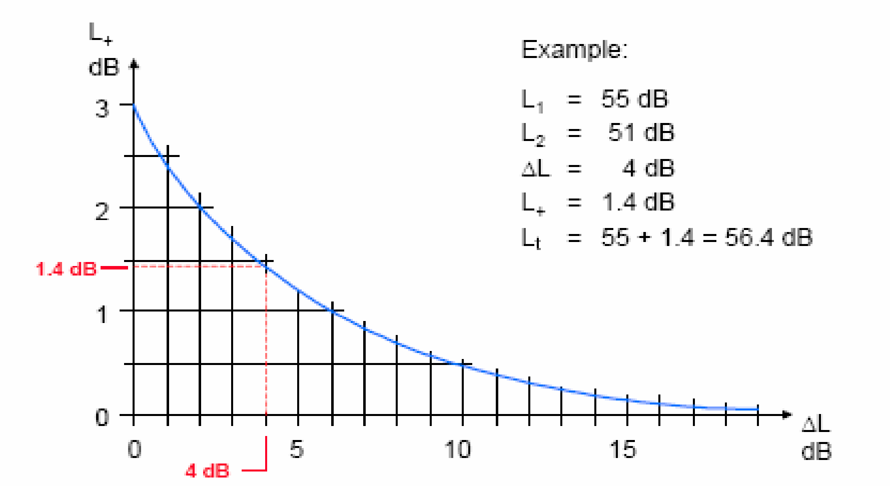


Fig.1 Decibel Addition Chart [40]

If the contribution from the two sources differs, the total sound pressure level can be found by converting the individual dB values to linear values, adding these and converting back to dB. But a somewhat easier method is to use this simple curve for addition of dB levels.

Curve above can be proceed as follows:

1. Calculate the difference, D L, between the two sound pressure levels.
2. Use the curve to find L+.
3. Add L+ to the higher level to get Lt, the total level.

Note that a difference of ΔL = 0 corresponds to the situation where 3 dB is added to the level caused by one source alone.

If the difference between the two sound pressure levels is more than 10 dB the contribution from the quieter source can be discarded.

Audible range of sound

- Human ear can hear the sound within frequency range of 20Hz to 20000Hz.
- Threshold of hearing is 0dB & Threshold of pain is 140dB.

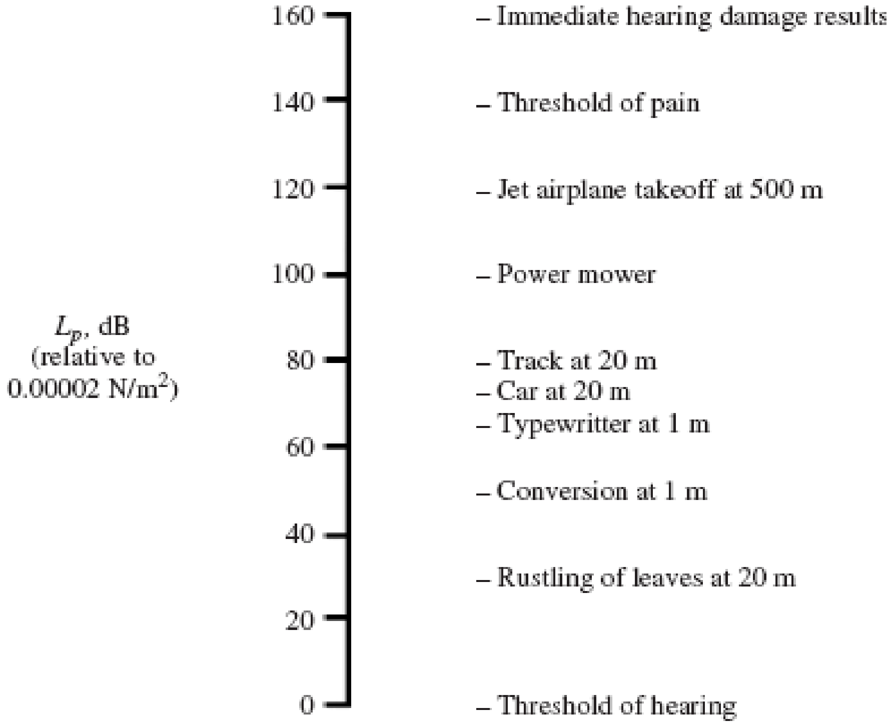


Fig.2 Some typical sound pressure levels, Lp [39]

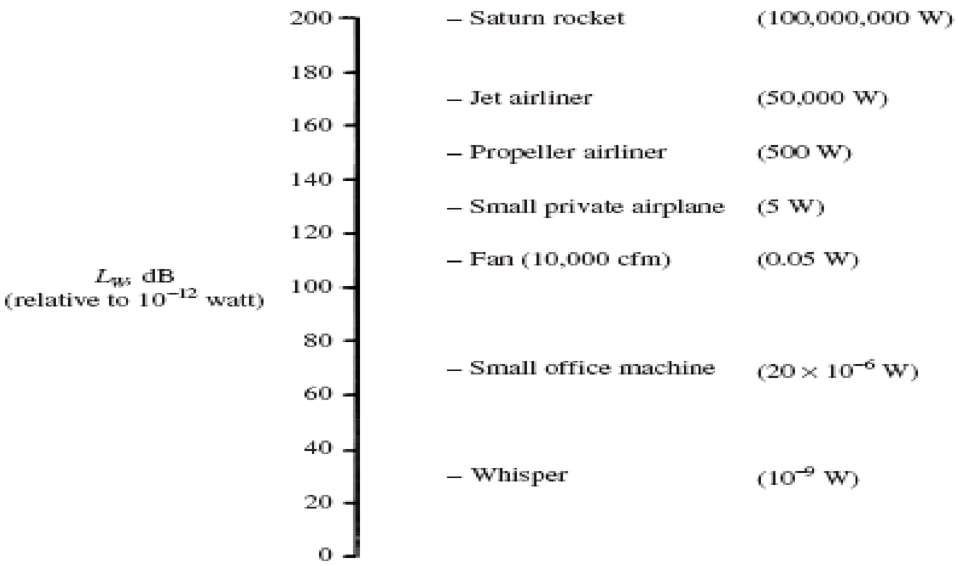


Fig.3 Some typical sound power levels, Lw [39]

1.2 Physical Properties of Sound [39]

1.2.1 Sound pressure level: The sound pressure level (in decibels) is defined by:

$$L_p=10\ \log_{10}(p/p_{ref})^2 \qquad \text{(eq 1)}$$

Where p is the absolute level of the sound pressure and p_{ref} is the reference pressure. Unless otherwise stated the pressure, p, is the effective root mean square (rms) sound pressure. This equation is also written as:

$$L_p=20\ \log_{10}(p/p_{ref}) \qquad \text{(eq 2)}$$

Although both formulas are correct, it is instructive to consider sound pressure level as the log of the pressure squared (eq 1). This is because when combining sound pressure levels, in almost all cases, it is the square of the pressure ratios (i.e. $\{p/P_{ref})^2\}$‘s) that should be summed not the pressure ratios (i.e. not the $\{p/P_{ref}\}$‘s). This is also true for sound pressure level subtraction and averaging.

1.2.2 Sound power level: The sound power level (in decibels) is defined by:

$$L_w = 10 \log_{10} (P / P_{ref}) \qquad \text{(eq3)}$$

Where P is the absolute level of the sound power and P_{ref} is the reference power. Unless otherwise stated the power, P, is the effective root mean square (rms) sound power.

1.2.3 Sound intensity level: The sound intensity level (in decibels) is defined by:

$$L_i = 10 \log_{10}(I / Iref) \qquad \text{(eq4)}$$

Where ,

I, is the absolute level of the sound intensity and I_{ref} is the reference intensity. Unless otherwise stated the intensity, I, is the effective root mean square (rms) sound intensity.

1.3 Characteristics of Sound

1.3.1 Background Noise:

Noise which is present in environment other than the source noise is called as background noise and in some cases it is necessary to subtract noise levels. This could, for example, be the case where noise measurements on a particular machine are carried out in the presence of background noise. It is then important to know if the measured noise is due to the background noise, the noise from the machine, or the combined influence. The procedure when performing the test is as follows:

- Measure the combined effect of machine noise and background noise, L_{S+n}
- Switch off the machine and measure the background noise, L_N. In most cases it is possible to switch off the machine under test, whereas the background noise normally cannot be switched off.
- Finally calculate the difference, DL = L_{S+N} - L_N and use the following simple curve to find the correct noise level caused by the machine.

1.3.2 Masking

The term ‘Masking’ is used about the phenomenon that the presence of a given sound can make another sound inaudible. When there are other sounds present in addition to the source sound or required sound then the phenomenon of masking could occur which makes source sound inaudible.

1.3.3 Loudness

Loudness is the subjectively perceived attribute of sound which enables a listener to order their magnitude on a scale from soft to loud. It is defined as subjective intensity of sound. Loudness is measured in phon or sone

The phon is a unit that is related to dB by the psychophysically measured frequency response of the ear. At 1 kHz, readings in phons and dB are, by definition, the same. For all other frequencies, the phon scale is determined by the results of experiments in which volunteers were asked to adjust the loudness of a signal at a given frequency until they judged its loudness to equal that of a 1 kHz signal.

A sone is defined to be equal to 40 phons. Experimentally it was found that a 10 dB increase in sound level corresponds approximately to a perceived doubling of loudness. So that approximation is used in the definition of the phon:0.5 sone = 30 phon, 1 sone = 40 phon, 2 sone = 50 phon, 4 sone = 60 phon, etc.

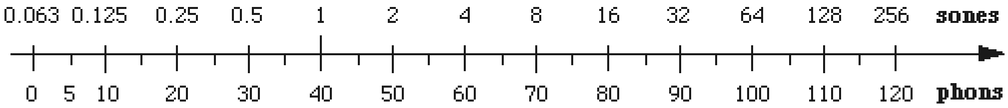


Fig.4 Sone to phon or vice-versa conversion scale [40]

1.3.4 **Equal Loudness Contours**

An "equal-loudness contour" is a measure of sound pressure level, over the frequency spectrum, for which a listener perceives a constant loudness. The human auditory system is sensitive to frequencies from 20 Hz to a maximum of around 20,000Hz, although the hearing range decreases with age. Within this range, the human ear is most sensitive between 1 and 5 kHz.

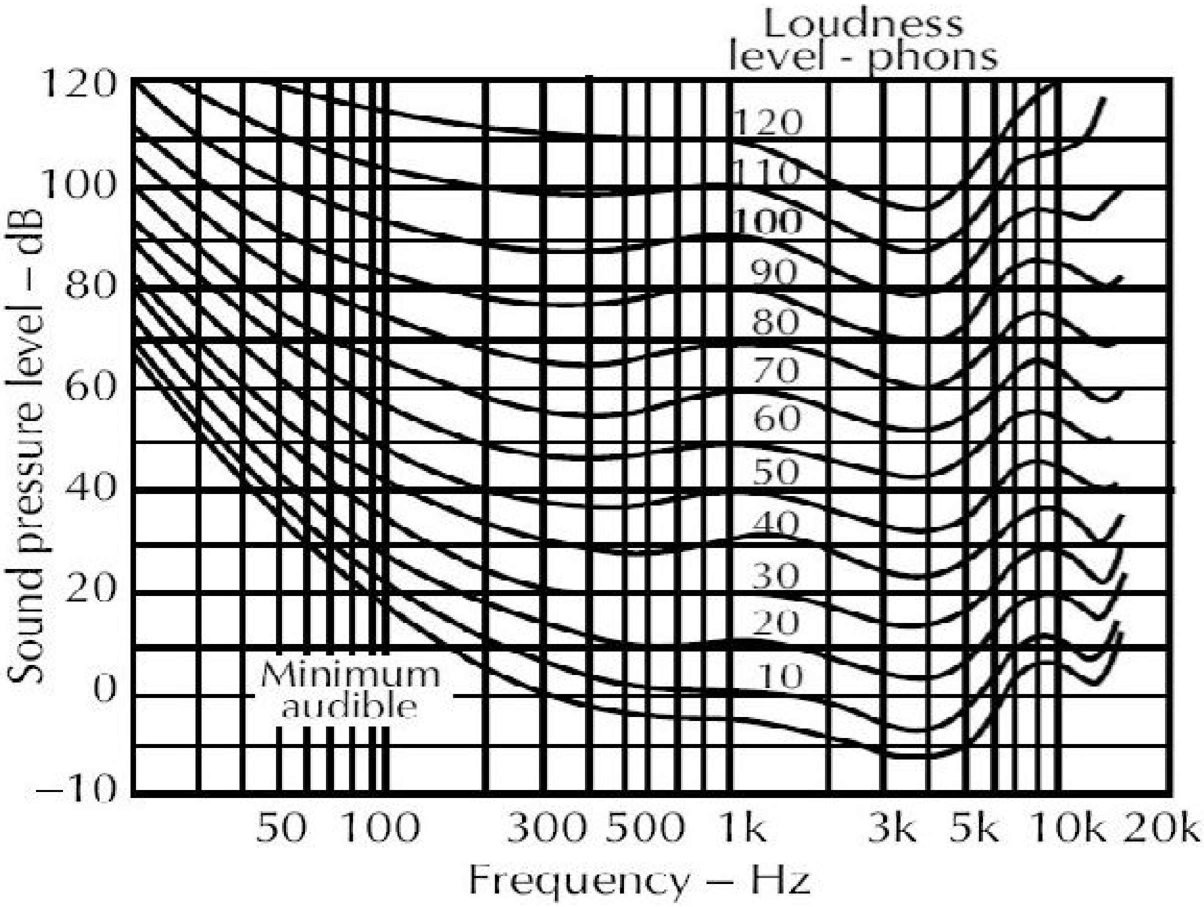


Fig.5 Equal loudness contours [39]

Figure shows an equal loudness contour chart. The sound levels for a particular sound as defined by the level at 1000 Hz will find the same for any given frequency along the curve. For example a 20decibel sound at 1000 Hz would be perceived as the same sound level of 50 decibels at 100 Hz. For a sound to be perceived as loud as the actual sound pressure level at frequencies less than the reference frequency i.e 1000Hz some subtraction in the sound pressure level should be done and some addition in the sound pressure level at higher frequencies than 1kHz because actual sound perceived by human ear is less than sound pressure level of the sound at lower frequencies but actual sound perceived at higher frequencies is more than sound pressure level. For this correction weighting filters are generally used.

1.3.5 Weighting Curves

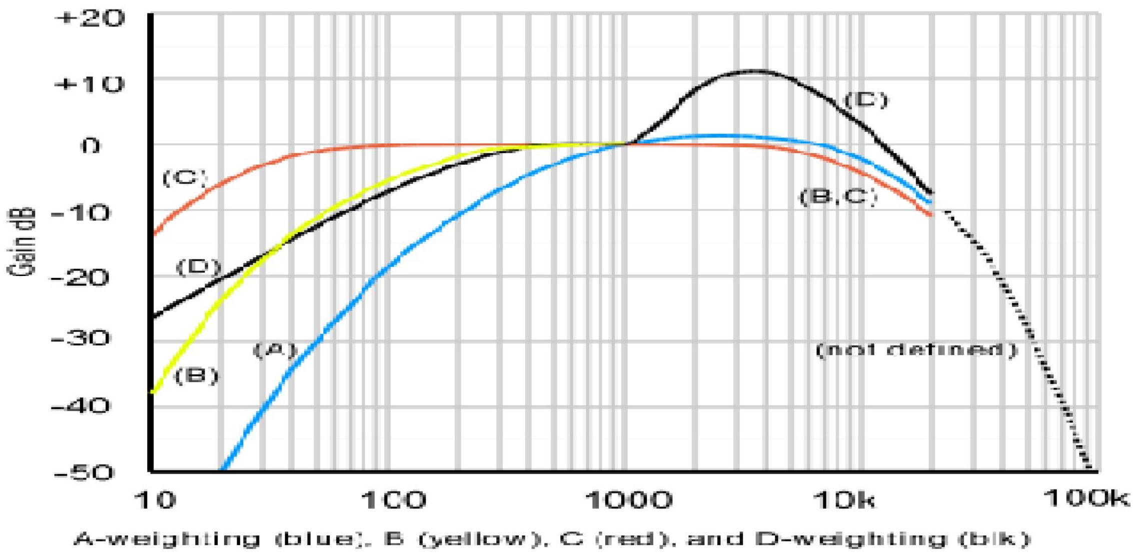


Fig.6 Weighting curves [40]

Ear is particularly sensitive to frequencies present in human speech, and it is less sensitive to very high frequencies and very low frequencies. The uneven frequency response of the ear causes a problem when trying to evaluate the annoyance of unwanted sounds, something that often has to be judged. Whether it is the noise in a transmission path, or trying to establish how annoying aircraft noise is compared to lawnmowers and all the other sonic tribulations of the urban environment, some steps have to be taken to allow for the greater sensitivity of the ear to noise at mid-frequencies between 3-6 kHz relative to other frequencies. To do this the noise is passed through a filter that approximates the frequency sensitivity of the ear to noise. That filter is the weighting filter. There is no universal agreement as to the response of this filter, but three different response curves are in common use: A, B, C and D weighting filters.

1.3.6 Importance of Noise Weighting

Human ear does not behave linearly with sound perception and the sound it perceives is not always as loud as its sound pressure level. As sound is composed of many frequencies having different levels of sound pressure and for making them to sound equally loud weighting of the sound is needed which is done with the help of noise weighting filters.

Basically there are four weighting filters are used which are named as A, B, C and D. A weighting filter is most commonly used because it gives the best correlation between measured values and the annoyance and harmfulness of the sound signal. It follow approximately 40 phon curve in Fig.5. Whereas B and C weighting filters follow 70 and 100 phon curves approximately. D-weighting curve follow a contour of perceived noisiness and is used for aircraft noise measurements.

1.3.7 Frequency Analyzer [39]

Sound we hear can be of single frequency that is pure tone (one frequency component) but most of the time we hear sounds of complex frequencies (many frequency components) having a broad frequency spectrum and for the investigation of such sounds it is desirable to investigate a limited part of the frequency spectrum. This can be done with the help of a filter which allows passage of only that part of the spectrum which lies inside the bandwidth (Δf) of the filter. These filters are named as frequency analyzers.

Frequency analyzers are of two types:

(a) Constant frequency bandwidth filters (these are independent of the center frequency)

(b) Constant percentage bandwidth filters (these are depend on the center frequency)

  (i) one-octave band

  (ii) one-third octave band

One-Octave Bands

For one-octave bands, the cutoff frequencies f_L and f_U are defined as follows:

$f_L = f_C/\sqrt{2}$

$f_U = \sqrt{2} f_C$

The center frequency (or geometric mean) is

$f_C = \sqrt{f_L f_U}$

Thus

$f_U / f_L = 2$

The bandwidth Δf is given by

$\Delta f = f_U - f_L = f_C(\sqrt{2} - 1/\sqrt{2}) = f_C/\sqrt{2}$

One-Third-Octave Bands

For one-third-octave bands the cutoff frequencies, f_L and f_U , are defined as follows:

$f_L = f_C/2^{1/6}$

$f_U = f_C/2^{1/6}$

The center frequency (geometric mean) is given by

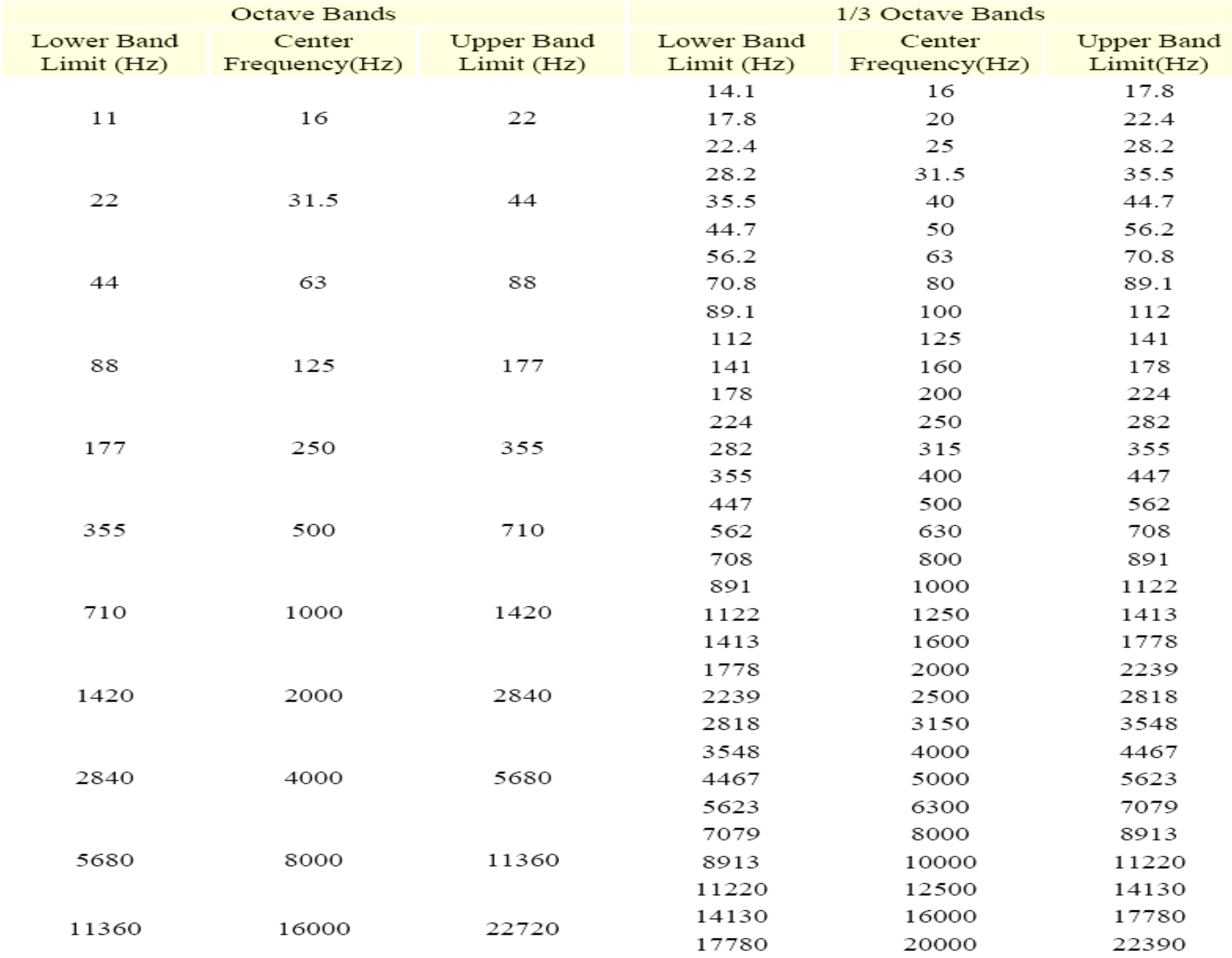
$f_C = \sqrt{f_L f_U}$

Thus

$f_U / f_L = 2^{1/3}$

The bandwidth Δ_f is given by

$\Delta f = f_U - f_L = f_C(2^{1/6} - 2^{-1/6})$



Octave Bands			1/3 Octave Bands		
Lower Band Limit (Hz)	Center Frequency(Hz)	Upper Band Limit (Hz)	Lower Band Limit (Hz)	Center Frequency(Hz)	Upper Band Limit(Hz)
11	16	22	14.1	16	17.8
			17.8	20	22.4
			22.4	25	28.2
22	31.5	44	28.2	31.5	35.5
			35.5	40	44.7
			44.7	50	56.2
44	63	88	56.2	63	70.8
			70.8	80	89.1
			89.1	100	112
88	125	177	112	125	141
			141	160	178
			178	200	224
177	250	355	224	250	282
			282	315	355
			355	400	447
355	500	710	447	500	562
			562	630	708
			708	800	891
710	1000	1420	891	1000	1122
			1122	1250	1413
			1413	1600	1778
1420	2000	2840	1778	2000	2239
			2239	2500	2818
			2818	3150	3548
2840	4000	5680	3548	4000	4467
			4467	5000	5623
			5623	6300	7079
5680	8000	11360	7079	8000	8913
			8913	10000	11220
			11220	12500	14130
11360	16000	22720	14130	16000	17780
			17780	20000	22390

Table1 Octave Bands and 1/3 Octave Bands frequency bandwidth [41]

1.3.8 A-Weighted Sound Pressure dB(A)

A-weighted sound pressure is “corrected” to more closely resemble the hearing characteristics of the human ear. The human ear approximates the A-weighted curve in the 20 to 30 dB range. At these low sound levels, the ear has relatively poor sensitivity to low frequency sound. Table 1 shows the adjustments for A-weighted sound with the very large adjustments in the lower frequency bands. There is also Band C-weighted sound data, which is meant for louder sound levels. These sound levels are not as common as A-weighted values. A-weighted sound criteria is most commonly used in outdoor sound evaluations. It is often used in city building codes when referencing the maximum acceptable sound pressure levels at the property line. It is popular because it is a single number that most sound meters include.

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Adjustment (dB)	-26	-16	-9	-3	0	1	1	-1

Table 2.A-Weighted Octave Band Adjustments

1.3.9 Equivalent Continuous (A-Weighted) Sound Level, L_{eq} [40]

Equivalent continuous (A-weighted) sound level is defined as the steady sound level that contains the same amount of acoustic energy as the fluctuating level over the prescribed period of time. The averaging time T can be, for example, 1 h, 8 h, 1 day, 1 week, 1 month, and so forth.

The equivalent sound pressure levels defined by

$$L_{eq} = 10 \log_{10} \frac{1}{T} \int_{O}^{T} \left[\frac{p}{p_{ref}} \right]^2 \qquad \text{epq 5}$$

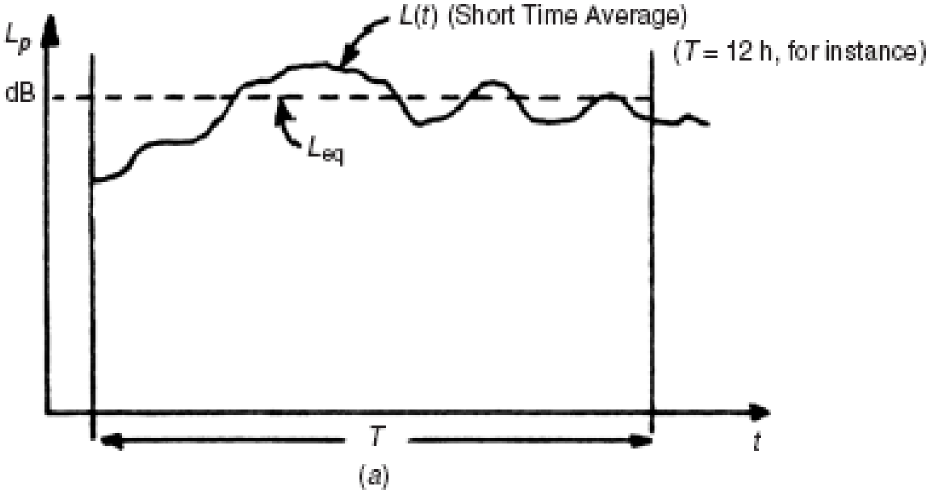


Fig.7 Equivalent sound pressure level.[40]

1.310 Sound Exposure Level (SEL)

It is defined as the L_{eq} value referred for one second, is useful for comparing individual noise event of different duration.

1.3.11 Noise Dose

The noise dose is variant of L_{eq} measurement for which the measurement time is fixed at eight hours. The only difference between noise dose and 8 hr $L_{eq\ is}$ that noise dose is expressed as a percentage of the allowable daily exposure, 100% corresponds to an L_{eq} level of 90 dB(A) for 8 hours.

1.4 Sound Sources

A distinction is made between three different types of sound sources:

- Point Source
- Line Source
- Plane Source

1.4.1 Point Source: A sound source can be considered as a point source, if its dimensions are small in relation to the distance to the receiver and it radiates an equal amount of energy in all directions. Typical point sources are industrial plants, aircraft and individual road vehicles. The sound pressure level decreases 6 dB whenever the distance to a point source is doubled.

1.4.2 Line Source: A line source may be continuous radiation, such as from a pipe carrying a turbulent fluid, or may be composed of a large number of point sources so closely spaced that their emission may be considered as emanating from a notional line connecting them. The sound pressure level decreases 3 dB, whenever the distance to a line source is doubled.

1.4.3 Plane Source: A plane source can be described as follows. If a piston source is constrained by hard walls to radiate all its power into an elemental tube to produce a plane wave, the tube will contain a quantity of energy numerically equal to the power output of the source. In the ideal situation there will be no attenuation along the tube. Plane sources are very rare and only found in duct systems.

1.5 Sound Propagation Fields [21]

Sound after generation propagates away from the source and depending upon the distance of reception or distance from the source, this propagation is divided into the fields shown in fig. 8.

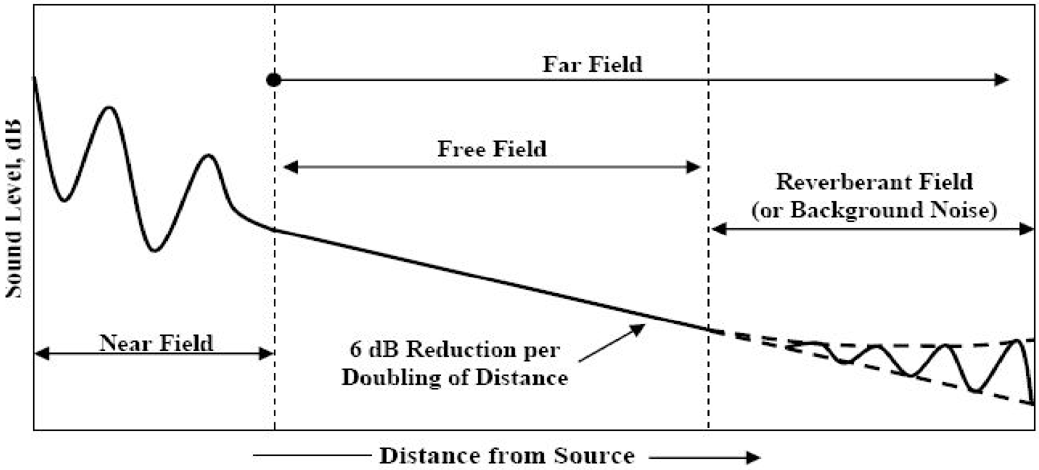


Fig.8 Definition of sound fields [21]

Near field- The near field is the area very close to the machine where the sound pressure level may vary significantly with a small change in position. The area extends to a distance less than the wavelength of the lowest frequency emitted from the machine, or at less than twice the greatest dimension of the machine, whichever distance is the greater. Sound pressure measurements in this region should be avoided.

Far field- The far field is divided into the free field and the reverberant field.

Free field- In the free field the sound behaves as if in open air without reflecting surfaces to interfere with its propagation. This means, that in this region the sound level drops 6 dB for a doubling in distance from the source.

Reverberant field.- In the reverberant field, reflections from walls and other objects may be just as strong as the direct sound from the machine.

1.6 Noise Measuring Instrument [38]

Noise measuring devices typically use sensor to receive the noise signals emanating from the source. The sensor, however not only detects the noise from the source, but also any ambient background noise. There are so many different types of instruments available to measure sound level and the most widely used are sound level meters.

Fig.9 Sound level meter [38]

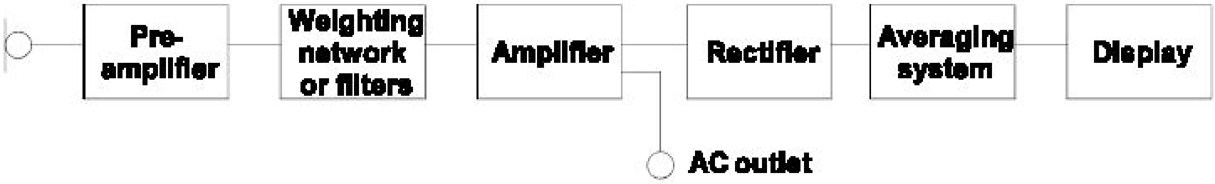


Fig.10 Sound level meter block diagram [38]

1.6.1 Elements of sound level meter

1.6.1.1 Microphone: Most measurement microphones generate a voltage that is proportional to the sound pressure at the microphone and is the electrical analog of sound waves impinging on the microphone’s diaphragm. The particular mechanism that converts the pressure variation into sound waves signal.

Different types of microphones are:

a. Capacitor (Condenser) Microphone
b. Pre-polarized Microphone
c. Piezoelectric Microphone

1.6.1.2 Amplifier: It amplifies the signal from microphone sufficiently to permit measurement of low sound pressure level. It amplifies sound over a wide frequency range. It maintains the amplification constant.

1.6.1.3 Rectifier: It rectifies the signal from analog signal to digital signal.

1.6.1.4 Smoothing circuit: The circuit through which the sound waves pass.

1.6.1.5 Meter: It is the part of the sound level meter by which observation are taken

CHAPTER 2

AUTOMOBILE NOISE

2.0 INTRODUCTION

Traffic noise is becoming a serious problem now a days. Traffic noise is the noise produced due the flow of vehicles on road.

About 25 % of the population in Europe is exposed to transportation noise with an equivalent sound level over 65 dB(A). At this sound level sleep is seriously disturbed and most people become annoyed

There are variety of vehicles that run on road at the same time, so the noise emission levels are also different. Some of them produce more noise than others.

Noise sources associated with transportation can include passenger vehicles, medium trucks, heavy trucks and buses. Each of these vehicles produces noise; however, the source and magnitude of the noise can vary greatly depending on vehicle type. For example, while the noise from passenger vehicles occurs mainly from the tire-roadway interface and is therefore located at ground level, noise from heavy trucks is produced by a combination of noise from tires, engine, and exhaust, resulting in a noise source that is approximately 8 feet above the ground. The following list provides information on the types of transportation noise sources that will be part of a roadway project, and describes the type of noise each produces.

Passenger Vehicles (cars): Noise emitted from 0 to 2 feet above roadway, primarily from tire-roadway interface. This category includes normal passenger vehicles, small and regular pickup trucks, small to mid-size sport utility vehicles, mini- and full-size passenger vans. Typical noise levels for passenger vehicles are 72 to 74 dB (A) at 55 mph at a distance of 50 feet.

Medium Trucks (MT): Noise emitted from 2 to 5 feet above roadway, combined noise from tire-roadway interface and engine exhaust noise. This category includes delivery vans, such as UPS and Federal Express trucks, large sport utility vehicles with knobby tires, large diesel engine trucks, some tow-trucks, city transit and school buses with under vehicle exhaust, moving vans (U-haul-type trucks), small to medium recreational motor homes and other larger trucks with the exhaust located under the vehicle. Typical noise levels for medium trucks are 80 to 82 dB (A) at 55 mph at 50 feet.

Heavy Trucks (HT): Noise emitted from 6 to 8 feet above the roadway surface, combined noise sources includes tire-roadway interface, engine noise, and exhaust stack noise. This category includes all long-haul tractor-trailers (semi-trucks), large tow trucks, dump trucks, cement mixers, large transit buses, motor homes with exhaust located at top of vehicle, and other vehicles with the exhaust located above the vehicle (typical exhaust height of 12 to 15 feet). Typical noise levels for heavy trucks are 84 to 86 dB (A) at 55 mph at 50 feet.

2.1 Characteristics of Vehicle Noise [42]

- Exterior road traffic noise results from the combined contributions from a large number of different vehicles.
- Trucks are typically noisiest followed by buses and motorcycles while cars are the quietest.
- The contribution of cars to the overall traffic noise level is however great because of their large numbers (about 80% of the road traffic). For lower speeds, below 40-50 km/h, engine noise including exhaust and intake noise dominates for cars.
- For higher speeds, above 70 km/h, tire-road noise dominates the car exterior noise generation.
- For heavier vehicles the engine noise is dominant under most condition

2.2 Source identification of Vehicle Noise and Vibration

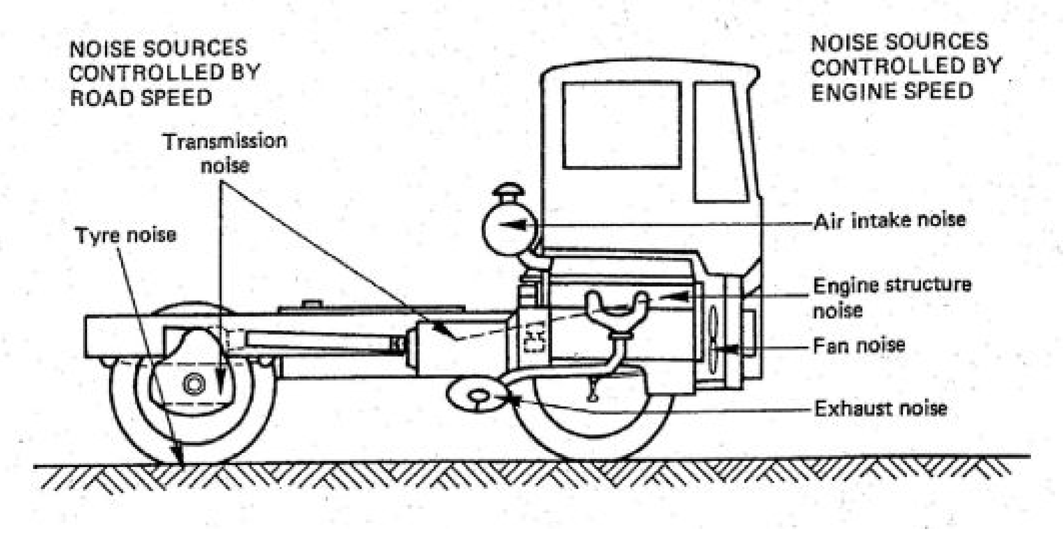


Figure 11 Main vehicle noise sources.[42]

2.3 Measurement of Exterior Vehicle Noise

Type of vehicle	Sound level dB(A)
Personal car	**74**
Bus and truck with total weight below	
3.5 ton with total weight below 2 ton	**76**
with total weight above 2 ton but	
below 3.5 ton	**77**
Bus with total weight above 3.5 ton	
with engine power below 150 kW	**78**
with engine power 150 kW or above	**80**
Truck with total weight above 3.5 ton	
with engine power below 75 kW	**77**
with engine power below between 75 kW	
and 150 kW	**78**
with engine power above 150 kW	**80**

Table3. Exterior vehicle noise for different vehicles under different conditions [42]

2.4 Sources of automobile noise

It is important to realize that the generation and propagation of noise from vehicles is governed by several different mechanisms. At low vehicle speeds the noise from the vehicle's power unit, i.e. the engine and its ancillaries, gearbox, exhaust, and cooling system etc., will often dominate the noise generated by the tire/surface interaction. This type of noise is referred to as propulsion noise. However, as the speed of the vehicle increases, noise generated by the tires will also increase and will eventually become the dominant noise source at high speeds. This type of noise is referred to as tire/road noise.

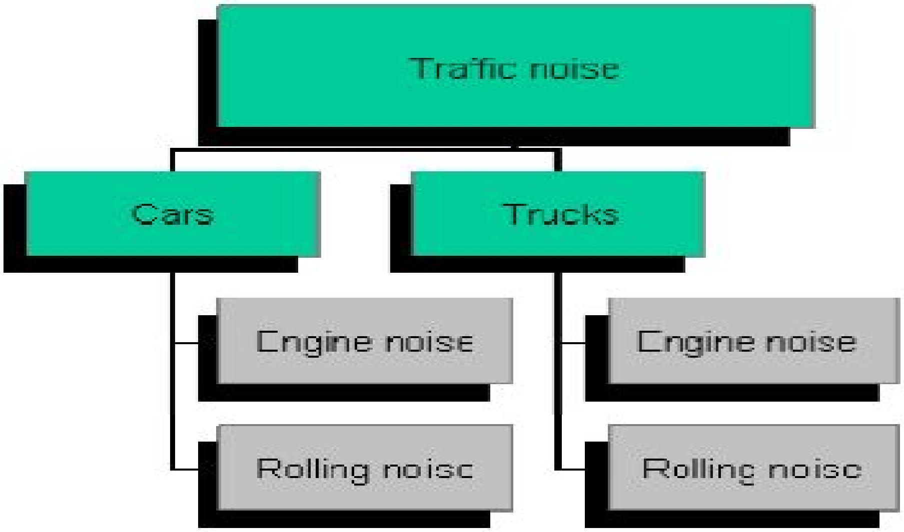


Figure12 Schematic overview of the major sources of traffic noise [42]

The contribution of these components to the overall noise emission depends on vehicle, tire and road surface. In figure 13 the respective contributions of propulsion noise and tire/road noise for both light vehicles and heavy vehicles are illustrated.

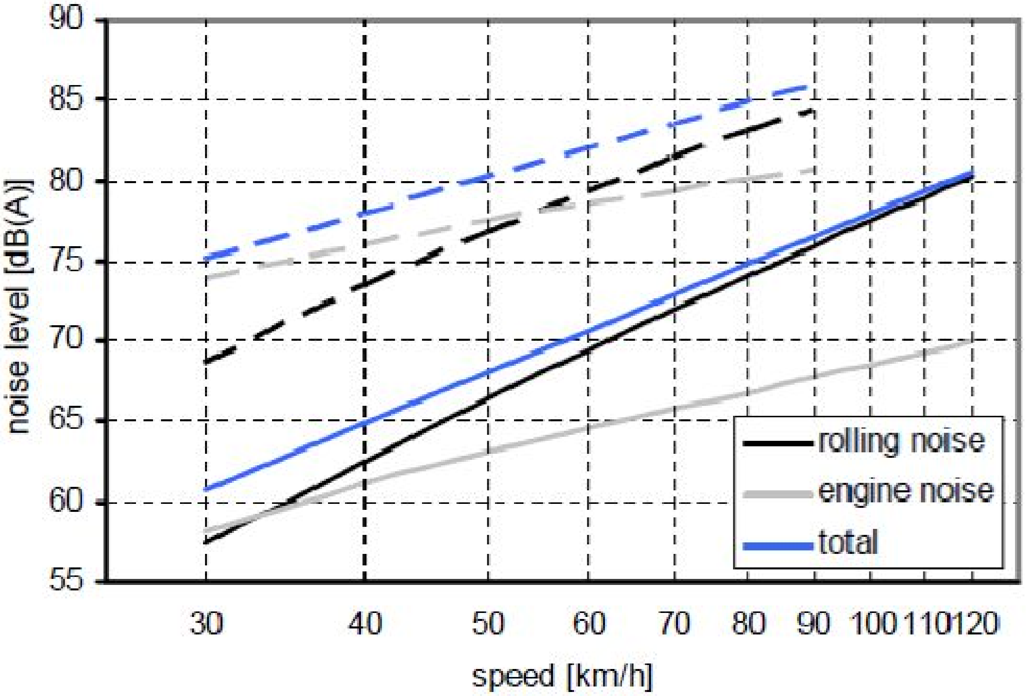


Figure13 Respective contributions of propulsion (engine) noise and tire/road (rolling) noise for light vehicles (continuous line) and heavy vehicles (dashed line) on a dense surface [42]

From the figure it can be seen that tire/road noise is dominant over propulsion noise for speeds of 35 and 50 km/h or higher for light vehicle (straight line) and heavy vehicles (dashed line), respectively. The contribution of propulsion noise in total traffic noise decreases with the speed while the share of tire/road noise continuously increases. At a speed of more than 80 km/h for light vehicles propulsion noise is negligible. However, in the case of heavy vehicles the contribution of propulsion noise cannot be neglected even at higher speeds.

Various sources which contribute to overall vehicle noise are: --

- **Engine noise** --- combustion-induced noise + mechanical noise
- **Combustion noise** -- periodic variation of cylinder pressure acting on the engine structure.
- **Mechanical noise** -- - piston slap impacts and other mechanical impacts in gears and bearings
- **Rolling noise** --- noise produced due to the interaction of rolling tire with the pavement surface

2.5 Most common sources of mechanical noise

•Piston slap which is generated when the piston moves from side to side during the engine cycle.

•Timing gear rattle which is generated when the teeth of the gears impact.

•It is coupled to torsional vibrations of the crankshaft.

•Bearing noise which is generated by impact and vibration caused by fluctuating forces during the engine cycle.

Exhaust and intake noise

Exhaust and intake system noise originates, from the pressure pulsations caused by the operation of the engine and additional flow generated noise.

2.6 Tire-road noise: Mainly occurs due to air pumping and tire vibrations when the tire contacts the road surface during running.

Aerodynamic noise

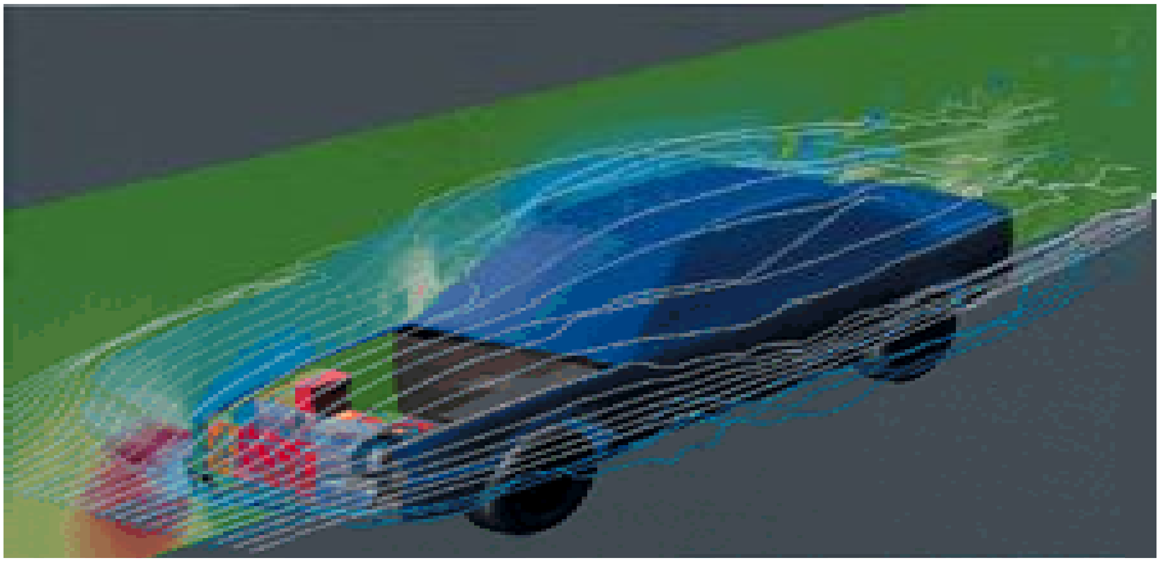


Figure 14 Simulation of flow field around a car causing aerodynamic noise generation at high vehicle speeds [42]

From all the different sources it has been found that engine noise can be reduced significantly by suitably redesigning of engine components, same with the transmission noise or suspension noise but most predominant source of noise at higher speeds is tire/road interaction noise which is very difficult to reduce because of the complex behavior of tire/road interaction noise and various noise generation mechanisms. So, tire/road interaction noise ,its generation mechanisms and its dependency upon different operating conditions need to be studied and then suitable measures need to be taken for reducing it to a safe level.

CHAPTER 3

TIRE NOISE

3.1 Introduction

Today traffic noise is of serious concern in many urban communities throughout the world. Traffic noise is increasing with the increase in volume of traffic (vehicles) on the road. Vehicles are main producers of traffic noise. Major contribution to the vehicle noise is of the noise produced by the tires running on the road. Tires surface when comes in contact with the road surface produces noise under the influence of various kind of mechanisms whether those are mechanical, aerodynamical, frictional or propagational. Tire characteristics and other operating parameters viz. load on the vehicle, speed of the vehicle, type of road surface, tread pattern, tire size etc. influence the tire noise level.

3.2 Importance of Tire Noise Study

Today traffic noise is one the major problems related to noise pollutions. It is increasing day by day with the increase in the number of vehicles on the road. The sources of noise from a vehicle can be separated into four main areas, the engine, exhaust exit, air intake and the noise produced as a result of the tires rolling in contact with the road surface. Reductions in the levels of noise from the former sources have been significant and it is now recognized that the tire/road interaction noise is dominant for constant speeds in almost all types of driving, certainly above 40 km/h for cars. It is also a significant contributor to the overall noise during acceleration, and is the dominant noise source above a vehicle speed of 50 km/h. For reducing the noise generation from tires and eliminating the ill effects caused by noise pollution to environment and society, noise produced form the tire/road interaction and the mechanisms involved for noise production have to be studied carefully.

3.3 Tire Definition [40]

A tire is a ring-shaped covering that fits around a wheel rim to protect it and enable better vehicle performance by providing a flexible cushion that absorbs shock while keeping the wheel in close contact with the ground. The word itself may be derived from the word "tie," which refers to the outer steel ring part of a wooden cart wheel that ties the wood segments together. The fundamental materials of modern tires are synthetic rubber, natural rubber, fabric and wire, along with other compound chemicals. They consist of a tread and a body. The tread provides traction while the body ensures support. Before rubber was invented, the first versions of tires were simply bands of metal that fitted around wooden wheels in order to prevent wear and tear. Today, the vast majority of tires are pneumatic inflatable structures, comprising a doughnut-shaped body of cords and wires encased in rubber and generally filled with compressed air to form an inflatable cushion. Pneumatic tires are used on many types of vehicles, such as bicycles, motorcycles, cars, trucks, earthmovers, and aircraft.

3.4 Types of Tires

In today's modern world there are no. of tires different in shapes and sizes being used in vehicles. Ply is used in manufacturing of every tire. Ply is defined as the layers of heat and impact resistant, rubber-coated fabric used to form the body of the tire. Automobile and light truck tire plies are normally constructed of nylon or polyester cords. It is a major factor of distinction between different tire types.

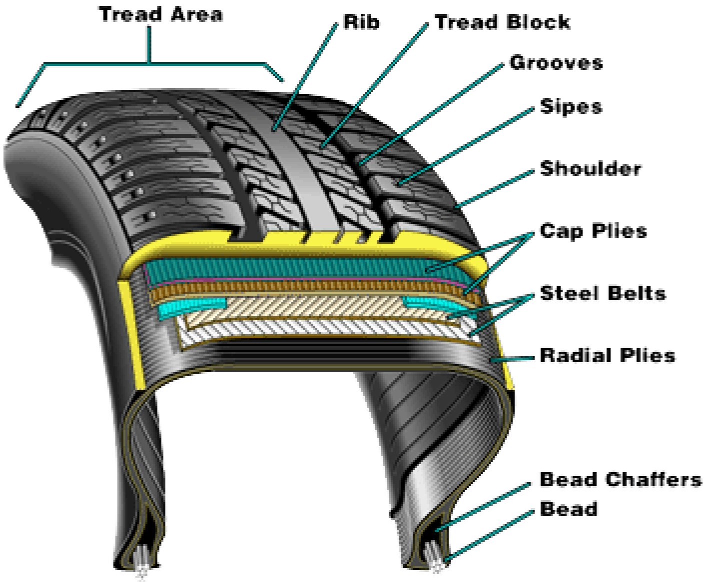


Fig.15 Tire construction diagram [40]

So based on ply type, tires are classified as follows:

Bias tire: (or cross ply) construction utilizes body ply cords that extend diagonally from bead to bead, usually at angles in the range of 30 to 40 degrees, with successive plies laid at opposing angles forming a crisscross pattern to which the tread is applied. The design allows the entire tire body to flex easily, providing the main advantage of this construction, a smooth ride on rough surfaces. This cushioning characteristic also causes the major disadvantages of a bias tire: increased rolling resistance and less control and traction at higher speeds.

Belted bias

A belted bias tire starts with two or more bias-plies to which stabilizer belts are bonded directly beneath the tread. This construction provides smoother ride that is similar to the bias tire, while lessening rolling resistance because the belts increase tread stiffness. The plies and belts are at different angles, which improve performance compared to non-belted bias tires. The belts may be cord or steel.

Radial

Radial tire construction utilizes body ply cords extending from the beads and across the tread so that the cords are laid at approximately right angles to the centerline of the tread, and parallel to each other, as well as stabilizer belts directly beneath the tread. The belts may be cord or steel. The advantages of this construction include longer tread life, better steering control, and lower rolling resistance. Disadvantages of the radial tire include a harder ride at low speeds on rough roads and in the context of off-roading, decreased "self-cleaning" ability and lower grip ability at low speeds.

Solid

Many tires used in industrial and commercial applications are non-pneumatic, and are manufactured from solid rubber and plastic compounds via molding operations. Solid tires include those used for lawn mowers, skateboards, golf carts, scooters, and many types of light industrial vehicles, carts, and trailers. One of the most common applications for solid tires is for material handling equipment (forklifts). Such tires are installed by means of a hydraulic tire press.

Semi-pneumatic

Semi-pneumatic tires have a hollow center, but they are not pressurized. They are lightweight, low-cost, puncture proof, and provide cushioning. These tires often come as a complete assembly with the wheel and even integral ball bearings. They are used on lawn mowers, wheelchairs, and wheelbarrows. They can also be rugged, typically used in industrial applications and are designed to not pull off their rim under use.

3.5 Tire Components

A tire carcass is composed of several parts.

Tread:-

Fig.16 Tire tread [40]

The tread is the part of the tire that comes in contact with the road surface. The portion that is in contact with the road at a given instant in time is the contact patch. The tread is a thick rubber, or rubber/composite compound formulated to provide an appropriate level of traction that does not wear away too quickly. The tread pattern is characterized by the geometrical shape of the grooves, lugs, voids. Grooves run circumferentially around the tire, and are needed to channel away water. Lugs are that portion of the tread design that contacts the road surface. Voids are spaces between lugs that allow the lugs to flex and evacuate water. Tread patterns feature non-symmetrical (or non-uniform) lug sizes circumferentially in order to minimize noise levels at discrete frequencies.

Tread lug

Tread lugs provide the contact surface necessary to provide traction. As the tread lug enters the road contact area, or footprint, it is compressed. As it rotates through the footprint it is deformed circumferentially. As it exits the footprint, it recovers to its original shape.

Tread void

Tread voids provide space for the lug to flex and deform as it enters and exits the footprint. Voids also provide channels for rainwater, mud, and snow to be channeled away from the footprint. The void ratio is the void area of the tire divided by the entire tread area. Low void areas have high contact area and therefore higher traction on clean, dry pavement.

Rain groove

The rain groove is a design element of the tread pattern specifically arranged to channel water away from the footprint. Rain grooves are circumferential in most truck tires. Many high performance passenger tires feature rain grooves that are angled from the center toward the sides of the tire. Some tire manufacturers claim that their tread pattern is designed to actively pump water out from under the tire by the action of the tread flexing. This results in a smoother ride in different types of weather..

Wear bar

Wear bars (or wear indicators) are raised features located at the bottom of the tread grooves that indicate the tire has reached its wear limit. When the tread lugs are worn to the point that the wear bars connect across the lugs, the tires are fully worn and should be taken out of service. Most wear bars indicate a remaining tread depth of 1.6 mm and are deemed "worn out" at that point.

Bead

The bead is that part of the tire that contacts the rim on the wheel. The bead is typically reinforced with steel wire and compounded of high strength, low flexibility rubber. The bead seats tightly against the two rims on the wheel to ensure that a tubeless tire holds air without leakage. The bead fit is tight to ensure the tire does not shift circumferentially as the wheel rotates. The width of the rim in relationship to the tire is a factor in the handling characteristics of an automobile, because the rim supports the tire's profile

Sidewall

Fig.17 Tire sidewall [40]

The sidewall is that part of the tire that bridges between the tread and bead. The sidewall is largely rubber but reinforced with fabric or steel cords that provide for strength and flexibility. The sidewall transmits the torque applied by the drive axle to the tread in order to create traction. The sidewall, in conjunction with the air inflation, also supports the load of the vehicle. Sidewalls are molded with manufacturer-specific detail, government mandated warning labels, and other consumer information, and sometimes decorative ornamentation, like whitewalls.

Shoulder

The shoulder is that part of the tire at the edge of the tread as it makes transition to the sidewall ply. Plies are layers of relatively inextensible cords embedded in the rubber to hold its shape by preventing the rubber from stretching in response to the internal pressure. The orientations of the plies plays a large role in the performance of the tire and is one of the main ways that tires are categorized

3.6 Tire Noise Generation Mechanisms [26]

Noise emanating from tires on road surfaces is caused partly by the generation of vibration in the tire structure, excited by the tire/road surface interaction, and partly by the movement of air in the cavities of the tread pattern principally in the region of the contact patch. These two parts are the very sources of tire/road noise. Further, the acoustical impedance of the surface is a property of the road and influences the propagation of originated sound towards its receiver. It is of importance not only to understand the mechanisms involved, but also to know the relative contribution of these various mechanisms. Tire/road noise arises from a combination of physical processes that can be categorized into four distinct groups:-

- **Mechanical:** generation of noise which results due to impacts and shocks formation when there is contact between the tire tread and road surface which lead to radial and tangential vibrations.
- **Aerodynamical:** processes between, and within, the tire tread and road surface patterns which generate noise due the movement of air.
- **Frictional:** processes of noise generation due to adhesion and micro-movement effects of the tread during its contact with the road.
- **Propagation:** acoustical impedance related properties of the surface that influence transmission paths.

3.6.1 Mechanical Processes

Radial and tangential vibrations of the tire tread

Vibrations are generated in vehicle tires due to the impacts and deflections that occur as the tread blocks enter and leave the contact with the road surface and as a result of movement of the tread elements in contact with the road base. An illustration of these mechanisms is shown in figure 19.

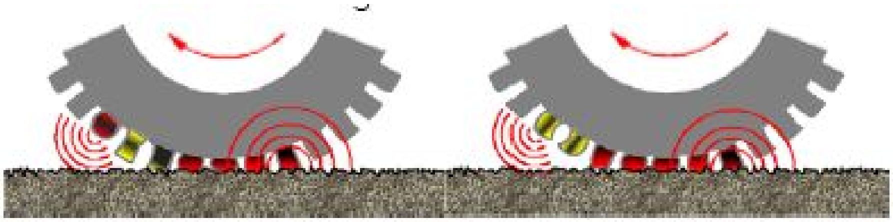


Fig.18 Radial and tangential vibrations of the tire tread [26]

The tread blocks entering the contact patch impact the road surface generating vibrations which are driven radially into the tire. Similarly, as the blocks leave the contact patch, the blocks return rapidly to their un-deflected tire/road radius and the rapid movement occurring during this process, known as block ‘snap out’, excites both radial and tangential vibration modes in the tire structure. As the tire flattens in the contact patch, the continually changing radial deflection produces additional tangential forces between the tire and the road, which are resisted by friction between the tire tread and the road surface. When the sliding forces exceed the frictional forces the tread elements slip across the road surface. This movement also excites primarily tangential vibration in the tire structure. The generation of vibration in a rolling tire is dependent on the design of the tire tread, the degree of macro texture (i.e. large scale asperities) in the road surface and by the frictional adhesion between the tire and the road surface. In addition the stiffness or mechanical impedance of the road may influence the levels of tire vibration generated by the tread block and road texture impacts. The noise that is generated by the tire as a result of vibrations tends to occur at frequencies at the lower end of the frequency range attributed to tire noise (i.e. at frequencies below 1 kHz).

Carcass Vibrations

The vibration energy created at the tire/pavement interface is enhanced by the response of tire carcass. Vibrational waves propagate in the tread band, which is structural element of tire located adjacent to the tire blocks. These waves create sound which is radiated to the tire carcass. In addition, the tire carcass side walls near the contact patch vibrate and radiate sound. The tread surface and side wall mode shapes of high frequencies play a important role in tire/road noise generation. For large size cross-bar bias truck tire, the vibration of the side wall is the major noise source.

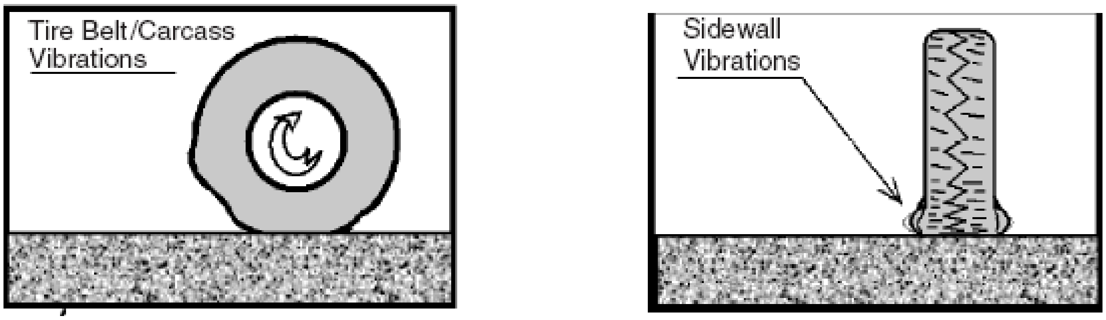


Fig.19 Tire belt carcass and sidewall vibrations [26]

3.6.2 Aerodynamic Processes

Air Turbulence

This is turbulence around the tire due to the tire displacing air when rolling on the road and air dragged around by the spinning tire/rim. This mechanism is comparable to a rotating fan. However, no evidence has been found that this effect affects overall noise levels significantly. Possibly at high speeds on porous roads it may have an effect on high frequencies.

Cavity Resonance in Tire Tube

Resonances in the cavity inside the tire-wheel assembly are known to contribute to the noise generated by the tires. These resonances are prominent at discontinuities like bridge transitions and railway crossings but not for a free rolling tire.

Air-Pumping

The original air-pumping theory was described as the sudden outflow of air trapped in the grooves in the tread pattern or road surface texture when the tire contacts the road surface and the sudden in-flow of air when the tire lifts away from the contact area. This pumping of air causes sound production. Noise is generated when this high pressure air is ejected to the atmosphere at the exit of the contact patch. Because of the high velocity of the air jets created by this process, air pumping can be a major contributor to radiated noise. A more recent description of air pumping is that a rolling tire displaces air from the tire when it deforms entering the contact patch region. The compressed air is then expelled as the tread elements emerge from the contact with the road.

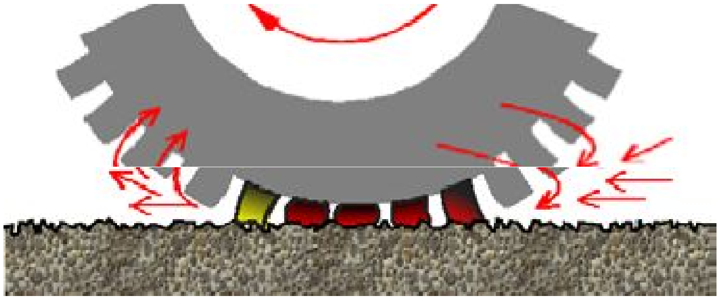


Fig.20 Air pumping [26]

3.6.3 Frictional Processes

Stick-Slip

Stick-slip or scrubbing vibrations are caused by tire vibrations associated with the frictional forces created in the contact patch between the tire and road surface. When the tire flattens in the contact patch, the changing radial deflection produces tangential forces between the tire and road. These forces are resisted by friction and tire stiffness and any residual forces are dissipated by slip of the tread material over the road surface.

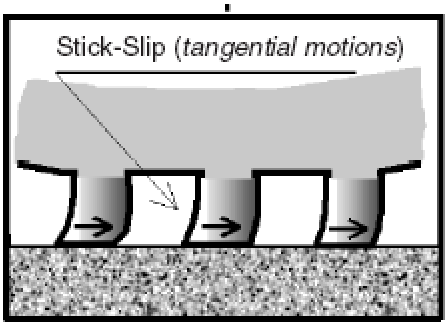


Fig.21 Stick-Slip [26]

Friction between the tread and the surface is divided between hysteresis and adhesion components. The adhesion component origins at a molecular level and is governed to a large extent by the small-scale roughness characteristics or micro texture of the road surface. During relative sliding between the tire and the road surface the adhesion bonds that have been formed between the tire and road surface begin to rupture and break apart so that contact is effectively lost and the tire rubber is then free to slip across the road surface. Contact may be regained as these residual forces are dissipated.

Stick-Snap

Stick-snap occurs when the tire tread surface gets sticky (for example ‘winter’ tread compounds at high temperature) and the road surface is very clean. The breaking of adhesive bonds between rubber and road causes vibrations and may-be a transient air flow through the opening slit. Also, tires may stick to hot asphalt road surfacing. In those cases the adhesive bond strength is increased which leads to an increase of the excitation at the trailing edge of the tire footprint. Until now, this process seems not to generate significant noise levels relative to other processes.

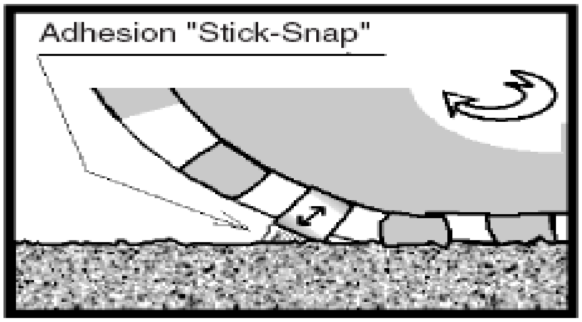


Fig.22 Stick-Snap [26]

3.6.4 Propagation Processes

Horn Effect

The road surface and tire surface mimic a cavity that acts like a horn. Sound emitted at the contact patch of tire and road is therefore radiated more effectively. Its characterization is to be based on two quantities: the sound pressure level amplification and the total radiated power amplification. The largest amplifications have been reported to occur in the region of 2 kHz. In figure24 the amplification as function of frequency depicted following from modeling.

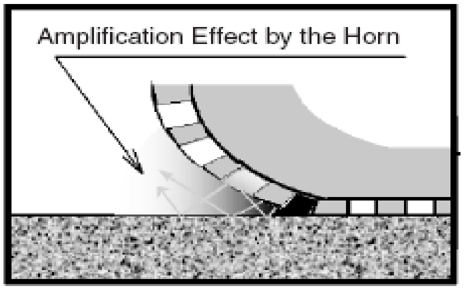


Fig.23 Amplification Effect by the Horn [26]

3.7 Different Operating Parameters of Tire Noise

All types of tire noise generation mechanisms are influenced by road characteristics as well as tire characteristics. Various kind of operating parameters including both road as well as tire characteristics are as follows:-

- Load on the vehicle
- Vehicle speed
- Inflation pressure
- Tread pattern
- Tread wear
- Tire size
- Road surface
- Temperature of road surface

3.8 Tire Noise Measurement Methods

Noise measurements must be performed in a consistent manner, so that the impact of external factors such as propagation effects and background noise are sufficiently suppressed. At the same time, measurement conditions need to be representative for 'normal' situations for both road surfacing and microphone positions simulating the environmental noise levels**.** Measurement techniques are categorized according to the type of measurement i.e whether it is done on whole vehicle or tire alone.

Vehicular measurement techniques:

- Statistical Pass-by method (SPB)
- Controlled Pass-by method (CPB)
- Coast-by method (CB)

Tire measurement techniques:

- Close proximity method (CPX)
- Trailer coast-by method (TCB)

3.8.1 Statistical Pass-by Method (SPB)

The SPB method according ISO 11819-1 consists of the measurement of the emitted noise of vehicles in the vehicle fleet. It is used merely to determine the road surfacing influence on the noise emission of road traffic. This is a standardized measuring method in which the microphone is placed at 7.5 m from the centre of the driving lane. The standardized microphone height is 1.2 m. The advantage in practice of a microphone height of 5.0 m is the exclusion of unwanted propagation effects effectively. Therefore, according to the Dutch standard the microphone height is fixed at 5.0 m. In Harmonize a microphone height of 3.5 m is chosen. Of every passing vehicle the maximum A-weighted sound level and the vehicle speed are registered simultaneously. The results are processed in a scatter diagram in which the maximum sound level is depicted as a function of the logarithm of the speed.

3.8.2 Controlled Pass by Method (CPB)

The controlled pass-by methods can be accomplished using either a single vehicle or selected vehicles .In this method, the noise generated from a single car or light truck is measured at a specially designed test site which means certain restrictions. The vehicle approaches the site at a specified speed in a specified gear.

The Controlled Pass by method (CPB) differs from the SPB method by that a limited number of vehicles are used.

3.8.3 Coast-by Method (CB)

The Coast-by method (CB) is almost identical to EU directive 2001/43 and differs from the SPB method by that during measurement of the emitted noise of a passing vehicle with turned-off engine and disconnected gear (coast-by, or coast-down). In this method 4 identical tires are mounted on a test vehicle. The experimental lay-out and statistical analysis is identical to the SPB-method. With this method only tire/road noise is included as vehicle has to pass through the test site at a requisite speed with turned-off engine and disconnected gear. Coast-by measurements are mainly used to test tires rather than vehicles. Measurements are performed on a road surface according to ISO 10844. Loading conditions and tire pressures have to meet the requirements of the directive. But the CB-method can also be applied on other road surfaces.

3.8.4 Close Proximity Method (CPX)

Near-field tire/pavement noise consists of measuring the sound levels at or near the tire/pavement interface. There are two approaches for measuring sound levels at the tire/pavement interface: the CPX as developed in Europe and defined by ISO Standard 11819-2 and the sound intensity technique developed at General Motors.

In the CPX method, sound pressure is measured using microphones located near the road surface. An alternate procedure for noise measurement is the use of sound intensity procedures. A sound source radiates acoustical power that results in sound pressure. Sound pressure is a measure of the variation in the density of the air caused by the source. This is measured by a standard sound level meter. Both sound pressure and sound intensity can be measured using a close-proximity trailer.

For CPX measurements according ISO/CD 11819-2, special vehicles and near-field microphones are used. The measurements are performed with microphones close to the test tires on a special testing vehicle. This vehicle will be driven across a designated or arbitrary part of the road. The obtained measurement results are normalized to the nominal speed that belongs to the road category. Generally speaking, the CPX method is a measurement procedure specifically designed to assess the influence of the road surfacing properties on vehicle and traffic noise. This can be done on distinct sections of the road surface. The conditions for the measurement are such that tire/road noise is dominant over propulsion noise. The CPX method gives a good estimate of the acoustic quality of the road surfacing. The method can be used to study the homogeneity of the road surfacing over a long distance and under a variety of conditions. The possible effects of wind on the microphones in an open CPX trailer are a major concern especially at high speeds.

Fig.24 Close Proximity Trailer [13]

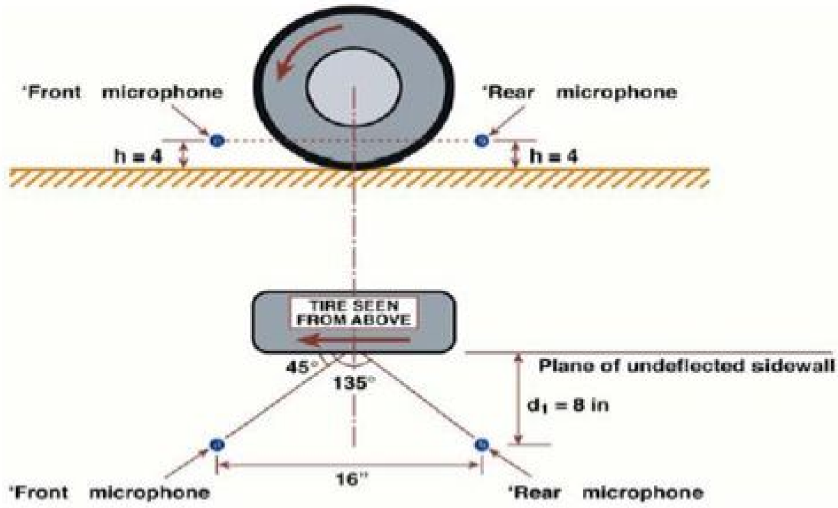


Fig.25 Microphone positions in close proximity method [13]

3.8.5 Trailer Coast by Method (TCB)

This method is a hybrid of CPB and CPX methods, and consists of the measurement of the emitted noise of two tires mounted on a trailer which is towed by a low-noise truck. Since also the time history of the passing vehicle without the trailer is measured, the influence of the tire/road noise level on tire can be calculated.

CHAPTER 4

LITERATURE REVIEW

A lot of research work has been carried out throughout the world to investigate and analyze the noise generated by tires rolling on the road surface at different operating parameters as load on the vehicle, speed of the vehicle, pavement surface type, tread pattern etc. A brief view of literature is discussed here.

William A .Leasure Jr. , Erich K Bender[1] studied the relative importance of noise to the overall vehicle noise. A general description of tire engineering noises and tire structure is then given. The important parameters which influence the tire noise are given based on the data available followed by an identification of unknown and contradictory areas. The basic mechanisms of tire/road noise generation, although not well understood are investigated largely on theoretical viewpoint..Areas for future research and development are identified based on the gaps in existing physical database and a rather primitive level of understanding of tire-noise generation mechanisms.

Iwao Keijiro, Yamazaki Ichiro [8] studied the Mechanisms involved in tire/road noise generation, which contribute very much to the vehicle exterior noise. For this study, factors of tire/road noise are divided into exciting force, vibration characteristics and acoustic radiation characteristics. In addition this paper shows the effectiveness of suppressing the distinctive tread vibration mode, which is the main mode of vibration radiating noise of around 1 kHz with high sound pressure level in radial tire for passenger cars.

Fujikawa Tatsuo, Koike Hiroshi et al.[12] presented the effect of **r**oad roughness in the generation of tire vibration noise. However, it was unclear which kinds of road roughness parameters should be controlled to reduce the noise. In this paper, essential road roughness parameters were discussed that govern tire tread vibration and provide information on tire/road noise abatement. The detailed effects of road roughness parameters on tire tread vibration were estimated using a tire/road contact model. The results reveal that pavement asperity height itself is not an essential parameter, but asperity height unevenness, asperity radius, and asperity spacing are important for the abatement of tire vibration noise.

Kim Byoung Sam, Kim Gi Jeon, Lee Tae Keun [17] discussed tire noise generation mechanisms. With a modern tire, wall vibration, air pumping and air resonant radiation are all considered to be important. But tire noise generating mechanisms are still not clear due to the complication of tire vibration behaviour. Vibrations of the tire shell are the combination of several different wave types which appear at different frequencies. In a low frequency range, where the tire behaves like an elastically supported beam, the circular ring model is used to analyze the dispersion relations. Above 300 Hz, which is the transition point from one dimensional to two-dimensional waveguide properties of the passenger car tire, a cylindrical shell model is used to analyze flexural wave propagation. Two important features on the wave propagation, wave-guide behaviour and the curvature effect of the tire wall are analyzed. As a result, It is observed that one of the most important features in sound radiation of a tire shell is acoustically excited wave motion of the tire wall.

Kim Byoung Sam, Kim Gi Jeon , Lee Tae Keun [15] studied sound transmission paths as sound transmission into a vehicle is classified as either airborne or structure borne sound. From the point view of noise control, the reduction of noise transferred by different paths requires different solutions. Coherence function analysis is often used to identify transmission paths. However it can be difficult to separate the airborne from structure borne components. The principle of acoustic reciprocity offers a convenient method for overcoming this difficulty. The principal states that the transfer function between an acoustic volume velocity source and an acoustic receiver is independent of a reversal of the position of source and receiver. The work done on this study involves exciting a stationary tire and measuring the surface velocity of the tire at a number of discrete points. The acoustic transfer functions between each point on the tire and a receiver point are measured reciprocally. Two sets of measurements are then combined to yield a measure of the sound pressure due to a point force on the tire via the acoustic transmission path only. This technique also provides information on the relative contributions of various regions of the tire wall to the resultant noise. Also the sound radiation characteristics, the horn effect, and resonance at the wheel housing are identified through the reciprocal measurement.

Narayanan Neithalath, Rolando Garcia, Jason Weiss and Jan Olek [14] discussed certain aspects of a recent large-scale research that has been carried out to examine the influence of cement concrete pavement surface type and texture on noise generation. One pavement surface type (Enhanced Porosity Concrete – EPC), and one surface texturing method (transverse tining) is dealt with in detail in this paper. Experimental studies to ascertain the physical (porosity and pore size), mechanical (strength), and acoustical (acoustic absorption using impedance tube) properties of EPC are discussed. It is shown in this paper that, with careful selection of aggregate gradation and cementing materials content, it is possible to generate a system of optimally-sized pores in the material to maximize acoustic absorption. Mathematical modeling of noise to evaluate the influence of transverse tine geometry (depth, width, and shape) on noise reduction characteristics is explained in the second part of this paper. A mathematical model has been used to determine the stress distribution between the concrete pavement and the tire. The stress distribution model is used to describe the stress and ultimately noise generated by various geometries of tinning patterns.

Bueno M., Viñuela U.,Terán F., Paje S.E. [19] investigated the behavior of sound generated from porous surface. For this analysis of sound generated from the interaction of tire and road surface near the contact patch in close proximity as a function of vehicle speed in acoustic range is done. Sound level behavior is observed at two frequency regions, one is low frequency and other is high frequency. Variation of sound with speed increases with frequency in low frequency region which is not so for high frequency region .Dependence of speed coefficient B at low frequencies seems to be correlated with high sound absorption of porous surface.

Cesbron Julien, Le de Fabienne Anfosso et al. [20] experimentally studied the dynamical tire/road contact for noise prediction. In situ measurements of contact forces and close proximity noise levels were carried out for as lick tire rolling on six different road surfaces between 30and50km/h. Additional texture profiles of the tested surfaces were taken on the wheel track.

Normal contact stresses were measured at a sampling frequency of 10752 Hz using a line of pressure sensitive cells placed both along and perpendicular to the rolling direction. The contact areas obtained during rolling were smaller than in static conditions. This is mainly explained by the dynamical properties of tire compounds, like the visco -elastic behavior of the rubber. Additionally the root-mean-square of the resultant contact forces at various speeds was in the same order for a given road surface, while their spectra were quite different. This is certainly due to a spectral influence of bending waves propagating in the tire during rolling, especially when the wavelength is small in comparison with the size of the contact patch. Finally, the levels of contact forces and close proximity noise measured at 30km /h were correlated. Additional correlations with texture levels were performed. The results show that the macro-texture generates contact forces linearly around 800Hz and consequently noise levels between 500 and 1000 Hz via the vibrations transmitted to the tire.

Andersson P.B.U., Kropp W. [21] studied the effect of adhesion forces in the tire/road contact interface, which significantly influence the contact dynamics and resulting noise generation for certain tire/road combinations. Hence, an experimental setup was built where tire tread samples are loaded and rapidly unloaded in the direction normal to a wearing course sample from an ISO10844-road. Time records of contact forces and sound pressures are acquired during the separation. The separation process in terms of the contact forces and noise generation is described and interpreted. The measured adherence force depends strongly on load, load duration, and unloading rate, in away supported by theories for contact of rough surfaces. The total sound pressure level of the noise generated during separation is directly related to the level of the adherence force, but the distribution of energy in 1/3-octave bands cannot be estimated from the adherence force record alone, as they also depend on the exact contact geometry. The details of the contact geometry are also very decisive for the magnitude of the adherence force.

Kindt P.,Berckmans D., DeConinck F., Sas P., Desmet W. [24] presented an experimental analysis of the generating phenomena of structure borne tire/road noise due to a road discontinuity. Both exterior and interior tire/road noise are considered. The influence of driving speed, cleat dimension, inflation pressure, tire temperature and pre-load on to the noise generating phenomena is investigated. An oval test setup was designed and built at the

K.U.Leuven Noise and Vibration Engineering Laboratory in order to measure the structural and acoustic response of a tire rolling over a cleat. The vehicle interior noise is analyzed by means of a test circuit cleat test.

Eisenblaetter Jochen, Walsh Stephen J., Krylov Victor V. [26] discussed the four main air-related noise generation mechanisms at the tire/road interface, which were all categorized more than 20 years ago. The first one is the so-called ‘air pumping’ mechanism. Two other air-related phenomena that occur when there are air movements near the contact patch of the tire are ‘air resonant radiation’ and ‘pipe resonances’ which appear at the footprint of the tire. In addition to these, there is a forth effect, which is mentioned in the literature, that is occurring due to turbulence effects of the air surrounding the spinning tire. There has been less focus on the air-related mechanisms than on other types of tire noise generation mechanisms. This paper attempts to add some detail to current understanding of the air-related noise generation at the tire road interface and gives some further information on how to identify the differences due to these mechanisms. Specifically in the present paper, a solid rubber tire running on a vehicle chassis dynamometer is used to study the first two mechanisms. This is done with emphasis on the time history of the recorded signal and not on the frequency spectrum, as is more commonly used. A comparison with existing theoretical models of these mechanisms reveals some of the strength and weaknesses of the current understanding of these phenomena.

Saeedi Khoda Bakhsh, Bhat Rama B. [27] studied the dynamics of a rolling tire in order to estimate the vibration transmitted to the structure of the vehicle, and the noise produced. The conventional model of a tire, adopted in previous studies, considered the tire a ring or shell rotating about a fixed center. In the present model, the tire is also modeled as a ring, but one whose center is not fixed and is free to move. Also it is assumed that there is one point on the tire that is always in contact with the ground. These assumptions make it possible to consider the influence of the inertia of translational motion of the tire body. In the present study, the large deformations due to the stationary loads such as the weight of the car or the passengers are neglected in order to highlight the effect of rotational speed and tire-road interaction on the tire vibrations. Equations of motion, written in polar coordinates system, are obtained by using

Hamilton’s principle. Numerical results are obtained by the application of the Galerkin Method. The results show that the natural frequencies of the tire obtained by the proposed method are significantly different from those obtained by the conventional method. Also it is observed that the so-called veering in the conventional model does not occur in the proposed model. Moreover, the differences between the lower natural frequencies obtained by using the proposed method and those obtained by using the conventional method are significant. By contrast, the effect of the translational motion of the tire on higher frequencies is negligible.

Bueno M., Luong J., Viñuela U.et al.[29] studied the influence of the surface temperature on the acoustical behavior of a semi dense asphalt pavement located in an urban area. For this, measurements of sound levels emitted by the interaction between a reference tire and the asphalt pavement at different surface temperatures were done with the trailer Tire sonic Mk4 LA2IC-UCLM rolling at a speed of 50 km/h. The analysis of the results shows that increasing pavement temperature leads to a reduction in the close proximity sound levels assessed at a rate of 0.06 dB (A)/°C. Moreover, spectral analysis confirms that both the mechanisms associated with vibration and impacts and those related to the friction and adhesion between tire and pavement in the contact patch could be affected by the variation of the surface temperature.

E.Rustighi, S.J. Elliott et al. [16] examined tire/road interaction, which is recognized as the main source of interior and exterior noise for velocities over the 40 km/h. In this paper, a three-dimensional (3D) elemental approach has been adopted to predict the stochastic tire vibration and hence the interior and exterior noise due to this kind of excitation. The road excitation has been modelled from the spectral density of a common road profile, supposing the road to be an isotropic surface. A linear Winkler bedding connects the 3D model of the tire with the ground. The exterior noise has been evaluated by an elemental calculation of the radiation matrix of the tire deformed by the static load on a concrete road. The noise inside the vehicle has also been calculated, using the transfer functions from the force transmitted to the hub and the noise inside the vehicle, which have been computed by a FEM model of a common car body.

K.L. Mak, W.T. Hung, S.H. Lee [33] studied the impacts of road surface texture on tire/road noise are explored by analysing field data applying fast Fourier transform technique to tire/road noise spectrum analysis. The results indicate that the tire/road noise can be higher at lower frequency bands but lower at higher bands. Cluster analysis on surface texture in terms of wavelength identified three cluster groups that centred at 1.32 mm, 3.65 mm, and 5.11 mm have different impacts on noise. The shorter wavelength group suppressed tire/road noise, medium group aggravated it and the high wavelength group were outliers.

Wolfgang Kropp , PatrickSabiniarz et al. [31] investigated the sound radiation from rolling tires, which is still not very well understood. Although details such as horn effect or directivity during rolling have been investigated, it is not clear which vibrational modes of the tire structure are responsible for the radiated sound power. In this work an advanced tire model based on Wave Guide Finite Elements is used in connection with a contact model validated in previous work. With these tools the tire vibrations during rolling on an ISO surface are simulated. Starting from the calculated contact forces in time the amplitudes of the modes excited during rolling are determined as function of frequency. A boundary element model also validated in previous work is applied to predict the sound pressure level on a reference surface around a tire placed on rigid ground as function of the modal composition of the tire vibrations. Taking into account different modes when calculating the vibrational field as input into the boundary element calculations, it is possible to identify individual modes or groups of modes of special relevance for the radiated sound power. The results show that mainly low-order modes with relative low amplitudes but high radiation efficiency in the frequency range around 1 kHz are responsible for the radiated sound power at these frequencies, while those modes which are most strongly excited in that frequency range during rolling are irrelevant for the radiated sound power. This fact is very essential when focusing on the design of quieter tires.

Gang Cheng, Weidong Wang et al. [30] studied the rolling properties of a radial tire. For that an accurate 3D 195/60R14 tire model is established. The modal includes the geometric nonlinearity due to large deformation, material nonlinearity, the anisotropy of rubber-cord composites, the nonlinear boundary conditions from tire-rim contact and tire-pavement contact. The model can be used to simulate the changes of a rolling tire and calculate the tire deformation for various operating conditions. The profile of inflated tire is studied experimentally and numerically. The simulation result is in good agreement with the test result. Some contact problems, such as the tire deformation, the shape of contact area, the contact pressure distribution, are discussed in detail.

Diange Yang ,ZitengWang et al. [28] studied the pass-by noise radiated by the running vehicles at high speeds and did quantitative measurements. A system composed of a microphone array is developed to do this work. An acoustic-holography method for moving sound sources is designed to handle the Doppler effect effectively in the time domain. The effective sound pressure distribution is reconstructed on the surface of a running vehicle. The method has achieved a high calculation efficiency and is able to quantitatively measure the sound pressure at the sound source and identify the location of the main sound source. The method is also validated by the simulation experiments and the measurement tests with known moving speakers. Finally, the engine noise, tire noise, exhaust noise and wind noise of the vehicle running at different speeds are successfully identified by this method.

Rufin Makarewicz [32] discussed the noise generation parameter for an individual road vehicle . It can be determined from the measurement of the pass-by maximum level. Along with the traffic flow and vehicle speed, it can be used for approximation of the long term A-weighted time average sound level.

D.J. O’Boy, A.P.Dowling [22] studied the noise which results from the interaction of pneumatic tires with a rough road surface, which is a significant contributor to an increasing local environmental problem. Above a steady forward vehicle speed of 40 km/h this is the dominant noise source of a modern car in good working condition, and is a significant contributor to the overall radiated noise during acceleration. In order to determine the noise produced by a patterned tire rolling on a rough road surface, the vibration characteristics of the tire must be known. A model of the tire belt is used to determine the parameters of an equivalent simple bending plate model which can be adapted to yield the response of a tire which includes sidewalls. A method is then described which uses this response to determine the acceleration of the tire surface as it rolls over a rough road. These accelerations are then used to predict the far-field radiated noise for a patterned tire on two rough road surfaces. Comparisons with experimental data are provided at each stage.

Byoung Sam Kim, Gi Jeon Kim, Tae Keun Lee [17] studied Tire noise generation by several mechanisms. With a modern tire, wall vibration, air pumping and air resonant radiation are all considered to be important. But tire noise generating mechanisms are still not clear due to the complication of tire vibration behaviour. Vibrations of the tire shell are the combination of several different wave types which appear at different frequencies. In a low frequency range, where the tire behaves like an elastically supported beam, the circular ring model is used to analyze the dispersion relations. Above 300 Hz, which is the transition point from one dimensional to two-dimensional waveguide properties of the passenger car tire, a cylindrical shell model is used to analyze flexural waves propagation. Two important features on the wave propagation, wave-guide behaviour and the curvature effect of the tire wall are analyzed. In consideration of noise radiation from tire waves, most of the tire waves observed in this study are inefficient sound radiators since their wave numbers are larger than the acoustic wave number. As a result, It is observed that one of the most important features in sound radiation of a tire shell is acoustically excited wave motion of the tire wall.

P.Kindt , P.Sas, W.Desmet [23] did the measurement and analysis of rolling tire vibrations due to road impact excitations, such as from cobbled roads, junctions between concrete road surface plates, railroad crossings. Vibrations of the tire surface due to road impact excitations cause noise radiation in the frequency band typically below 500 Hz. Tire vibration measurements with a laser Doppler vibrometer are performed on a test set-up based on a tire-on-tire principle which allows highly repetitive and controllable impact excitation tests under various realistic operating conditions. The influence on the measured velocity of random noise, cross sensitivity and alignment errors is discussed. An operational modal analysis technique is applied on sequential vibration measurements to characterise the dynamic behaviour of the rolling tire. Comparison between the operational modal parameters of the rolling tire and the modal parameters of the non-rolling tire allows an assessment of the changes in dynamic behaviour due to rolling.

D.J. O’Boy, A.P.Dowling [25] studied the tire/road interaction noise as vehicle noise is an increasing local environmental problem. For cars, above a steady speed of 40 km/h the noise produced by the interaction of the tires with the road surface is the dominant noise source. In order to be able to predict this noise, the vibration characteristics of a stationary tire must be determined. A multilayer viscoelastic cylindrical representation of the tire belt, located between the sidewalls of the tire and excluding the tread, is provided which yields the displacement and velocity response of the tire belt when excited in the radial or tangential directions for a wide range of excitation frequencies, using only data from the design process. This model includes a representation of an air cavity and sidewalls and the response of the tire belt is determined in both the frequency–wave number and time–spatial domains. The model can then be used to determine the noise of a tire rolling on a rough road.

Maik Brinkmeiera, Udo Nackenhorsta, Steffen Petersenb, Otto von Estorf [18] presented a physically motivated modeling process for the prediction of noise radiated from rolling tires. The overall simulation procedure is based on a decomposition into the nonlinear stationary rolling case, the Eigen value analysis in the deformed state, and the calculation of the noise radiation including a modal superposition approach with an excitation by deterministic functions. The simulations cover detailed finite element models of the tire/road system. This allows for various parameter studies with respect to noise reduction potentials. The new model was applied to representative numerical examples, and its accuracy as well as its efficiency were discussed.

CHAPTER 5

EXPERIMENTAL INVESTIGATION AND MEASUREMENTS

5.1 PROBLEM FORMULATION

Traffic noise becomes a severe problem and a hazard for the environment now a days. It is basically generated due to two main factors, one is engine or other moving parts of the vehicle and second is tire/road interaction noise. Engine or moving part noise cannot be eliminated but tire/road interaction noise can be eliminated or reduced up to a large extent once fully understood. There are certain mechanisms some of them are aerodynamic, frictional, mechanical etc which are responsible for the generation of tire noise and there are some operating parameters like speed of the vehicle, load on the vehicle, type of tread pattern, type of pavement surface, tire wear etc. For understanding the behavior of tire noise, the effect of these operating parameters on the sound pressure level with different combination of these parameters need to be studied. There are many methods for studying the effect of these operating parameters but for closely monitoring the effect of only tire/road interaction noise, a method named as close proximity method is used. An experimental rig need to be designed for artificially monitoring the effect of operating parameters on tire/road interaction noise using close proximity method. From all mentioned operating parameters there are three major parameters which are mainly responsible for the tire/road interaction noise, first is speed of the vehicle, second is tread pattern and third is pavement surface.

Operating parameters need to be studied:-

Tread pattern For studying the effect of tread pattern on sound pressure level, tires of different tread patterns are used.

Basically three tires having different tread patterns are used which are shown below—

Tire A Tire B Tire C

Figure26. Three tires of different tread design

All these tires are radial rib tires having dimensions 3.50-10 and of 4 ply ratings.

Speed:-This is also one of the major parameter which need to be studied because vehicle noise above 30mph is majorly from the tire/road interaction and very less from engine or other moving parts of the vehicle. Also, above the effect of speed variation on tire/road interaction sound pressure level need to be studied. For this, four different speed variations are used with the help of attaching multiple pulleys of varying diameters with the motor shaft.

Pavement surface:- The third and of same importance operating parameter is pavement surface. It has been found that it’s the pavement surface texture which affects the tire noise level. Tire noise beside speed, tread pattern depends upon the roughness, smoothness, different conditions like dry, wet or oily nature of these rough or smooth surfaces. So, not only the type of pavement surface but the conditions need to be studied. For now, two surfaces are prepared for study, one is asphalt and other is concrete. Each surface has three conditions like dry, wet, oily. So, total there are two surfaces and six different conditions.

Asphalt Concrete

Figure27. Pavement surfaces

Wear :- Although tire wear is not a major contributor to tire/road interaction noise because tire wear out in negligible amount, so may be having a little affect on tire noise but once the tires wear out then whether these have more or less effect on tire noise, this behavior need to be studied. For this a new tire has to be worn out at constant speed on a single pavement surface whether that is asphalt or concrete. Tread depth level and corresponding sound pressure levels should be measured.

5.2 EXPERIMENTAL SET-UP

For studying the tire/road interaction noise and the effect of different operating parameters on the same, an experimental set-up need to be prepared. Experimental set-up should have provision for the change of tires for the variation of tread pattern, for the variation in speed, for change in the pavement surface.

Requirements for the preparation of experimental set-up: --

- One A.C motor of approximately 1 H.P capacity.
- Multiple pulleys for the variation in speed.
- One shaft of mild steel of 105cm long and 3.6cm diameter.
- One circular plate of mild steel approximately of the size of internal diameter of scooter tire having five holes on the periphery for the tightening of the rim.
- Two wooden pieces of approximately 167cm of height and 152cm long, 1.2cm thick.
- One wooden box having length 68cm, width 38cm, height 27cm and 1.2cm thick.
- Two pieces of sound absorbing foam having dimensions of 182cm long and 91cm wide. Foam should be dense enough to absorb most of the noise being generated during operation so that there should be no mix up with the source noise.

Experimental rig is fabricated by using an old lathe machine, which was having an A.C motor and multiple pulleys for attaining the speed variation. A mild steel rod of 105 cm long, 3.6 cm diameter and a plate of same diameter as that of the scooter rim internal diameter was prepared. Two road surfaces one is asphalt and other is concrete were casted. A wooden box and a wooden wall having sound absorbing material (foam) fixed were prepared for shielding purpose.

Schematic view of experimental rig

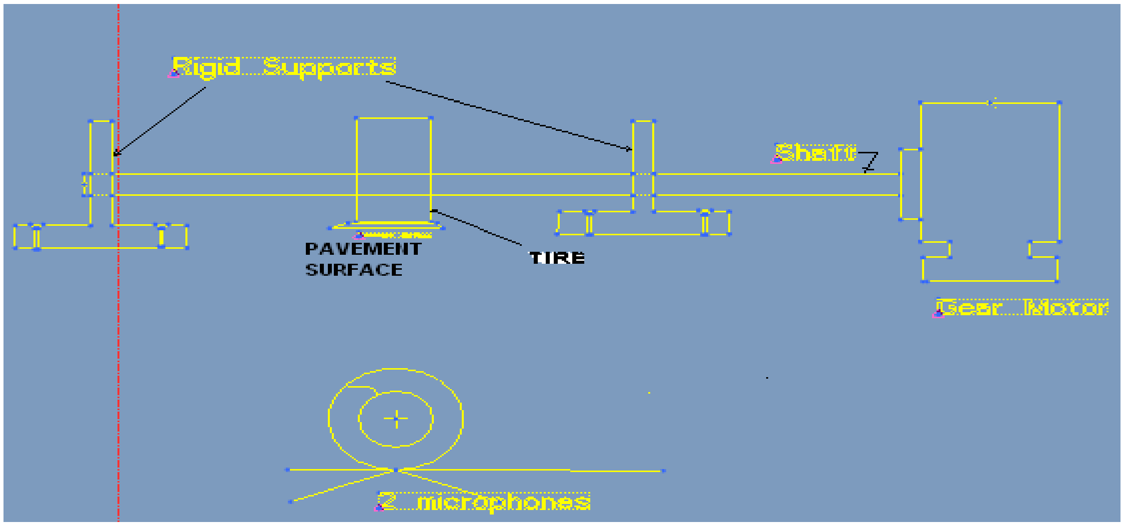


Fig.28 Schematic view of experimental rig

Pictorial view of experimental rig:

Fig.29 Experimental set-up

5.3 MEASUREMENT METHOD

There are many methods for the measurement of tire/road interaction noise. Broadly these methods depending upon the type of measurement are classified as far field and near field measurement methods. Some of them are listed below---

- Statistical pass by method (SPB)
- Trailer coast-by method (TCB)
- Coast-by method (CB)
- Controlled pass-by method (CPB)
- Close proximity method (CPX)
- Measurements on stationary vehicles

The only problem in these methods except close proximity method is that all these methods not only gives the sound pressure level measurements for tire/road interaction noise but also combine engine or moving part noise of the vehicle with tire noise. So, for solely seeking the tire noise and the effect of different operating parameters on tire noise, the method which only concentrates on the tire/road interaction noise and not on the whole vehicle noise need to be used. Close proximity method is one of them.

So, the method used for the measurement of tire/road interaction noise in this work is close proximity method.

Close proximity method

Near field or close proximity methods consist of measuring the sound levels at or near the tire/pavement interface. In CPX method sound pressure or sound intensity is measured by locating the microphones near the road surface. So, depending upon the measurement requirement i.e whether sound pressure or sound intensity need to be measured, near field measurement methods can be further classified as close proximity method (CPX) and close proximity sound intensity method. In case of CPX microphones are placed near the tire / pavement interface to directly measure the tire/pavement noise levels and not the whole vehicle noise. According to the ISO standards microphones are mounted 20 cm(8 inches) from the centre of the tire and 10 cm (4 inches) above the surface of the pavement as shown in the figure below.

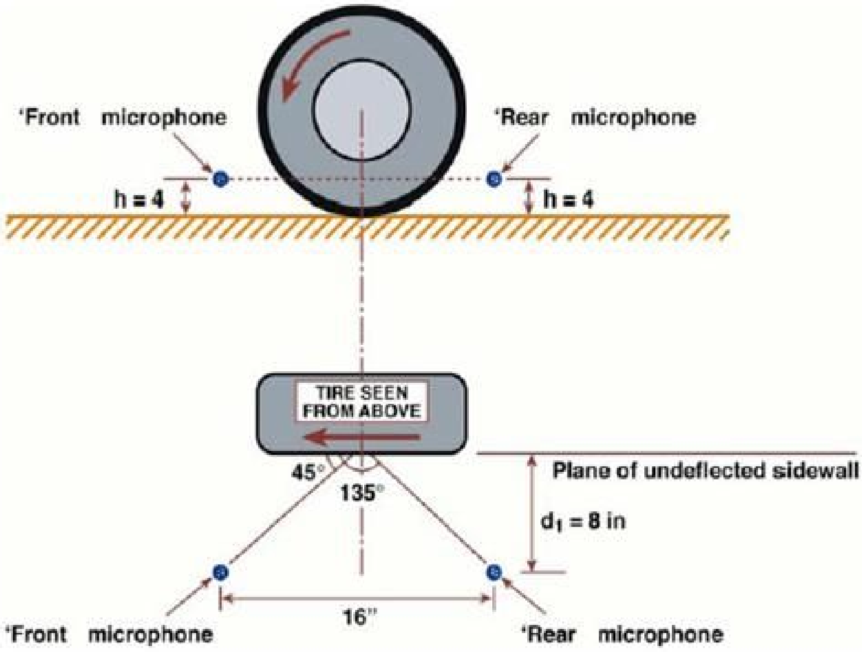


Figure 30 Microphone positions in close proximity method [13]

Microphones need to be shielded for background or any other unwanted noise other than the source noise because microphones measure the sound from all directions. A concern with regard to the near field measurement is that they measure only the tire/pavement noise component of traffic related noise.

The near field or close proximity procedures offer many advantages: ---

- The ability to determine the noise characteristics of the road surface at almost any arbitrary site.
- The ability to check the state of maintenance i.e wear or damage to the surface, as well as the clogging of porous surfaces and the effect of cleaning clogged pores.
- It is much more portable than pass-by methods requiring little set-up prior to use.

- The testing can be done on the run at any selected speed.

5.4 MEASUREMENT PROCEDURE

Measurements are taken after preparing the experimental rig under different operating conditions according to CPX method with help of an instrument called sound level meter SC-310 and the measurements are recorded in the CESVA software of sound level meter. Measurements are taken for equivalent sound level Leq and 1/1 octave band frequency spectrum.

Fig.31 sound level meter (SC 310)

Before taking the measurements one predominant factor called background noise need to be checked and it should be ensured that there is no noise other than source noise.

Background noise is the noise other than source noise which if not eliminated would interfere with the source noise and all measurements taken will get affected. For checking the background noise, measurement for sound pressure level first be taken for source noise combined with outside noise, denoted by L_{s+n}. After that, one measurement is taken for outside noise alone, denoted by Ln. Then the difference between the two is calculated, if the difference is more than 10 dB then there is no need of background noise elimination because it’s interference is found to be negligible, but if the difference is less than 10 dB i.e between 3-10 dB then deduction should be made in the sound level measurement according to the background noise curve.

After setting up the experimental rig, the main problem which occurred was predominant background noise, so before moving further it had to be reduced.

Figure32 Experimental set-up, without any preventive measures, for background noise estimation

Firstly for checking the level of background noise, measurements were taken and it had been found that the difference between L_{s+n} and L_n is only 1.5-2 dB, which is very much less and it was also not in the range of background noise curve to follow for the deduction of some dB from the main sound level.

So, it became important to reduce background noise and for that shielding of moving parts and motor was done with help of making a wooden box of 68.57cm long, 38.2 cm width, 11 inch height and 1.2 cm thick fitted with an absorbing material (foam).

After that again measurement for background noise was taken and now the difference between L_{s+n} and L_n was 5-6 dB.

Figure33 wooden box for shielding of moving parts of experimental rig

For further reducing the background noise and making the difference between L_{s+n} and L_n at least 10 dB, so that the use of background noise curve could be avoided, a wooden wall of approximately 167cm height, 135cm wide and 1.2cm thick having a layer of absorbing material attached to the side of noise prone area so that it will absorb, reflect the sound waves and should not let the sound waves reach the source. After that again measurements were taken for background noise and now the difference had reached to 10 dB.

Figure 34 wooden walls for shielding of remaining background noise

As the difference between L_{s+n} and L_n is 10 dB, so the main measurements can be taken now.

Steps for taking the measurements: -

- First the sound level meter will be placed at a distance of 20cm away from the centre of tire mounted on a shaft being rotated by a motor. Shafts, pulleys, belts and motor all these are the components of experimental rig. Sound level meter should be at a height of 10cmfrom the surface of pavement. All the measurements would be taken for the leading edge at an angle of 45 degree to the travelling axis of the tire
- Now, after the placement of sound level meter, measurements for the effect of tread pattern would be taken. For this, three tires of different tread pattern named as tire A, tire B, tire C would be taken. First, tire A will be mounted on the shaft, pavement surface and speed need to be constant. In this case, first the pavement would be concrete, speed should be 58 km/h and tire A would be used. Tire will be rotated for the duration of 30 sec on concrete pavement and sound pressure level will be recorded on sound level meter. Measurements for L_{eq} and 1-1 octave band frequency spectrum would be taken. Whole process will be repeated three times and average L_{eq} will be obtained so that any variation if occurred should be eliminated.
- Whole process discussed above would be repeated for tire B and tire C.
- Now, same measurements should be taken again for tire A, tire B, tire C but the only change would be in pavement surface.
- After tread pattern measurements, now its turn for studying the effect of speed, pavement surface and its different conditions like dry, wet, oily. For this, tire A would be mounted on the shaft, concrete dry pavement will be placed beneath tire A. Speed variation possible with the help of multiple pulley attached with the motor would be of four types i.e 12 km/h, 20 km/h, 34 km/h and 58 km/h. So, first the speed would be 12 km/h and three measurements are taken for L_{eq} of 30 sec duration each. Average L_{eq} is obtained. Measurement for 1/1 octave band should also be taken.
- After that, speed will have to be changed to 20 km/h, 34 km/h and 58 km/h. Whole process would be repeated for tire A and concrete dry pavement.

- Now, the surface taken would be asphalt dry and all processes discussed above will be repeated again for tire B and tire C.
- For studying the behavior of surface conditions on sound level, same process as discussed above would be repeated with concrete dry, wet, oily and asphalt dry, wet, oily conditions at different speeds i.e 12 km/h, 20 km/h, 34 km/h, 58 km/h for tire A, tire B ,tire C. Tires will be changed just for understanding the behavior of different tread patterns on surface conditions and speed.
- Now, after taking the measurements for different tread pattern, surfaces and its conditions, speed variations, next would be to study the effect of tire wear on noise level. For this, measurements of sound level for tread depth for tires A,B and C will be taken.
- In this case, first the tire would be mounted on the shaft, speed and pavement will be constant, tread depth would be measured with the help of depth gauge and then tire will have to be rotated for the duration of at least 20 sec and sound pressure level will be measured for the same. After that, again tire will be rotated for wearing it to a certain level so that considerable difference between tread depths would be maintained and L_{eq} measurements corresponding to that should be taken. After that, again tread depth will be measured and corresponding sound level will be recorded for the duration of 20 sec. whole process would be repeated for tires B and C.

5.5 MEASUREMENTS

Based upon the measurement procedure discussed above, measurements for the sound level L_{eq} and 1-1 octave band frequency spectrum for tires A,B,C, different speeds, different surfaces and their various conditions and tire wear are taken at leading edge with help of sound level meter at an angle of 45 degree to the travelling axis of tire.

Table 4 Measurements for equivalent sound level under different operating conditions

S.No.	Tread Pattern	Surface	Speed km/h	Equivalent Sound Level, L_{eq} dB (A)			Average L_{eq} dB (A)
				1	2	3	
1	A	Asphalt dry	12	78.1	78.6	77.9	78.3
2			20	86.3	86.2	87.1	86.6
3			34	88.3	87.8	88.1	88
4			58	89.8	90.1	90.2	89.9
5	A	Asphalt wet	12	79.8	80.2	80	80
6			20	87.3	86.8	87.1	87
7			34	89.3	89.8	89.5	89.6
8			58	90.1	90.5	89.9	90.3
9	A	Asphalt oily	12	69.7	69.9	70	69.8
10			20	79.9	79.6	80.0	79.8
11			34	84.1	84.3	83.7	84
12			58	87.3	87.4	86.9	87.2
13	A	Concrete dry	12	71.8	72.2	72.3	72.1
14			20	78.7	78.8	78.3	78.6
15			34	81.8	82.3	82.2	82.1
16			58	84.4	84.0	84.8	84.3

S.No.	Tread Pattern	Surface	Speed km/h	Equivalent Sound Level, L_{eq} dB (A)			Average L_{eq} dB (A)
				1	2	3	
17	A	Concrete wet	12	72.5	72.9	80.0	72.8
18			20	79.2	78.8	79.3	79.1
19			34	83.3	82.6	83.1	83
20			58	86.7	86.2	86.9	86.6
21	A	Concrete oily	12	69.1	69.5	69.7	69.4
22			20	74.3	73.8	74.5	74.2
23			34	78.5	79.2	79.0	78.9
24			58	81.9	82.4	82.6	82.3
25	B	Asphalt dry	12	76.1	76.6	76.8	76.5
26			20	84.3	84.0	83.5	83.9
27			34	85.3	85.8	85.9	85.7
28			58	88.5	88.7	88.0	88.4
29	B	Asphalt wet	12	78.4	77.9	78.6	78.3
30			20	85.2	84.7	85.4	85.1
31			34	88.1	87.4	87.9	87.8
32			58	89.2	89.3	88.8	89.1

S.No.	Tread Pattern	Surface	Speed km/h	Equivalent Sound Level, L_{eq} dB (A)			Average L_{eq}dB(A)
				1	2	3	
33	B	Asphalt oily	12	69.1	69.6	69.8	69.5
34			20	78.5	78.0	78.7	78.4
35			34	84	84.1	83.6	83.9
36			58	87.4	87.9	88.1	87.8
37	B	Concrete dry	12	73.2	73.4	72.7	73.1
38			20	78.5	78.0	78.4	78.3
39			34	83.9	83.6	83.7	83.8
40			58	87.6	87.2	87.7	87.5
41	B	Concrete wet	12	74.5	73.8	74.3	74.2
42			20	79.8	79.4	79.9	79.7
43			34	85.6	85.1	85.4	85.3
44			58	87.2	86.7	87.4	87.1
45	B	Concrete oily	12	69.6	70.3	70.5	70.1
46			20	76.4	76.7	75.9	76.3
47			34	82.5	83.0	83.3	82.9
48			58	85.2	84.7	85.4	85.1

S.No.	Tread Pattern	Surface	Speed km/h	Equivalent Sound Level, L_{eq} dB (A)			Average L_{eq} dB (A)
				1	2	3	
49	C	Asphalt dry	12	77.5	78.1	78.2	77.9
50			20	84.4	83.9	84.7	84.3
51			34	86.9	86.4	86.8	86.7
52			58	88.4	89.1	89.3	88.9
53	C	Asphalt wet	12	79.5	79	79.4	79.3
54			20	86.6	86.1	86.7	86.5
55			34	87.6	86.9	87.5	87.3
56			58	89.9	89.4	90.1	89.8
57	C	Asphalt oily	12	70.4	70.3	69.8	70.2
58			20	79	79.6	79.5	79.4
59			34	84.8	84.2	85.1	84.7
60			58	86.6	86.1	86.7	86.5
61	C	Concrete dry	12	75.4	74.8	75.5	75.2
62			20	77.8	77.1	77.6	77.5
63			34	84.9	84.3	84.7	84.6
64			58	88.4	88.6	87.9	88.2

S.No.	Tread Pattern	Surface	Speed km/h	Equivalent Sound Level, L_{eq} dB (A)			Average L_{eq} dB (A)
				1	2	3	
65	C	Concrete wet	12	76.9	76.3	76.8	76.7
66			20	77.4	78.1	77.9	77.8
67			34	83.4	84	84.2	83.9
68			58	87.3	86.8	87.2	87.1
69	C	Concrete oily	12	71.3	70.9	71.4	71.2
70			20	74.7	74.1	74.6	74.5
71			34	80.9	80.4	81	80.8
72			58	86.3	85.9	86.4	86.2

S.No.	Tire A		Tire B		Tire C	
	Tread depth(mm)	L_{eq} dB (A)	Tread depth(mm)	L_{eq} dB (A)	Tread depth(mm)	L_{eq} dB (A)
1	6.96	83.8	6.72	85.7	6.83	84.2
2	5.12	85	5.10	87.1	5.16	86.7
3	4.32	85.5	4.28	87.9	4.30	87.3
4	4.14	87	4.01	88.7	4.00	88.9
5	3.69	89.6	3.92	89.4	3.60	90.1
6	3.08	92.5	3.10	92.2	3.09	92.1

Table 5 Tire wear measurement data

Measurements for tire wear are taken at constant speed of 58 km/h and on concrete dry pavement.

Table 6 Frequency spectrum analysis in 1-1 Octave band:

Tread pattern	Surface	Speed (km/h)	Frequency spectrum and their corresponding Leq dB(A)level									
			31.5 Hz	63 Hz	125 Hz	250 Hz	500Hz	1kHz	2kHz	4kHz	8kHz	16 kHz
A	Asphalt dry	12	57.9	60.0	62.7	64.1	69.1	73.8	74.1	62.1	61.0	57.9
		20	59.2	65.0	65.7	65.9	70.3	79.3	82.2	72.5	70.2	65.5
		34	60.9	65.4	65.9	66.2	71.1	81.1	83.8	75.5	73.5	69.5
		58	61.2	66.1	67.7	69.4	72.8	83.1	84.3	78.2	76.9	72.2
A	Asphalt wet	12	59.7	62.7	63.5	65.3	71.6	75.1	79.2	75.1	69.3	64.3
		20	59.9	62.9	63.7	65.8	73.0	78.3	80.3	80.2	76.8	69.3
		34	64.2	64.6	65.7	66.8	74.2	80.2	83.7	82.9	82.4	74.2
		58	64.9	65.3	66.4	69.6	74.9	82.8	85.8	84.9	83.5	79.8
A	Asphalt oily	12	58.9	60.2	60.8	62.4	64.2	64.9	67.1	66.1	47.9	43.6
		20	61.8	64.4	64.9	65.4	67.0	73.7	71.7	67.5	58.3	52.2
		34	62.7	66.2	66.6	67.0	70.6	77.6	77.3	74.3	68.9	62.8
		58	63.9	66.9	67.4	67.6	73.2	82.7	82.0	81.4	76.3	70.8
A	Concrete dry	12	58.6	60.4	61.4	62.4	64.4	66.1	67.7	69.9	70.1	65.4
		20	61.7	61.9	62.3	64.1	66.1	68.7	70.6	73.4	73.7	66.6
		34	65.0	66.0	66.7	67.2	68.3	74.1	74.5	76.6	79.3	71.6
		58	66.7	67.6	68.2	68.9	69.5	77.2	77.8	81.8	82.8	74.1
A	Concrete wet	12	58.2	58.4	61.7	62.4	62.8	66.3	59.2	67.3	66.5	59.6
		20	60.4	62.9	63.7	65.1	66.4	69.2	65.2	69.9	69.4	62.3
		34	60.5	63.2	63.8	66.8	69.3	70.6	69.0	71.6	71.1	65.8
		58	61.8	64.5	67.7	68.1	70.7	81.1	77.7	82.1	81.8	75.5

Tread pattern	Surface	Speed (km/h)	Frequency spectrum and their corresponding Leq dB(A)level									
			31.5 Hz	63 Hz	125 Hz	250 Hz	500Hz	1kHz	2kHz	4kHz	8kHz	16 kHz
A	Concrete oily	12	58.2	60.3	61.0	61.8	62.7	63.4	60.5	64.4	56.3	51.2
		20	59.6	61.1	61.5	63.3	66.9	68.0	66.1	68.6	64.4	57.6
		34	59.8	63.4	64.2	64.9	67.2	71.9	70.3	74.0	71.2	65.7
		58	60.3	63.9	64.6	65.8	66.9	72.2	71.1	74.6	71.8	68.3
B	Asphalt dry	12	53.9	57.2	60.7	62.5	67.1	72.8	74.1	60.2	59.0	54.9
		20	57.2	63.0	64.7	65.7	68.3	77.7	80.5	70.3	69.2	62.5
		34	60.6	64.4	65.7	66.8	70.2	78.1	81.8	74.5	72.4	68.7
		58	60.9	65.3	66.4	69.6	72.8	82.1	85.2	77.2	74.3	71.1
B	Asphalt wet	12	57.7	60.7	61.2	63.3	69.6	73.1	76.2	73.6	67.5	62.3
		20	58.6	60.9	61.5	64.8	71.0	76.3	78.3	78.8	74.7	67.3
		34	62.2	64.6	65.2	65.7	69.2	78.2	81.7	83.5	81.4	72.2
		58	67.9	69.3	70.4	69.6	72.9	82.8	85.8	87.9	86.5	76.8
B	Asphalt oily	12	56.9	58.2	59.8	60.4	63.2	64.9	59.1	54.1	46.9	42.3
		20	60.8	62.4	58.1	63.4	65.0	71.7	70.1	66.5	57.3	50.2
		34	61.7	65.2	61.2	64.0	69.6	76.6	76.1	73.3	66.9	60.8
		58	61.8	65.9	62.4	63.6	71.2	84.7	85.0	82.4	77.3	68.8
B	Concrete dry	12	58.8	60.9	61.8	62.7	64.8	65.4	62.9	70.1	69.8	65.7
		20	61.8	62.9	59.9	64.8	66.7	69.9	70.8	73.7	73.9	66.8
		34	65.6	66.8	63.9	65.2	67.3	74.6	73.5	76.9	79.5	71.8
		58	66.8	69.9	66.5	67.2	69.8	77.7	75.8	81.8	83.1	74.8

Tread pattern	Surface	Speed (km/h)	Frequency spectrum and their corresponding Leq dB(A)level									
			31.5 Hz	63 Hz	125 Hz	250 Hz	500Hz	1kHz	2kHz	4kHz	8kHz	16 kHz
B	Concrete wet	12	58.9	61.1	61.9	62.9	64.9	65.8	63.2	65.9	64.5	61.6
		20	61.4	62.9	65.7	66.1	67.4	70.7	65.2	70.9	68.8	62.3
		34	61.5	63.1	65.9	66.8	69.3	71.6	69.0	70.6	69.9	65.8
		58	65.8	68.5	69.7	70.1	73.7	81.1	77.7	80.1	79.8	75.5
B	Concrete oily	12	57.2	58.3	61.0	61.8	64.7	67.4	62.5	67.9	63.3	51.2
		20	58.6	60.7	61.3	63.3	66.9	68.0	66.1	68.9	64.4	57.6
		34	59.8	63.4	64.2	64.9	66.6	71.9	70.3	74.0	71.2	65.7
		58	60.3	63.9	64.6	65.8	66.9	72.2	71.1	73.6	70.9	66.3
C	Asphalt dry	12	54.1	57.7	60.7	62.5	67.7	73.8	74.5	69.2	61..0	56.9
		20	57.6	63.0	63.7	63.9	68.9	78.7	80.3	72.3	69.9	63.5
		34	60.9	63.4	64.1	64.8	70.6	79.1	81.9	75.5	72.6	70.5
		58	61.2	64.2	64.9	66.8	73.8	83.1	85.3	77.2	75.9	73.2
C	Asphalt wet	12	57.9	61.7	62.3	63.5	69.8	74.1	76.9	77.6	68.5	63.3
		20	58.7	61.9	62.8	64.8	71.4	76.7	78.7	79.8	75.3	68.3
		34	62.8	64.8	66.2	66.9	69.8	78.9	81.7	83.8	81.8	73.2
		58	67.9	69.7	70.4	71.2	73.1	83.0	85.8	87.9	86.9	77.8
C	Asphalt oily	12	57.1	58.0	59.3	60.4	63.1	64.9	58.9	54.1	46.2	42.1
		20	60.4	62.3	59.7	63.4	65.0	71.3	69.8	66.5	57.1	50.0
		34	61.3	65.0	65.8	66.3	69.2	76.2	75.8	73.3	66.2	60.3
		58	61.4	65.2	66.1	67.6	71.0	84.1	83.6	82.2	77.3	68.5

Tread pattern	Surface	Speed (km/h)	Frequency spectrum and their corresponding Leq dB(A)level									
			31.5 Hz	63 Hz	125 Hz	250 Hz	500Hz	1kHz	2kHz	4kHz	8kHz	16 kHz
C	Concrete dry	12	58.3	60.9	61.8	62.7	64.8	65.4	66.6	70.1	71.8	65.7
		20	61.8	62.9	63.3	64.8	66.9	70.3	70.9	74.1	74.9	66.8
		34	65.7	66.2	67.9	68.2	69.3	74.8	75.1	77.2	78.5	71.8
		58	66.8	67.9	68.5	68.9	70.1	77.9	78.8	82.2	83.1	74.8
C	Concrete wet	12	58.9	61.4	62.0	62.9	65.2	65.9	63.3	66.2	64.6	61.7
		20	61.5	63.1	65.7	66.5	67.8	70.9	65.8	71.2	68.9	62.6
		34	61.8	63.9	65.9	66.9	69.7	71.8	69.5	72.4	70.1	65.9
		58	65.9	68.8	69.7	70.5	73.8	81.4	77.8	81.8	79.8	75.7
C	Concrete oily	12	57.6	58.3	61.1	61.9	64.8	67.8	62.6	68.0	63.7	51.4
		20	58.8	60.8	61.8	63.5	66.9	68.7	66.3	69.1	64.8	57.7
		34	60.2	63.7	64.8	65.4	67.6	70.7	69.3	74.3	71.9	65.9
		58	60.7	64.0	65.6	65.9	67.9	73.2	71.3	73.9	70.9	66.8

CHAPTER 6

RESULTS AND DISCUSSION

6.1 Effect of tread pattern on sound pressure level

Measurement is taken for studying the effect of tread pattern on sound pressure level. L_{eq} is recorded for three types of tread pattern on two pavement surfaces at constant speed of 58 km/h.

Tire	Concrete pavement			Asphalt pavement		
	Dry	Wet	Oily	Dry	Wet	Oily
A	84.3dB(A)	86.6dB(A)	82.3dB(A)	89.9 dB(A)	90.3dB(A)	87.2dB(A)
B	87.5dB(A)	87.1dB(A)	85.1dB(A)	88.4 dB(A)	89.1 dB(A)	87.8dB(A)
C	88.2dB(A)	87.1dB(A)	86.2dB(A)	88.9 dB(A)	89.8 dB(A)	86.5dB(A)

Table 7 measurement data of three tires on different road surface conditions

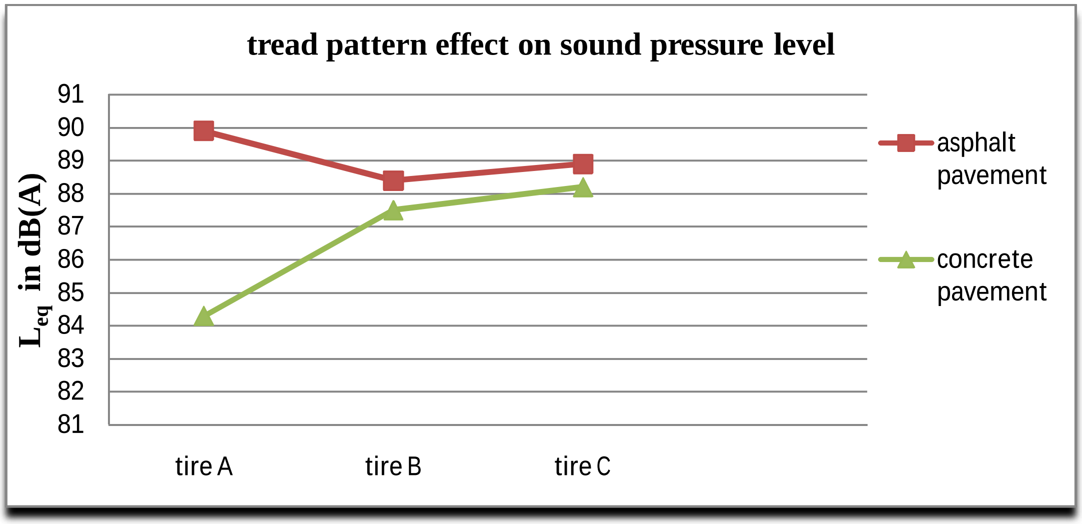


Figure 35 L_{eq} vs Tread Pattern

It is observed that for asphalt surface tire A is having maximum sound pressure level than tire B and C but for concrete surface it is having less sound pressure level than B and C, whereas tire C has maximum sound pressure level for concrete surface than tire A and B. Tire B and C are showing similar kind of response for asphalt and concrete surfaces having a little difference in sound pressure level but for tire A, there is a difference of approximately 5 dB in sound pressure level. But that difference is between surfaces, for concrete and asphalt surfaces individual difference between maximum and minimum sound pressure level between three types of tread patterns is found to be approx. 4dB and 1.5dB respectively. So, it is clear that tread patterns also have an effect on sound pressure level, although the effect is not so much in case of asphalt pavement but that 1.5 dB difference cannot be neglected.

6.2 Effect of speed and road surface on sound pressure level

Sound pressure level is recorded for tire A at varying speeds on asphalt dry and concrete dry surface.

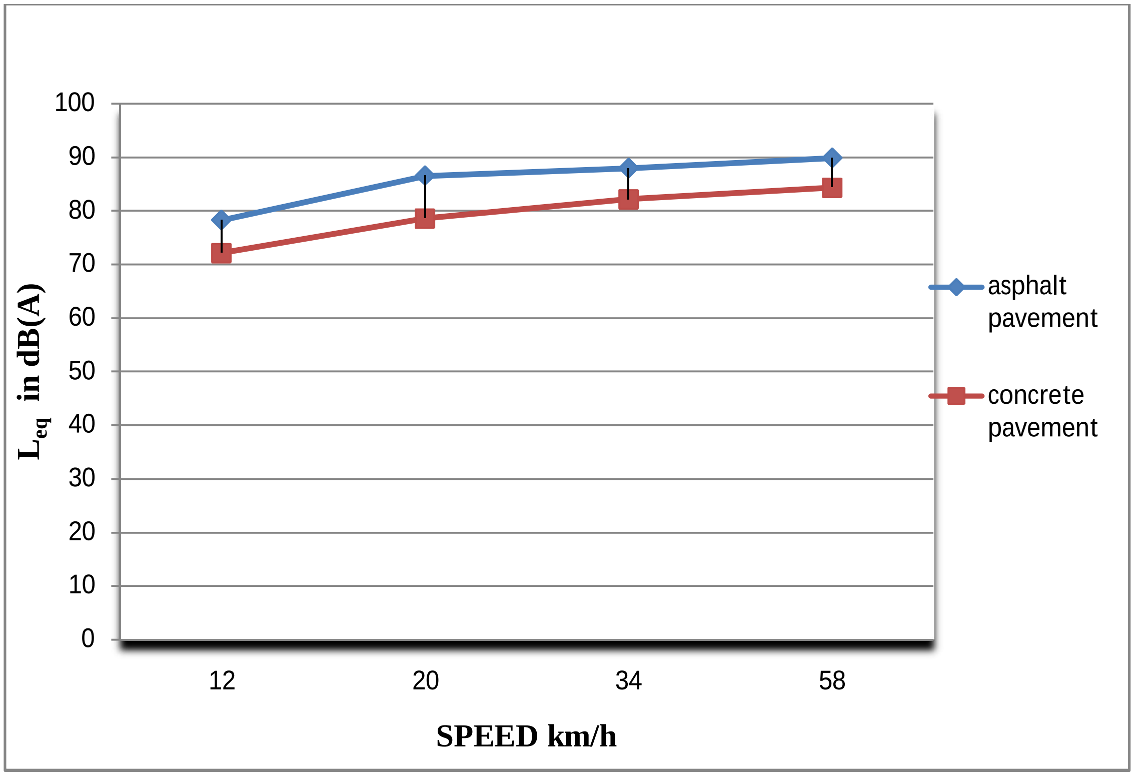


Figure 36 L_{eq} vs Speed vs Road Surface

For tire B:

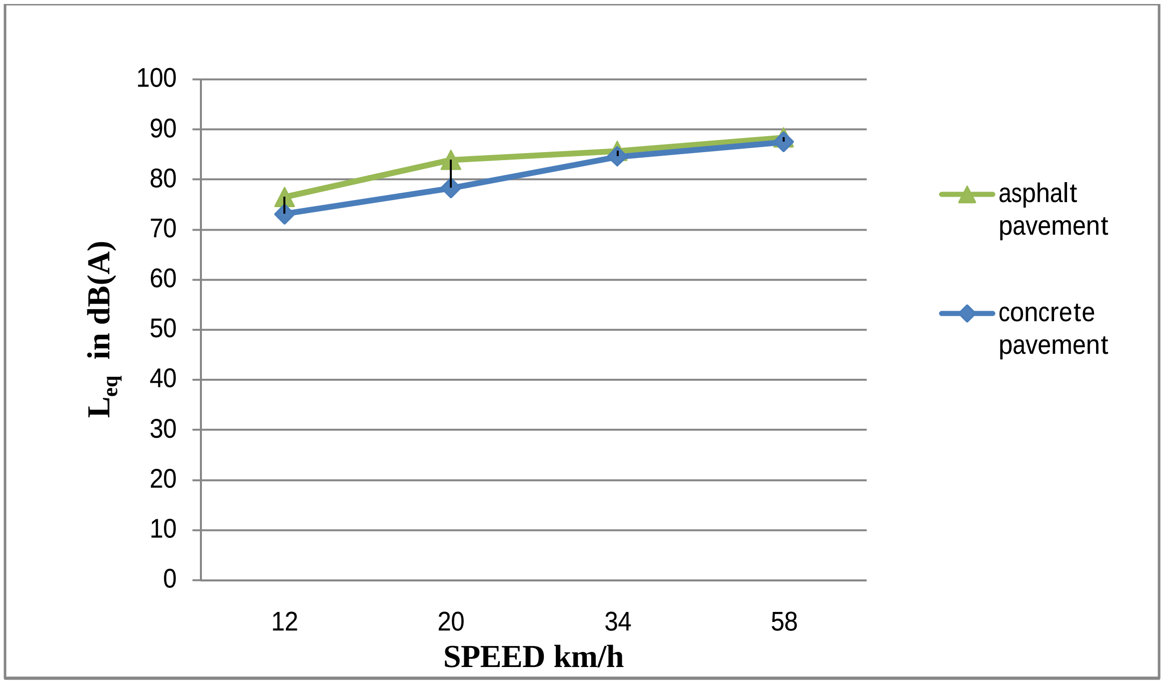


Figure 37 L_{eq} vs Speed vs Road Surface

For tire C:

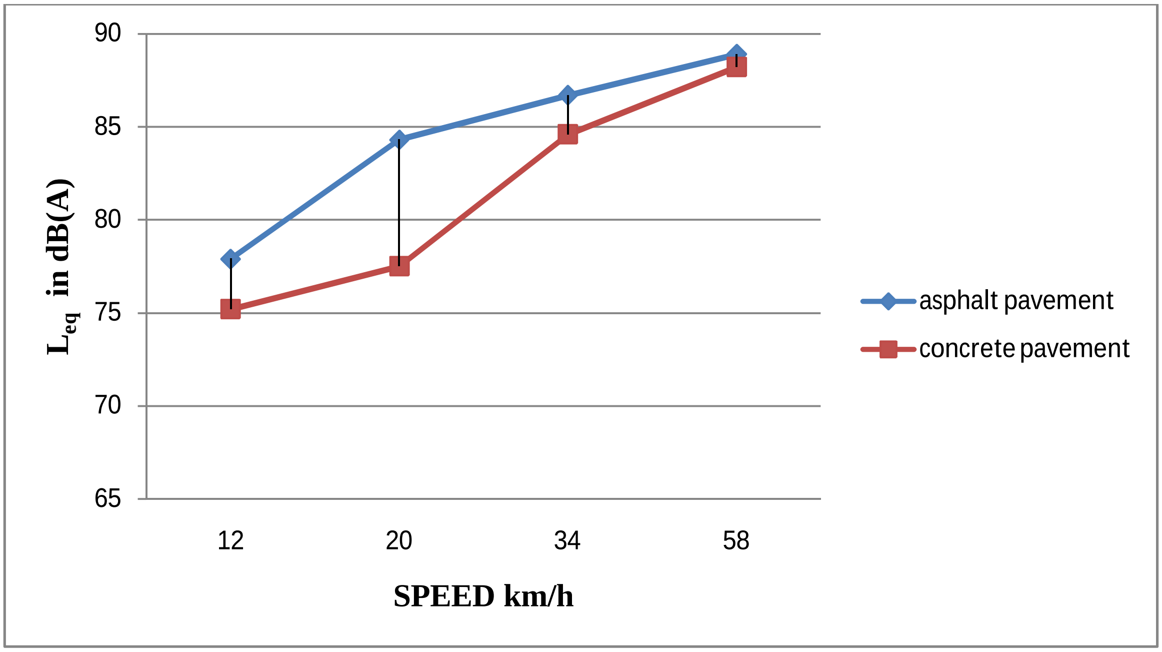


Figure 38 L_{eq} vs Speed vs Road Surface

Effect of speed: From the graphs, it is observed that sound pressure level increases with the increase in speed for both kind of pavements and for all three tires. Increase is tremendous when the speed is increased from 12 km/h to 20 km/h in case of asphalt pavement i.e sound pressure level increases from 78 db to 86dB, which is about 8 dB for tire A and approximately of the same amount for other tires also, for concrete surface this difference is about 5dB. It has been found that there is an increase of about (3-4) dB between (20-58) km/h speeds for asphalt pavement and approx. (5-6) dB for concrete pavement. But overall It has been found that for an increase of about 40 km/h speed i.e from (12-58) km/h, sound pressure level increase is about 8dB for concrete pavement and about 11 dB for asphalt pavement. So, speed is found to be a predominant factor.

Effect of surface: It is observed from the graph that asphalt surface shows more noise levels than concrete surface at all speeds. It depends upon certain factors like porosity, smoothness, rough nature of surface and some of the aerodynamic mechanisms involved which are responsible for the increase or decrease in sound pressure levels. It has been found that asphalt surface is more noisy than concrete and the difference between sound pressure levels is about (5-6) dB approximately for all speeds. At speed 58 km/h maximum sound level obtained from asphalt surface is around 89.9 dB and that for concrete is 84.3 dB.

6.3 Effect of different surface conditions on sound pressure level

Measurements for different surface conditions of concrete & asphalt surface for tire A at varying speeds have been taken and corresponding sound pressure levels (L_{eq}) are recorded.

Concrete surface:

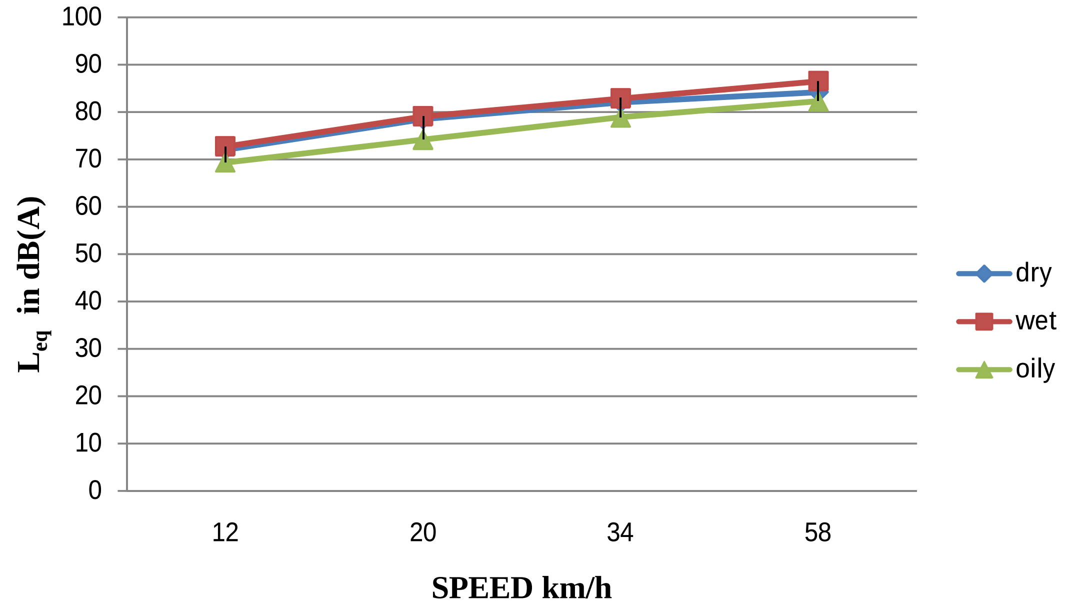


Fig.39 L_{eq} vs Road Surface Conditions

For asphalt surface: --

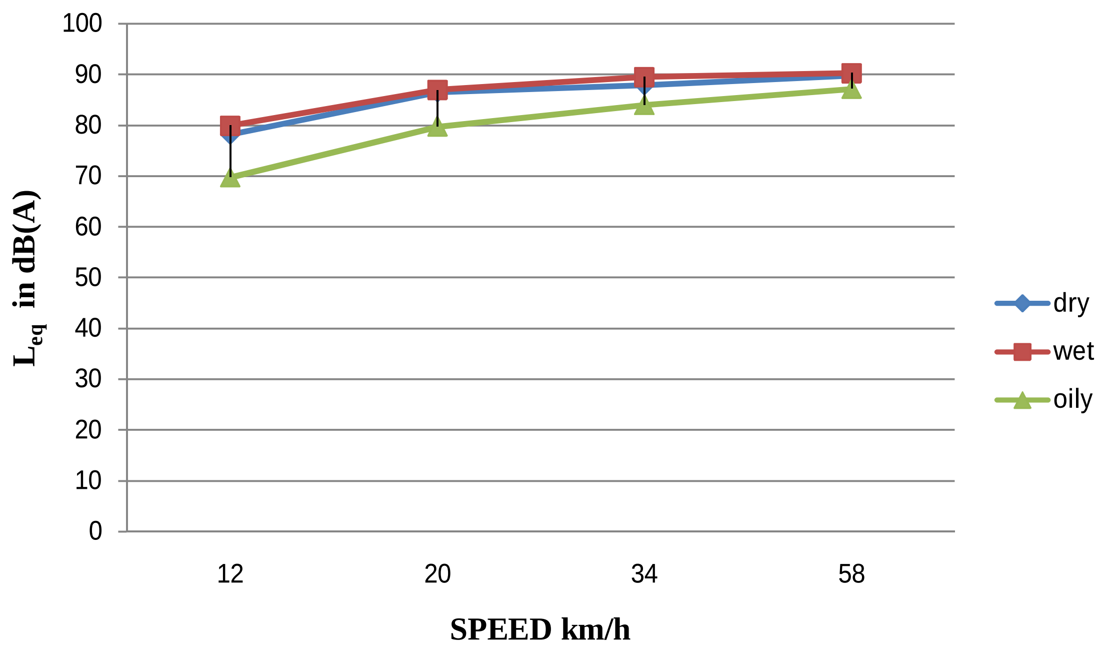


Fig.40 L_{eq} vs Road Surface Conditions

It is observed that as different surface type affect the sound pressure levels; different-different conditions of the same surface can also affect the sound levels. As it is clear from the graphs shown above for concrete and asphalt pavement and their conditions of wet type, dry, oily. It has been found that for both concrete and asphalt pavement, it is the wet condition of the surface which produces more noise than other two types. Although the difference between sound levels for dry and wet condition is only about (1-2) dB (A) and that for oily surface is about (3-4) dB (A). In a nutshell it is not wrong to say that wet condition of a surface is noisier than other two and it's the oily condition which less noisy than other two.

6.4 Effect of tire wear on sound pressure level

Measurements have been taken for tread depth and corresponding sound pressure levels for different tires at constant speed 58 km/h and concrete pavement surface.

For tire A: ----

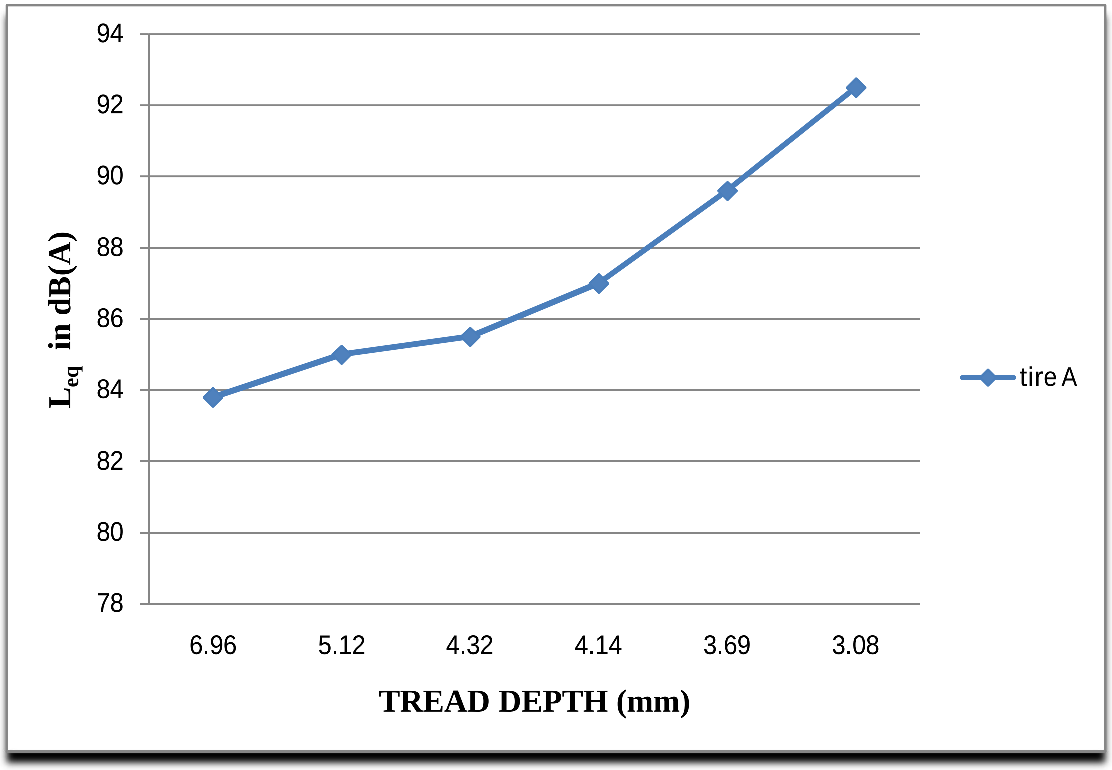


Figure 41 L_{eq} vs Tread Depth

For tire B: ---

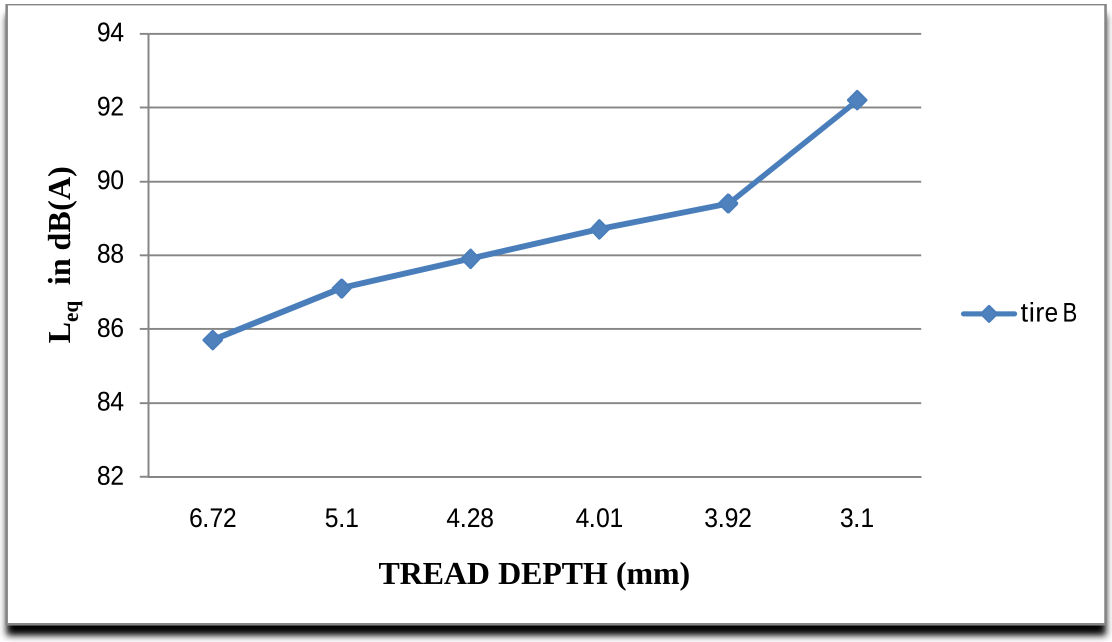


Figure 42 L_{eq} vs Tread Depth

For tire C: --

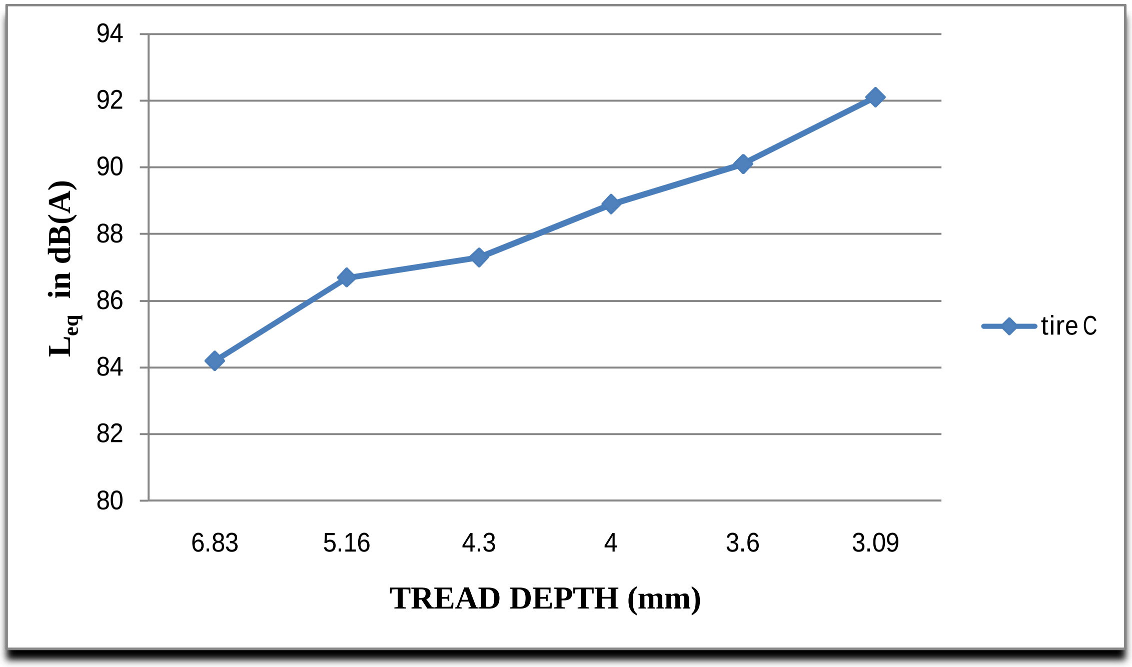


Figure 43 L_{eq} vs Tread Depth

It is observed that wearing of tire increases the sound pressure level. Data being plotted for three tires of different tread pattern type and it has been found that with the decrease in tread depth from approximately full to half, sound pressure level increases from approx. (84-86) dB (A) to (92-93) dB (A) which is about 8 dB (A), reason for this is somewhat due to the increase in contact area because of wear of tread.

6.5 Analysis for frequency spectrum

6.5.1 Frequency spectrum analysis for tire A on asphalt & concrete surfaces.

In this analysis, frequency spectrum is recorded in sound level meter at one-one octave band mode by rotating tire A on different conditions of asphalt & concrete pavement at varying speeds.

Asphalt dry: ---

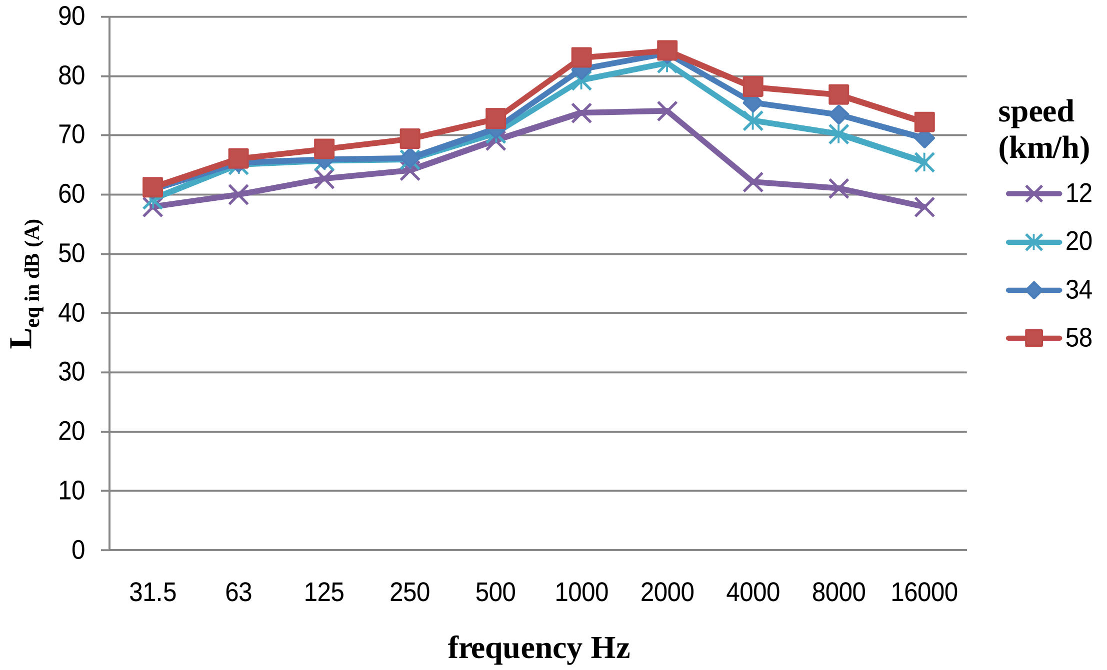


Fig. 44 L_{eq} vs Frequency

From the graph, it is observed that sound pressure level increases from 31.5 Hz to 2000 Hz frequency and then it start decreasing. Peak level is found at 2000 Hz frequency for all four speeds, maximum sound pressure level is 74.1 dB (A), 82.2 dB (A) , 83.8 dB (A) and 84.3 dB (A) at speeds of 12 km/h, 20 km/h, 34 km/h, 58 km/h. L_{eq} is not varying much between (31.5-500) Hz frequency band but at high frequencies (500-4000) Hz, it increases sharply and human ears are very sensitive at high frequencies, so it will create an annoying situation.

For asphalt wet: --

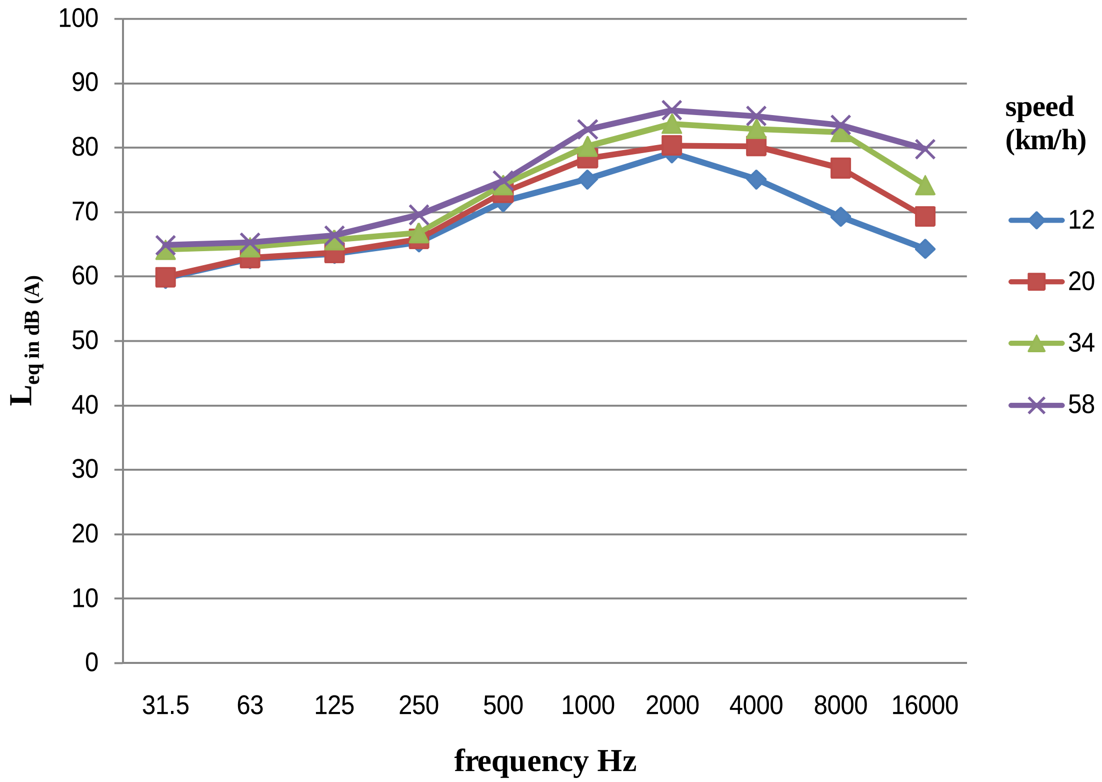


Fig. 45 L_{eq} vs Frequency

Now, for asphalt wet surface behavior of sound pressure level at all frequency is of same nature as that for asphalt dry. Sound pressure level increases from 31.5 Hz to 2000 Hz and decreases little from 2000 Hz to 8000 Hz as the difference between dB (A) levels is marginal. Sound pressure level at 2000 Hz is 85.8 dB (A) and that for 4000 Hz is 84.9 dB (A) at 58 km/h. L_{eq} level decreases sharply from (2000-16000) Hz at speed of 12 km/h.

For asphalt oily:

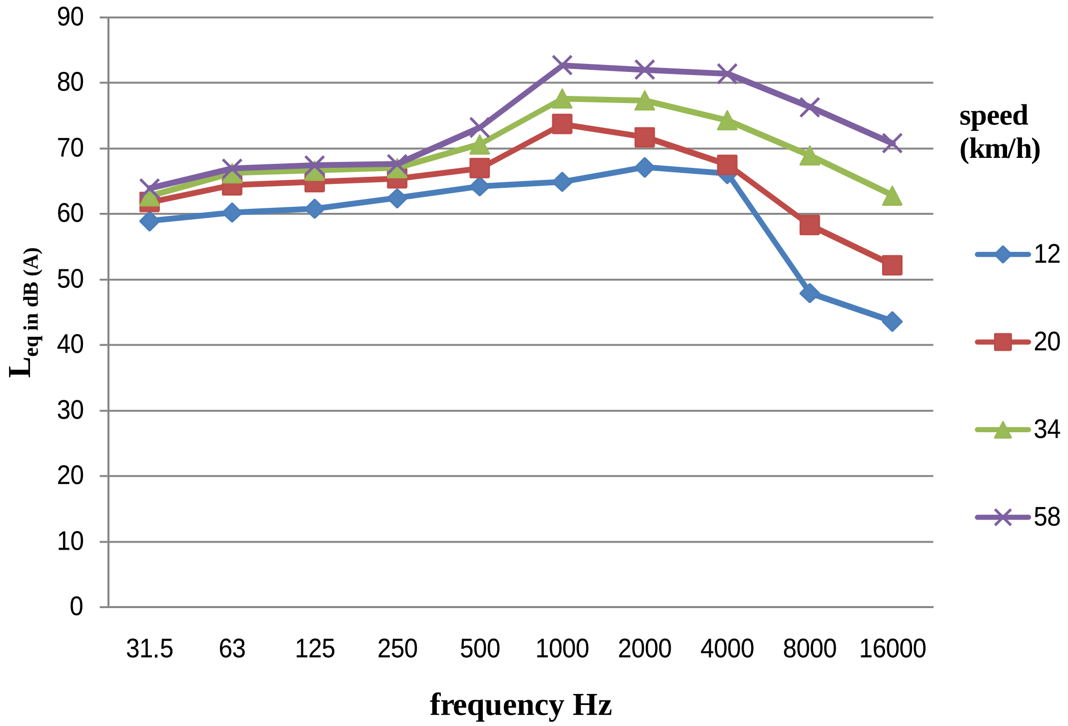


Fig. 46 L_{eq} vs Frequency

The behavior of asphalt oily surface is somewhat different than asphalt dry and wet as sound pressure level increases from 31.5 Hz to 1000 Hz frequency and then decreases up to 16000 Hz. Peak level is found at 1000 Hz, which is 82.7 dB (A). In case of asphalt dry and wet surfaces the peak levels are found at 2000 Hz frequency. For speed of 12 km/h, spl increase up to 4000 Hz frequency and then decreases sharply, which is not the case for other three speeds.

For concrete dry: ---

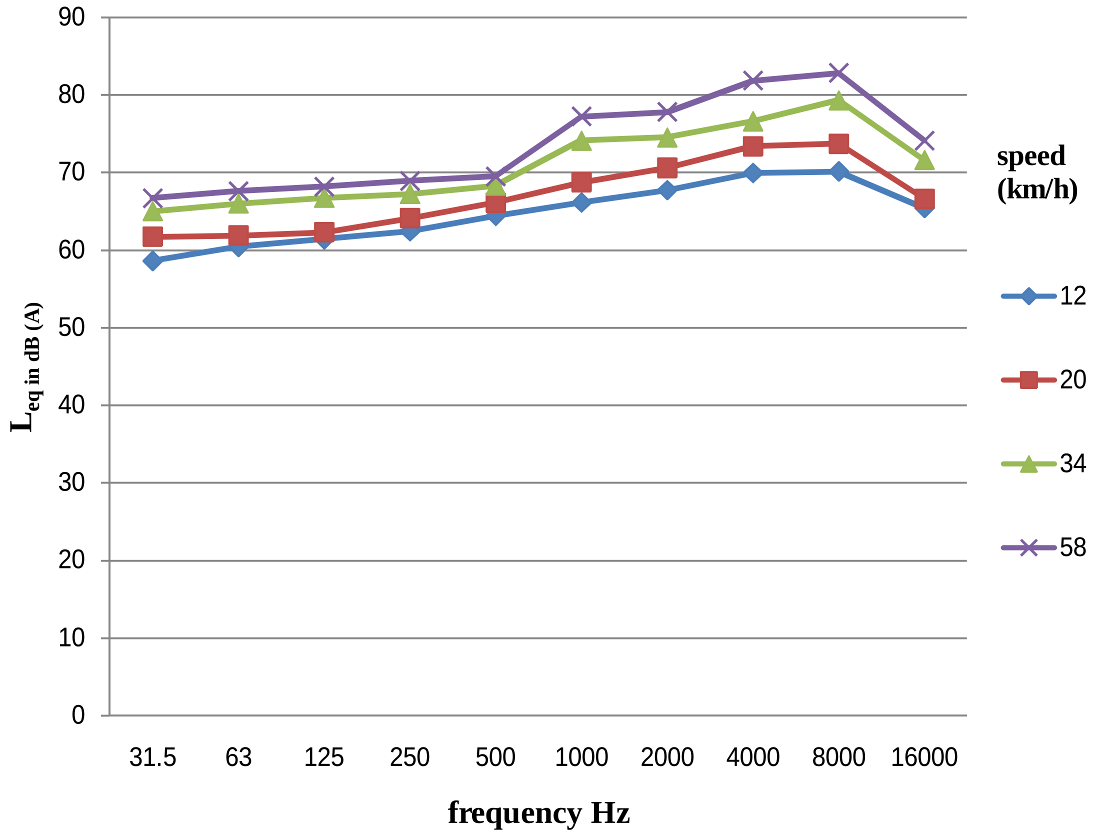


Fig. 47 L_{eq} VS Frequency

Sound pressure level increases from 31.5 Hz to 8000 Hz and then decreases in case of concrete dry surface at all speeds. Peak level is found at 8000 Hz. Maximum sound pressure is found out to be 82.8 dB (A) at 58km/h. Increase in the spl is gradual up to 500Hz for all speeds but then there is a sudden increase in spl for speeds of 34 km/h and 58 km/h then other two slow speeds.

For concrete wet: ---

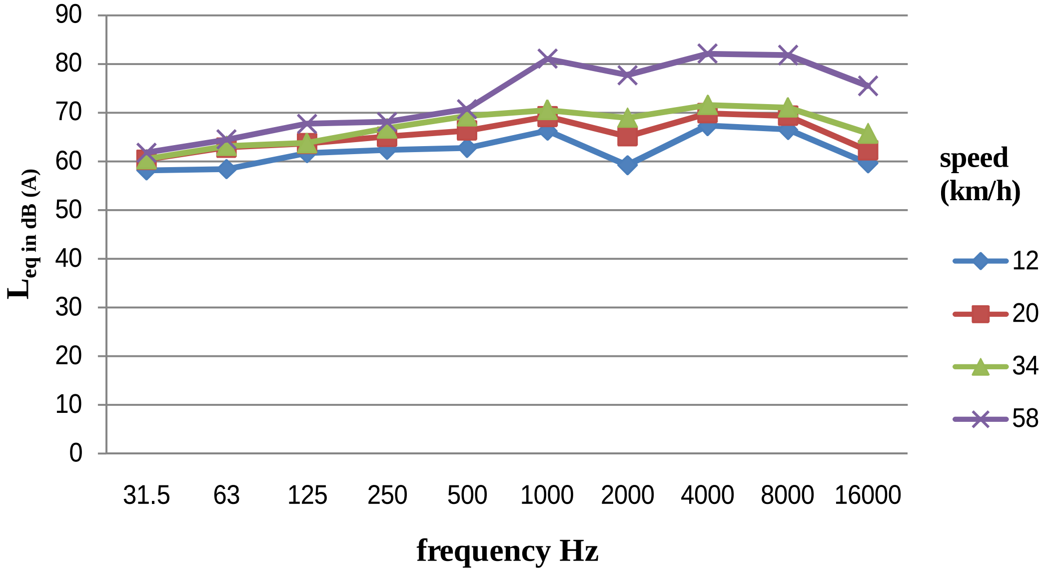


Fig. 48 L_{eq} VS Frequency

Sound pressure level increases from 31.5 Hz to 1000 Hz and then decreases at 2000 Hz , after that there is again an increase recorded from 2000 Hz to 4000 Hz which is at a peak level and slowly decreases again up to 16000 Hz. Maximum sound pressure level is found at 4000 Hz, which is 82.1 dB (A) at 58 km/h. Sound pressure level does not vary much and remains approximately equal from (31.5-16000) Hz.

For concrete oily: -

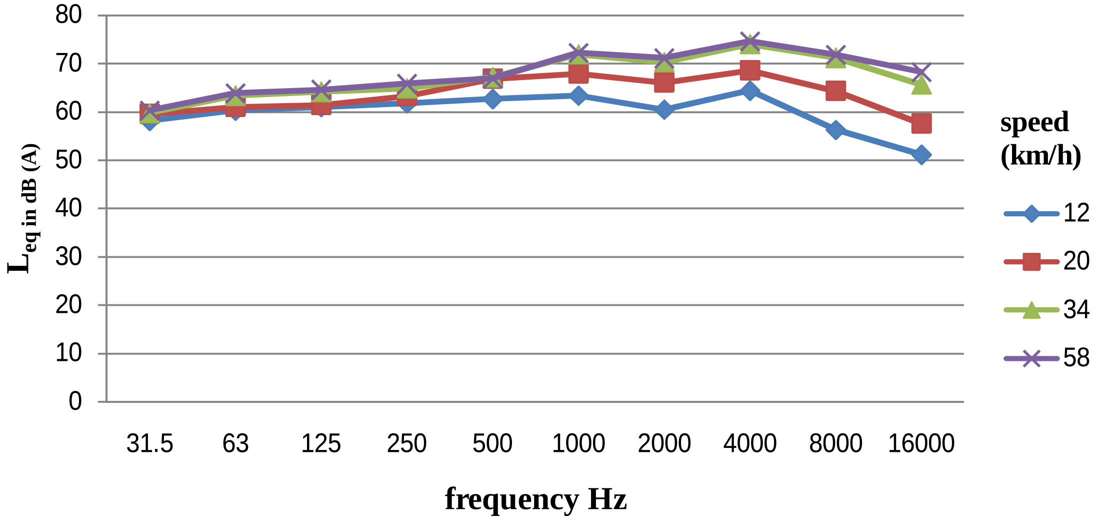


Fig. 49 L_{eq} VS Frequency

Sound pressure level increases from 31.5 Hz to 1000 Hz at all speeds, after that it decreases at 2000 Hz frequency and then again increases and touches the peak level between a frequency band of (31.5-16000) Hz. After sound pressure level again decreases for 8000 and 16000 Hz frequencies. Peak level is found at 4000 Hz, which is 74.6 dB (A) at 58 km/h.

6.5.2 Frequency spectrum analysis for tire B on asphalt & concrete surfaces:

Frequency spectrum is recorded in sound level meter at one-one octave band mode by rotating tire B on different conditions of asphalt & concrete pavement at varying speeds.

Asphalt dry:

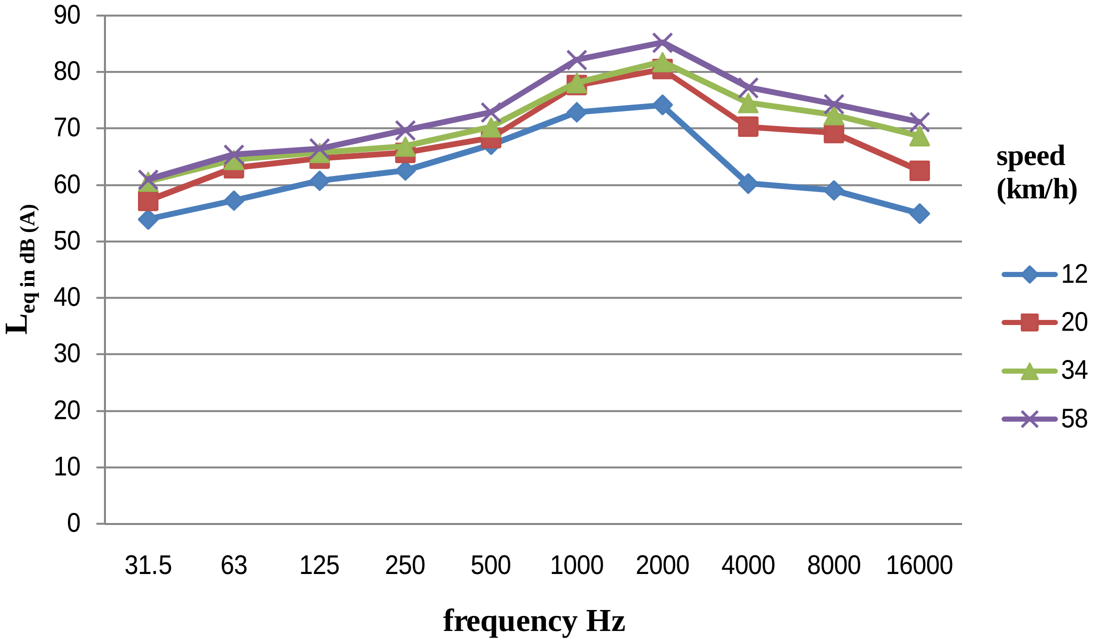


Fig. 50 L_{eq} VS Frequency

Sound pressure level increases from 31.5 Hz to 2000 Hz at all speeds, after that it start decreasing. There is less variation in spl at low frequencies than at higher frequencies at different speeds. Peak level is found at 2000 Hz frequency for all speeds. At 58km/h peak level is 85.2 dB (A).

Asphalt wet:

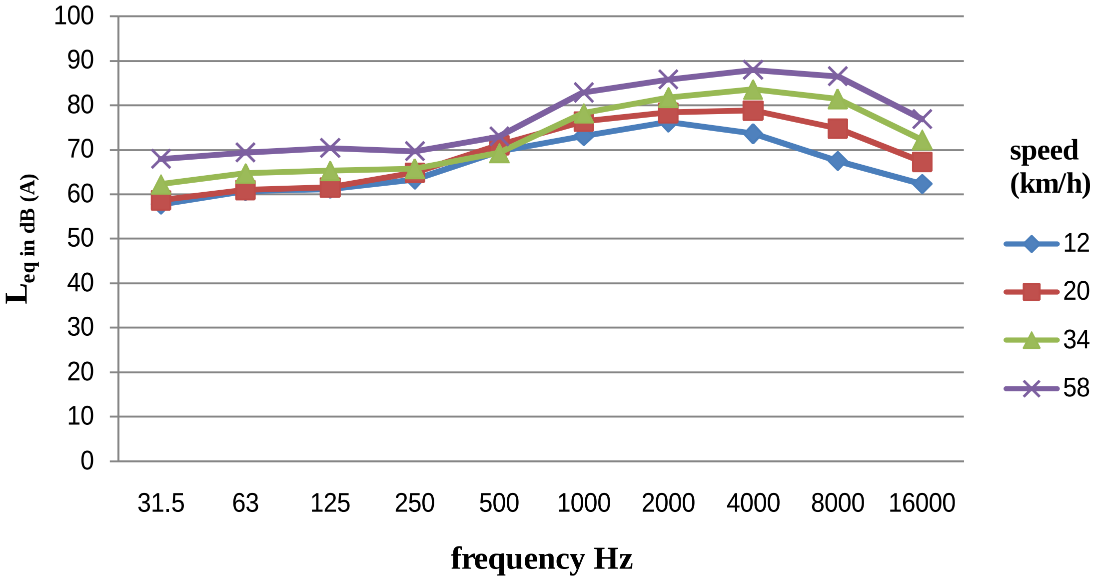


Fig. 51 L_{eq} VS Frequency

Sound pressure level is increasing from (31.5-4000) Hz at all speeds except for 12km/h. spl is almost constant up to 250 Hz at all speeds. Sound pressure level increases up to 2000 Hz for speed of 12 km/h but for all other speeds increase is up to 4000 Hz. After 4000 Hz, sound pressure level decreases gradually. Peak level for 12 km/h is found at 2000 Hz and for all other speeds, peak level is found at 4000 Hz.

Asphalt oily:

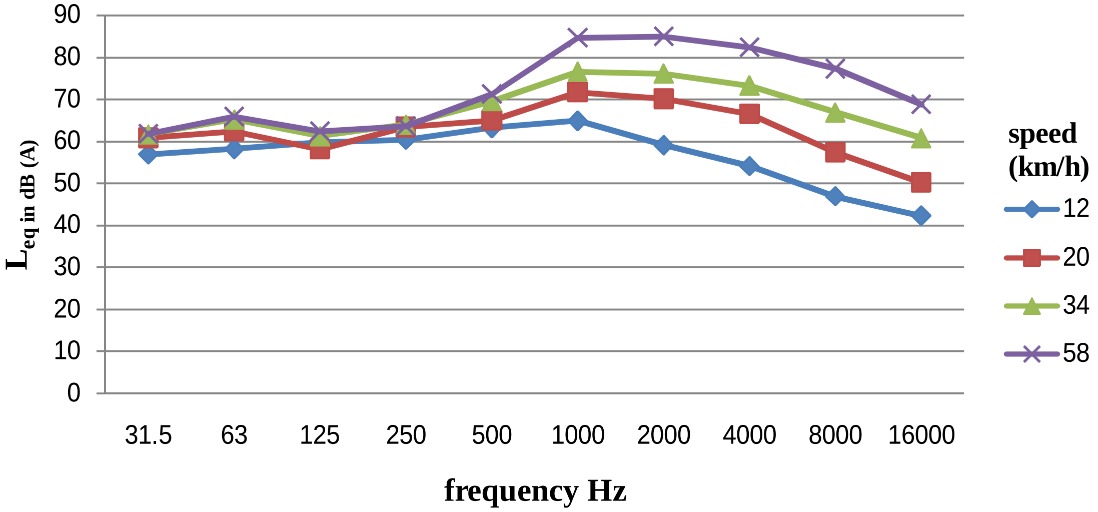


Fig. 52 L_{eq} VS Frequency

Sound pressure level increases first from (31.5- 63) Hz then there is a decrease in spl up to 125 Hz and then again there is an increase in spl from (125-1000) Hz, after 1000 Hz spl decreases gradually for all speeds. Variation in spl is more at higher frequencies (1000-16000) Hz, but very much less at low frequencies (31.5-500) Hz. Peak levels are found at 1000 Hz and the maximum level of L_{eq} at 58 km/h for 1000 Hz is 84.7 dB (A)

Concrete dry :

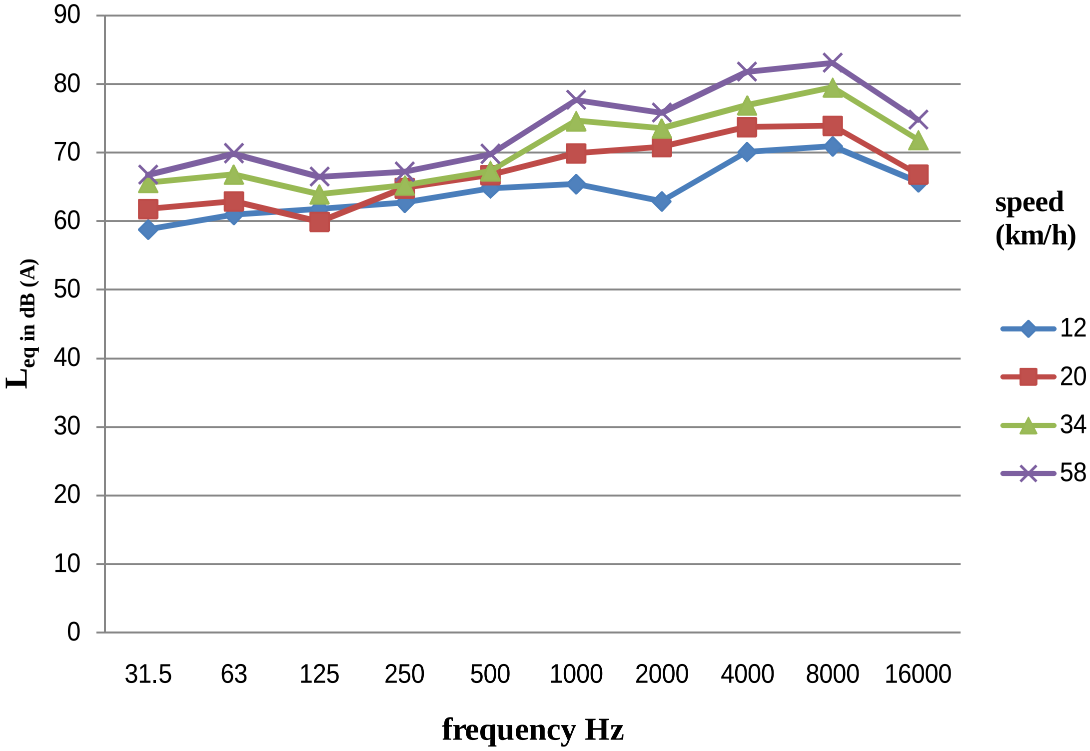


Fig. 53 L_{eq} VS Frequency

Sound pressure level is first increases from (31.5-63) Hz at all speeds then decreases at 125 Hz for all speeds except for the speed of 12 km/h. After 125 Hz, spl again starts increasing for all speeds up to 1000 Hz. At 250 Hz and 500 Hz, spl is almost same for speed of 20km/h and 34 km/h. There is a decrease in spl at 2000 Hz at all speeds although the decrease is small at 20 km/h speed. Again, spl increases from 2000 Hz to 8000 Hz, which is peak level for all speeds. Maximum spl found at 8000 Hz for speed of 58 km/h is 83.1 dB (A)

Concrete wet:

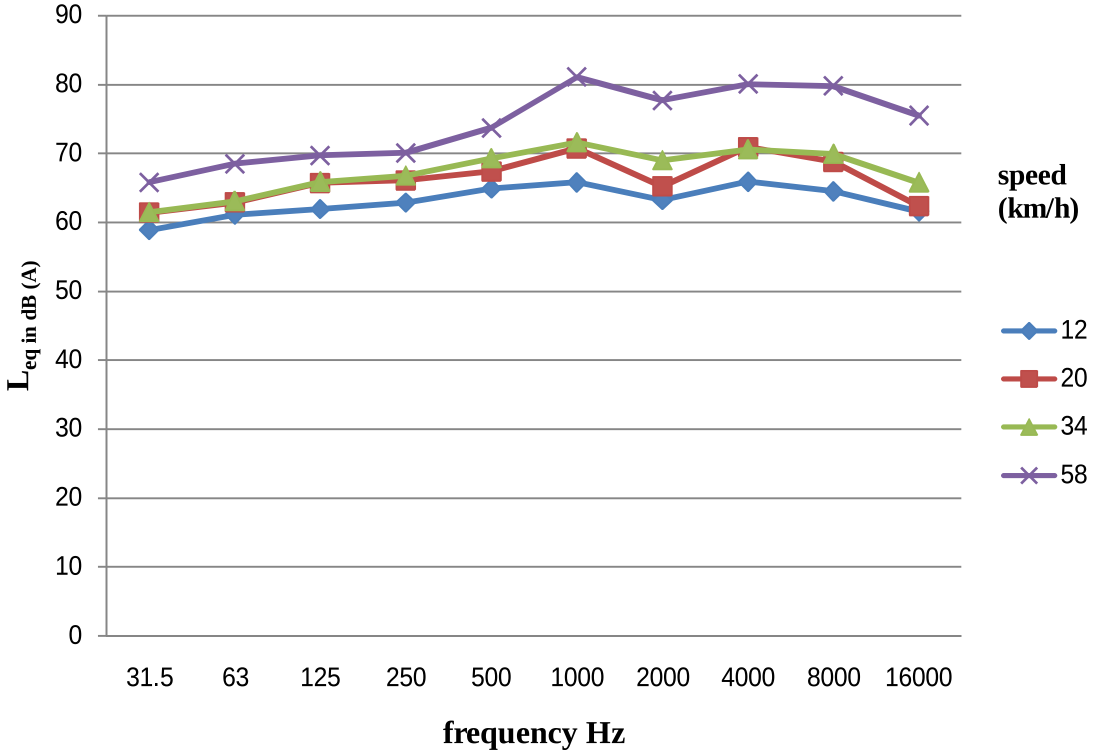


Fig. 54 L_{eq} VS Frequency

Sound pressure level increases at all speeds from (31.5-1000) Hz then decreases at 2000 Hz and then again increases from (2000-4000) Hz. Sound pressure level again decreases gradually from (4000-16000) Hz. Sound pressure level varies less for all frequencies between speeds of 12 km/h, 20km/h, 34km/h than between speed of 58km/h and 34 km/h.. Peak level is found at 4000 Hz at all speeds. At speeds of 20km/h and 34 km/h, spl is almost same from (31.5-16000) Hz.

Concrete oily:

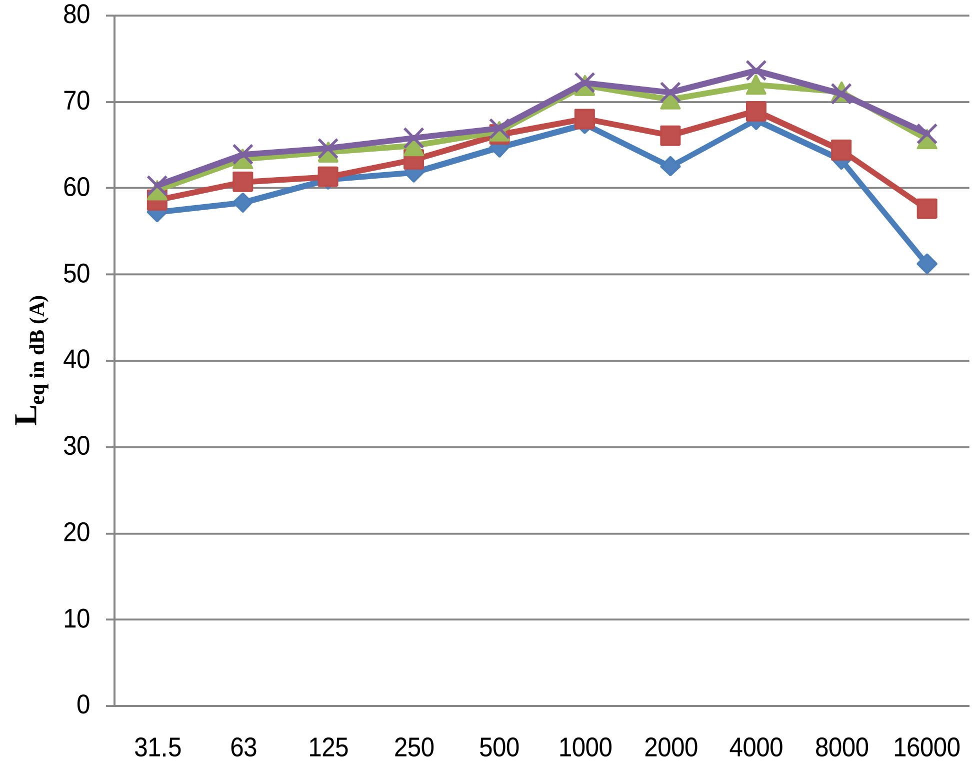


Fig. 55 L_{eq} VS Frequency

Sound pressure level is showing same kind of behavior as that for concrete wet surface but here spl is almost same at 31.5 Hz, 500 Hz for all speeds and at 125 Hz, 1000 Hz, 4000 Hz for 12 km/h and 20 km/h speeds. There is a minor variation in spl at speeds of 34 and 58 km/h between frequency bands of (31.5-16000) Hz. Peak level is found at 4000 Hz.

6.6.3 Frequency spectrum analysis for tire C on asphalt & concrete surfaces:

Asphalt dry:

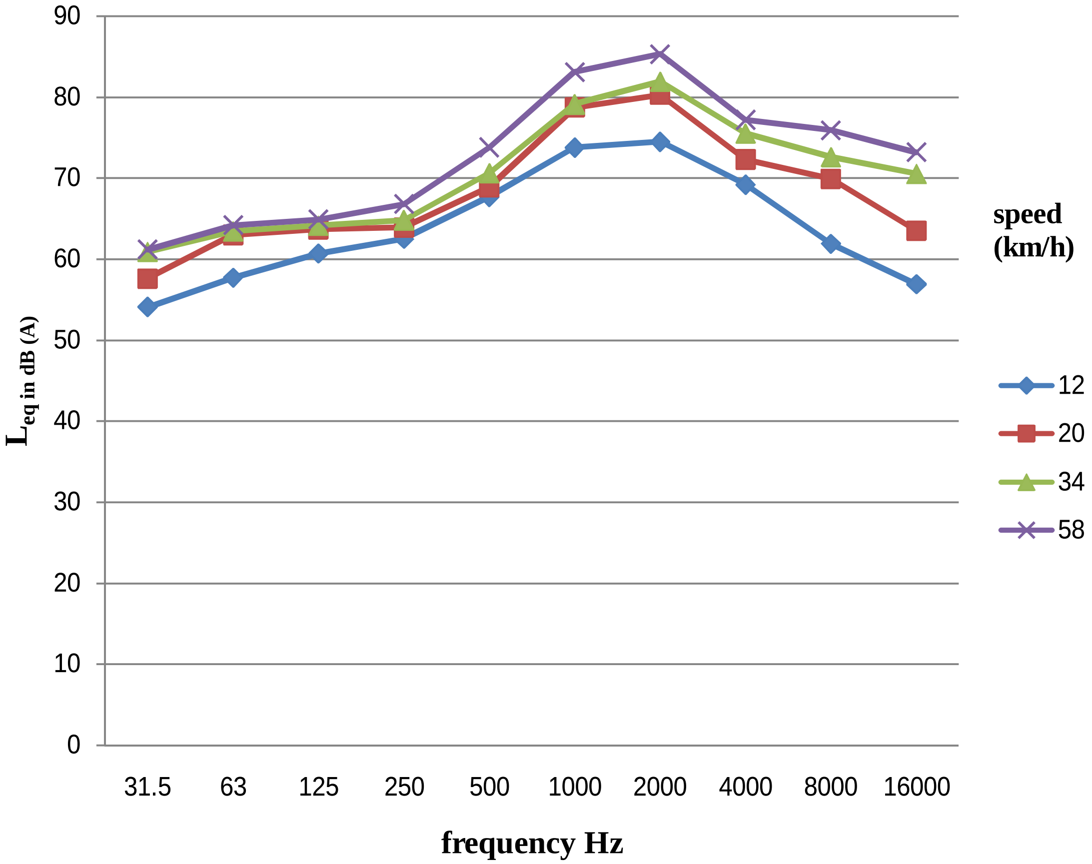


Fig. 56 L_{eq} VS Frequency

Sound pressure level is increasing first from (31.5-2000) Hz and then decreases at all speeds. Variation in spl is very less up to 2000 Hz between 20 and 34 km/h speeds. Sound pressure level is very much near at 31.5 Hz at speeds of 34 and 58 km/h. Peak level is found at 2000 Hz at all speeds. Peak value at 58 km/h is 85.3dB (A).

Asphalt wet:

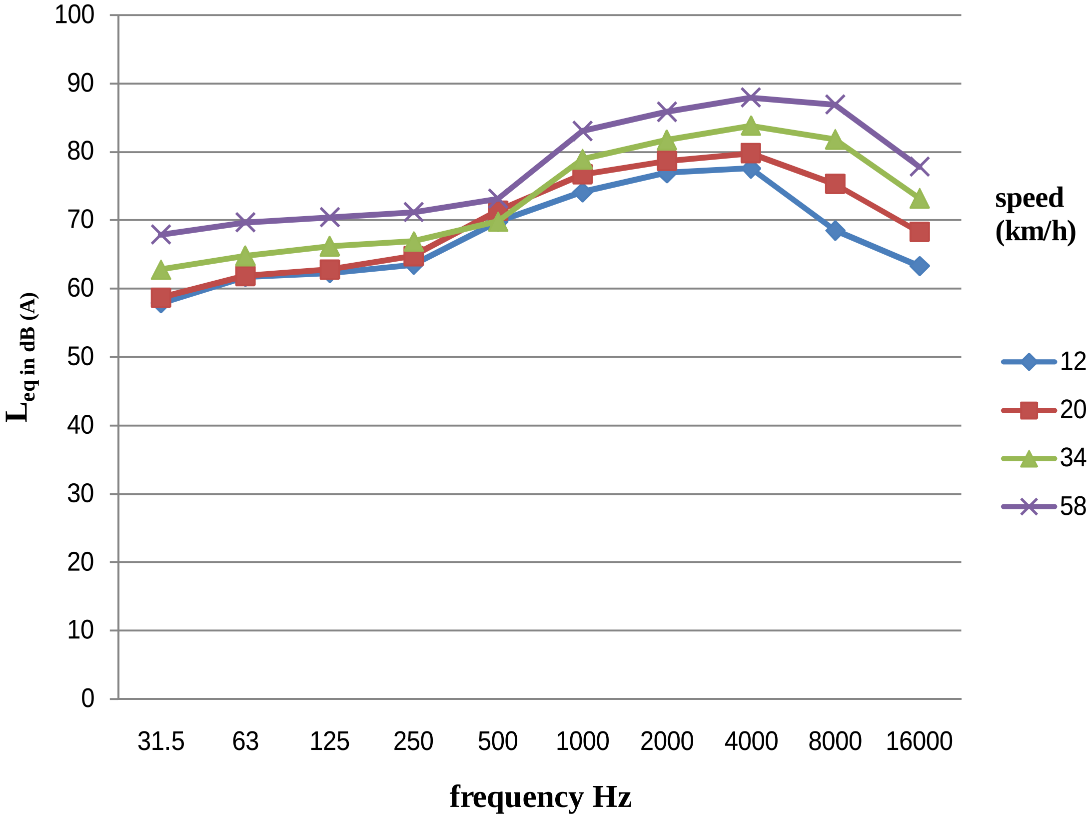


Fig. 57 L_{eq} VS Frequency

In case of asphalt wet surface, although spl is increasing from (31.5-4000) Hz at all speeds but the increase is almost constant up to 500 Hz then there is a steep increase at 58 km/h speed and at all other speeds the increase is gradual from (500-1000) Hz. From 4000 Hz to 16000 Hz, spl decreases.

Asphalt oily:

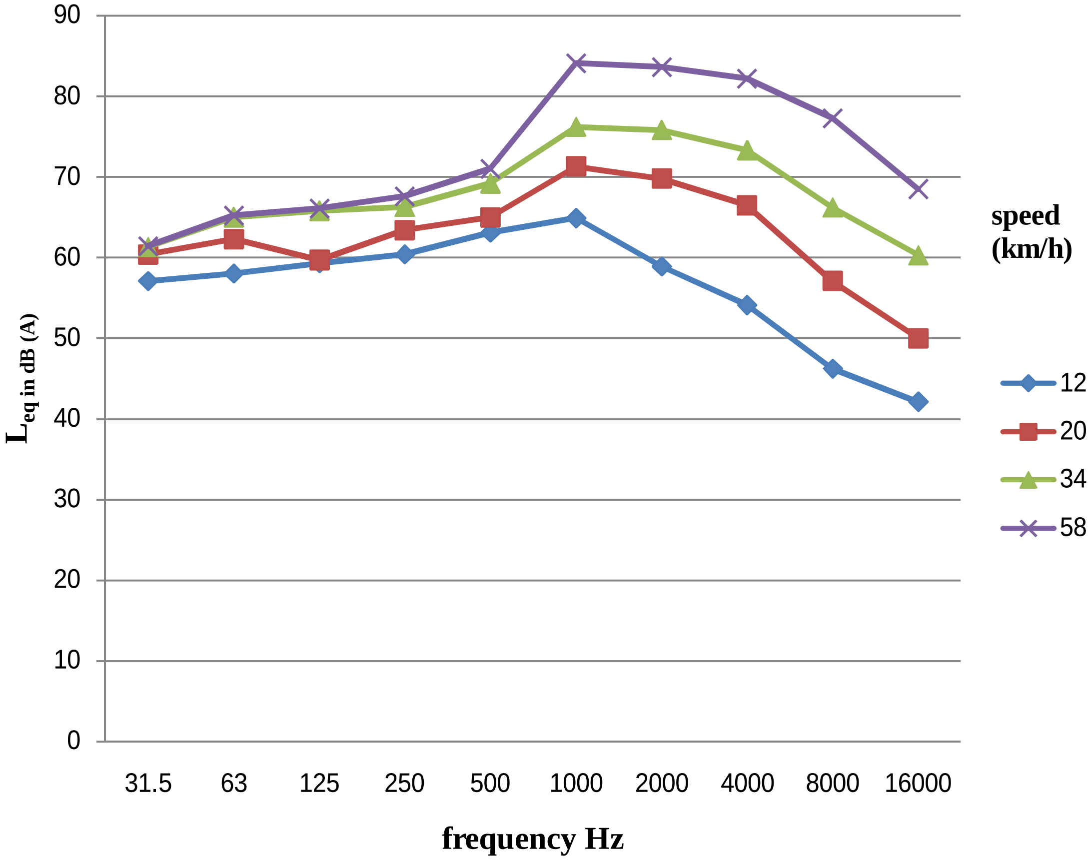


Fig. 58 L_{eq} VS Frequency

Sound pressure level is increasing gradually up to 500 Hz, after which there is steep increase up to 1000 Hz and then decreases up to 16000 Hz at all speeds but at 20 km/h speed there is a decrease in spl at 125 Hz and almost having the same level as that of the spl at 12 km/h speed. Spl is very near from 31.5 Hz to 125 Hz for speeds of 34 and 58 km/h. Peak level is found at 1000 Hz for all speeds.

Concrete dry:

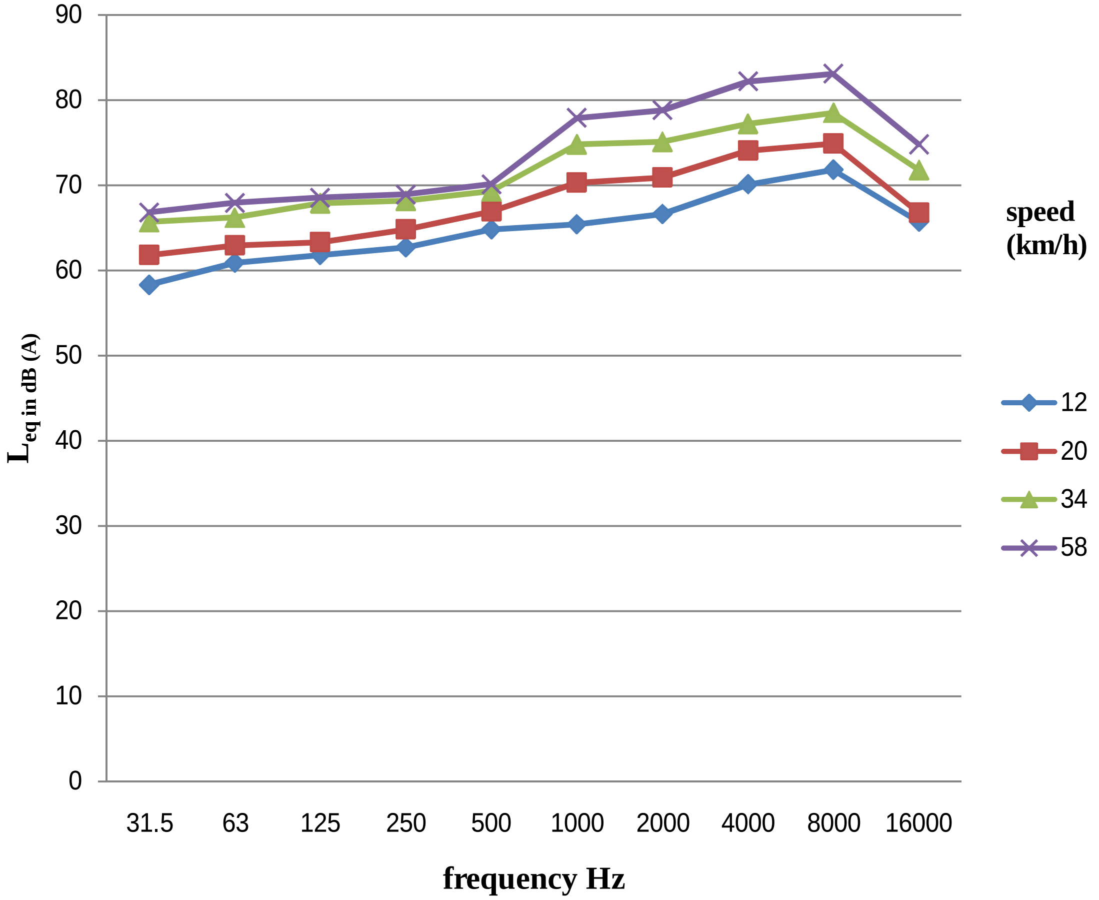


Fig. 59 L_{eq} VS Frequency

For concrete dry surface, spl is increasing up to 8000 Hz and then decreases. Increase is gradual up to 500 Hz but steep at 1000 Hz. Spl remain constant from 1000 Hz to 2000 Hz at all speeds. Spl is very close at 500 Hz for all speeds. Variation in spl is less at 125 Hz and 250 Hz for speeds of 34 and 58 km/h. Peak level is found out at 8000 Hz.

Concrete wet:

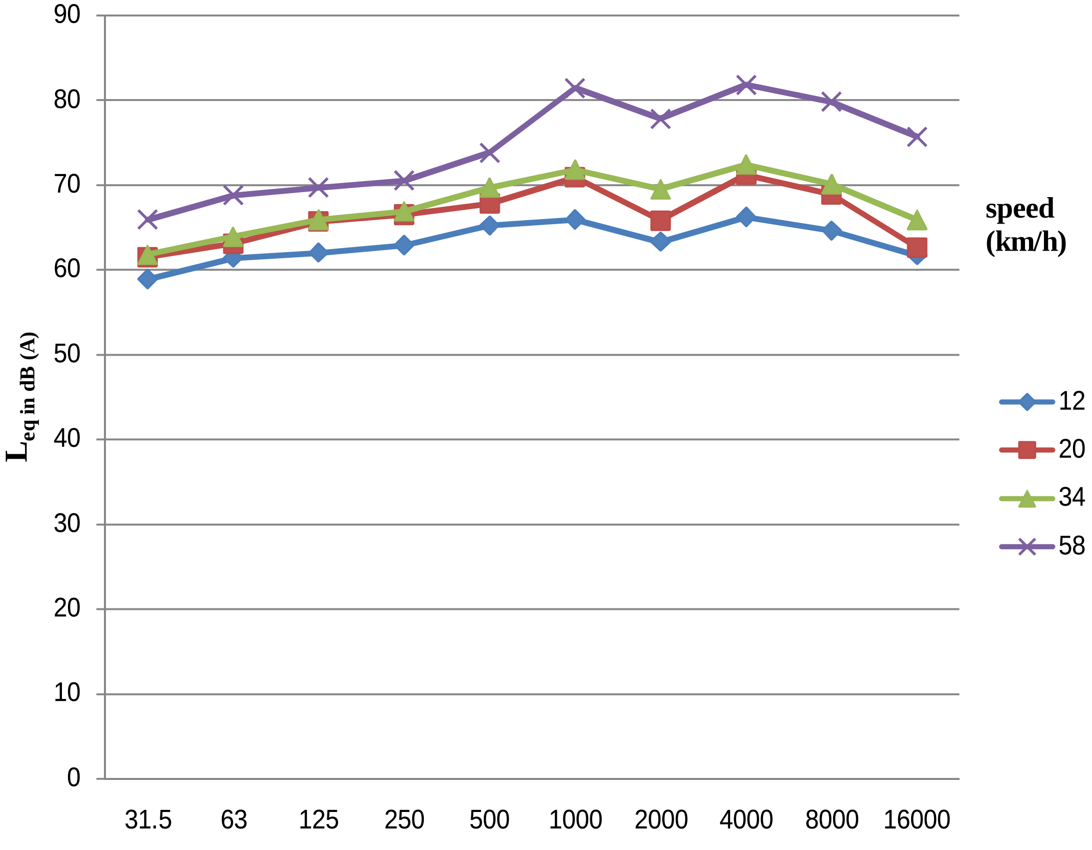


Fig. 60 L_{eq} VS Frequency

For concrete wet surface, spl increases up to 1000 Hz, increase is sharp from 500 Hz to 1000 Hz at 58 km/h speed and then there is a decrease is spl from 1000 Hz to 2000 Hz after that spl again increases and reaches at the peak level. Peak level is found out at 4000 Hz for all speeds. Frequency spectra remain very close for speeds of 20 and 34 km/h.

Concrete oily:

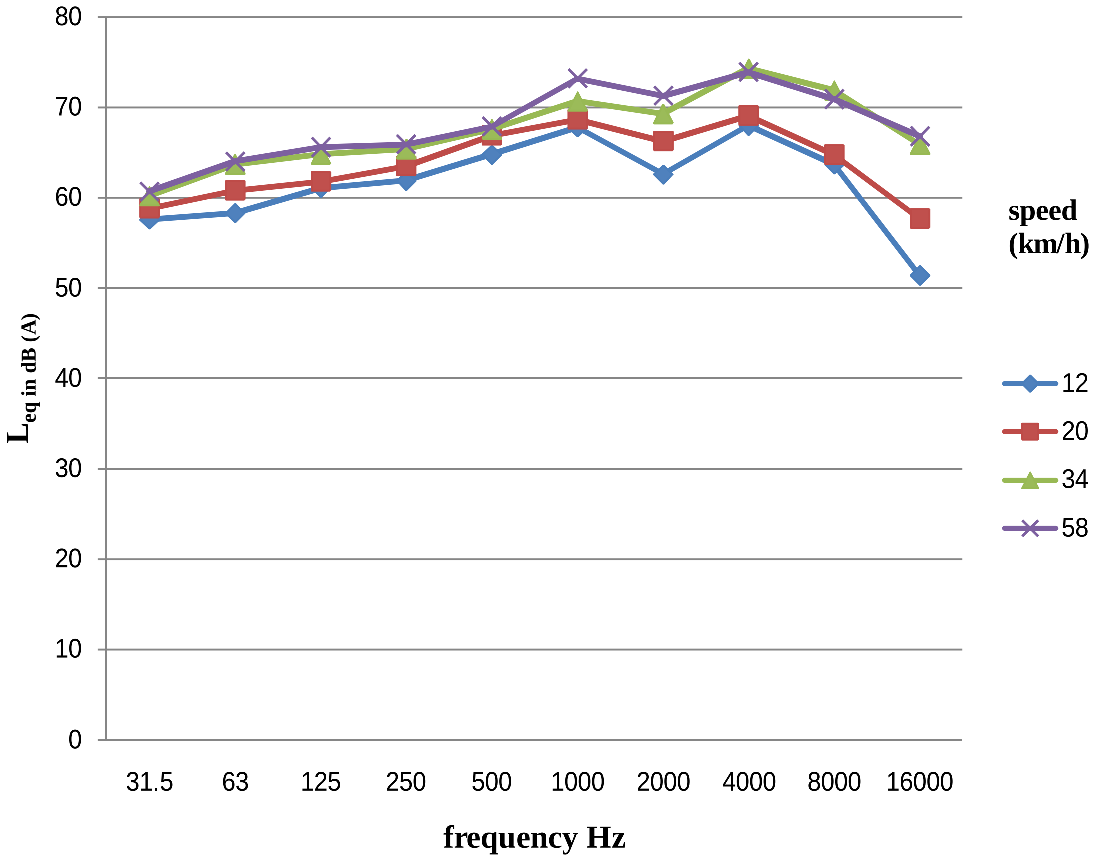


Fig. 61 L_{eq} VS Frequency

For concrete oily surface, spl increases up to 1000 Hz then decreases at 2000 Hz, after that again there is an increase in spl at 4000 Hz and finally decreases for all speeds. Now, it has been found that variation in spl is very less at 31.5 Hz, 250 Hz for all speeds and from 31.5 Hz to 500 Hz for 34 and 58 km/h speeds. Also, there is a decrease in spl at 2000 Hz for all speeds. Peak level is found at 4000 Hz.

FINDINGS: ----

- Sound pressure level for tire A, tire B and tire C at max speed of 58 km/h is found out to be 84.3 dB (A), 87.5 dB (A), 88.2 dB (A) for concrete pavement and 89.9 dB (A), 88.4 dB (A), 88.9 for asphalt pavement respectively.
- Sound pressure level increases with increase in speed for all kind of tread patterns and pavements. Sound pressure level for tire A increases from 78.3 dB (A) to 89.9 dB (A) when the speed is increased from 12 km/h to58 km/h for asphalt pavement. For concrete pavement, with the increase in speed from 12 km/h to 58 km/h, sound pressure levels increases from 72.1 dB (A) to 84.3 dB (A) respectively.
- Sound pressure level for tire B increases from 76.5 dB (A) to 88.4 dB (A) when the speed is increased from 12 km/h to58 km/h for asphalt pavement and for concrete dry pavement for same speed increase the sound level increase is 73.1 dB (A) to 87.5 dB (A). For tire C on asphalt dry pavement at speeds 12 km/h, 20 km/h, 34km/h, 58 km/h, sound pressure levels are 77.9 dB (A), 84.3 dB (A), 86.7 dB (A), 88.9 dB (A) and on concrete dry pavement for same speed sequence, sound pressure levels recorded are 75.2 dB (A), 77.5 dB (A), 84.6 dB (A), 88.2 dB (A) respectively.
- Sound pressure level vary with the change in surface conditions as for asphalt dry, wet and oily conditions, sound pressure levels at maximum speed of 58 km/h for tire A are 89.9 dB (A), 90.3 dB (A), 87.2 dB (A) and for concrete surface conditions of dry, wet, oily, sound pressure levels are 84.3 dB (A), 86.6 dB (A), 82.3 dB (A) respectively.
- Sound pressure level increases with the decrease in tread depth. Sound pressure level for tire A at maximum tread depth of 6.96 mm as recorded as 83.8 dB (A) and with 50% decrease of tread depth i.e at 3.08 mm, sound pressure level reaches to 92.5 dB (A).

Frequency spectrum analysis: ---

For tire A:

- Sound pressure level increases from 31.5 Hz to 2000 Hz frequency for asphalt dry and asphalt wet surface at all speeds. Peak level is found at 2000 Hz, which is 84.3 dB (A) at 58 km/h. and for asphalt wet sound pressure level is 85.8 dB (A).

- Peak level for asphalt oily surface is found at 1000 Hz frequency having a value of 82.7 dB (A).
- Sound pressure level increases from 31.5 Hz to 8000 Hz for concrete dry surface. Peak level is found at 8000 Hz, which is 82.8 dB (A) at 58 km/h.
- For concrete wet and concrete oily conditions, peak level is found at 4000 Hz frequency. Maximum sound pressure level for concrete wet surface is 82.1 dB (A) and for concrete oily, it is 74.6 dB (A).

For tire B:

- At asphalt dry surface, Peak level is found at 2000 Hz frequency for all speeds. At 58km/h peak level is 85.2 dB (A). At asphalt wet surface, Peak level for 12 km/h is found at 2000 Hz and for all other speeds, peak level is found at 4000 Hz.
- At asphalt oily surface, Peak levels are found at 1000 Hz and the maximum level of L_{eq} at 58 km/h for 1000 Hz is 84.7 dB (A)
- At concrete dry surface, at 250 Hz and 500 Hz frequency, spl is almost same for speed of 20km/h and 34 km/h. Maximum spl found at 8000 Hz for speed of 58 km/h is 83.1 dB (A).
- At concrete wet surface, peak level is found at 4000 Hz at all speeds. At speeds of 20km/h and 34 km/h, spl is almost same from (31.5-16000) Hz.
- For concrete oily surface, spl is almost same at 31.5 Hz, 500 Hz for all speeds and at 125 Hz, 1000 Hz, and 4000 Hz for 12 km/h and 20 km/h speeds. There is a minor variation in spl at speeds of 34 and 58 km/h between frequency bands of (31.5-16000) Hz. Peak level is found at 4000 Hz.

For tire C:

- At asphalt dry surface, variation in spl is very less up to 2000 Hz between 20 and 34 km/h speeds. Peak level is found at 2000 Hz at all speeds. Peak value at 58 km/h is 85.3dB (A). For asphalt wet surface, peak level is found at 4000 Hz. Variation in spl is very much less from 31.5 Hz to 125 Hz at speeds of 12 and 20 km/h.
- At asphalt oily surface, peak level is found at 1000 Hz for all speeds.

- At concrete dry surface, spl remain constant from 1000 Hz to 2000 Hz at all speeds. Peak level is found out at 8000 Hz.
- At concrete wet surface, peak level is found out at 4000 Hz for all speeds Frequency spectra remains very close for speeds of 20 and 34 km/h.
- At concrete oily surface, variation in spl is very much less at 31.5 Hz, 250 Hz for all speeds. Peak level is found at 4000 Hz.

CHAPTER 7

CONCLUSION AND FUTURE SCOPE

7.1 Conclusion

The object of the present work is to study the effect of different operating parameters i.e speed, surface type, tread patterns and tread wear on sound pressure level generated during the tire/road interaction. It concludes the following points:

- Sound pressure level is effected by the change in the tread pattern as for tire A the sound pressure level is different from tire B and tire C for both pavement types at max speed of 58 km/h.
- Sound pressure level increases with the increase in speed for both concrete and asphalt pavements. With an increase in speed from 12- 58 km/h, there is about 11 dB (A) increase in sound pressure level for asphalt pavement and about 8 dB for concrete pavement.
- Sound pressure level is affected by surface type and different conditions of a surface. Sound pressure level for tire A for asphalt dry, asphalt wet, asphalt oily is 89.9 dB (A), 90.3 dB (A), 87.2 dB (A) and for concrete dry, wet and oily sound pressure level is 84.3 dB (A), 86.6 dB (A), 82.3 dB (A). These dB (A) values are for maximum speed of 58km/h.
- Wet condition for both the surfaces is noisier than other two and oily condition is least noisy.
- Tire wear also have an effect on sound pressure level as with the increase in wear rate of tire i.e decrease in tread depth sound pressure level increases. For tire A , at tread depth 6.96 mm, sound pressure level is 83.8 dB (A) and at 3.10 mm approximately more than half wear out of tire sound pressure level reached to 92.5 dB (A). So, there is a 9 dB (A) increase in sound pressure level from full to half wear of the tread.

Frequency spectrum analysis:

- For all speeds, sound pressure level increases from 31.5 Hz to 2000 Hz for asphalt dry and asphalt wet surface and peak level is found at 2000 Hz, which is 84.3 dB (A) at 58 km/h. and for asphalt wet sound pressure level is 85.8 dB (A).
- For asphalt oily surface, peak level is found at 1000 Hz having sound pressure level of 82.7 dB (A).
- Sound pressure level for concrete dry surface increases from 31.5 Hz to 8000 Hz, for concrete wet and oily surface it increases up to 4000 Hz. Peak level for concrete dry surface is found at 8000 Hz having sound pressure level of 82.8 dB (A) and for concrete wet & oily surface peak level is found at 4000 Hz having sound pressure level of 82.1 dB (A) & 74.6 dB (A) at 58 km/h.
- It has been found that change in the tread pattern has no effect on frequency spectra as tire A, B and C has shown almost same kind of frequency spectrum for different surface conditions and different vehicle speeds.

7.2 Future Scope:

- The present work can be elaborated further for studying the factors or various mechanisms involved during the effect of different operating parameters on sound pressure level, so that tire/ road interaction noise can be reduced.
- Better tread patterns can be designed which will produce less noise during running.
- Surface characteristics can be studied deeply, so that a surface can be made which would be quieter.
- Tires should be made from a material having high durability and less wearing rate.
- Mechanism involved during tire/road interaction which are responsible for generating peak levels at high frequencies between 1 kHz to 8 kHz at all speeds for different surfaces will have to be studied and work need to be done for reducing these, so that overall tire/road interaction can be reduced.
- Present work is totally limited to two-wheeler tires so it could be extended to various tires of different sizes.

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