Transportation Noise and Vibration-Sources, Prediction, and Control

Sharad R.Mahajan, Rahul D.Rajopadhye

Abstract*— A major part of the world energy consumption is related to transportation. The extensive use of automobile vehicles causes harmful effects on the surrounding environment. The 20-25% of the total greenhouse gas emission in industrialized countries is generated by transportation. Vehicle noise (NVH) is becoming the most important factor to customers. The transportation noise is one of the major sources of noise exposure in residential areas and causes substantial annoyance during night. Noise is unwanted sound; vibration is the oscillation that is typically felt rather than heard. Harshness is generally used to describe the severity and discomfort associated with unwanted sound and/or vibration, especially from short duration events. Considering this, many countries have implemented legislation limiting the noise levels in residential areas. For today's compact era the trend towards compact power units is substantially increased resulting in components/vehicles running at higher level of noise and vibrations.Vehicle manufacturers work with noise and vibration control to fulfil legislation demands and to meet customer requirements. The exterior noise control work is mainly motivated by legislation demands while interior noise and vibration control work is motivated by driver and passenger noise and vibration comfort requirements.The motivation for reducing traffic noise is that it is the most important environmental noise source in Europe and in the rest of the world. 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 .

***Keywords*-Transportation, Vehicle noise, vibrations, Vibration isolation, surface pavement.**

I. INTRODUCTION

Sound is a propagating type of energy traveling through a medium with particular velocity. The unwanted sound is noise. Vibration is the variation or displacement of a body with respect to specific reference position with time when displacement is alternatively greater or smaller than reference. Harshness is defined as vibration perceived actually and audibly produced by interaction of the tyre with road irregularities and vibrations of the structure and components. The acceptance criterion of any vehicle in terms of user comfort depends on the vehicle interior noise and vibration characteristics. In the highly competitive global automotive market the need to develop high quality products and achieve product excellence in all areas to obtain market leadership is critical.

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, tyre-road noise dominates the car exterior noise generation. For heavier vehicles the engine noise is dominant under most conditions.

II. INTERNATIONAL AND INDIAN STANDARDS

Various international and Indian Standards for vehicles consider two types of noise measurement viz. pass by noise (PBN) and stationary Noise (SN).The oil thickness plays a major role in determining the engine's vibration characteristics. The acceptance criterion of any vehicle in terms of user comfort depends on the vehicle interior noise and vibration characteristics. The levels of sound energy and structural excitation inside the vehicle compartment measures the amount of annoyance in terms of quality and comfort. For vehicle interior noise identification and treatment, quantification of noise sources by determining the sound power contribution from each vehicle component, acoustic leakages inside the vehicle body panel, vibrations during gear shifting at lever and steering wheel vibrations needs to be identified, because interior noise in a vehicle has a major impact on customers perception of operation, performance and quality.

The development of personal transporting vehicles shows a tendency for lighter bodies and more power-intensive engines. Weight reduction and increased power requirements often have unfavorable effects on the vibratory performance, greatly increasing the vibration and noise levels.

III. NOISE FROM TRAFFIC

The sources of noise from traffic can be separated into two components.

- The first is generated by the engine exhaust system and transmission, and is the dominant source when traffic is not freely flowing, particularly from heavy vehicles which contribute a significant proportion of low frequency noise. Noise levels will vary primarily according to engine speed rather than vehicle speed.
- The second noise source component is generated from the interaction of tyres with the road surface and is the dominant noise source under free flow traffic conditions at moderate to high road speeds and contributes a significant proportion of high frequency noise. Noise levels will vary depending on vehicle speed, the road surface and whether the surface is wet or dry. (Fig.1 and Fig.2)

Thin metal parts and structures easily transmit noise when impacted or by natural resonance when excited by acoustic energy. Vibrating or resonating metal is a common noise problem in industrial and commercial

Manuscript received November, 2013.

Dr.Sharad R.Mahajan. Professor, Rajaram Shinde. College Of Engineering, ,Alore, Mumbai University, Chiplun ,India.

Shri. Rahul D.Rajopadhye, Automobile Dept., Mumbai University / Rajendra Mane College Of Engineering, Devrukh, India.

environments and one that OEM's must often take into consideration. These types of noise problems are often easily solved by applying damping material to these metal surfaces. Damping materials work by changing the natural vibration frequency of the vibrating surface and thereby lowering radiated noise and increasing the transmission loss of the material. Damping Compound and Vibration Damping Sheets, that convert ordinary sheet metal into damped metal - greatly reduces the tendency to transmit noise and vibration. This noise and vibration can be tamed by various solutions; the most popular in the car audio industry would be a mat or a spray application. The mat application will consist of thin squares or sheets, one side having an adhesive background. The adhesive background is layed and pressure rolled on. The spray will prove "dampening" in harder to get areas. The sound dampening will provide low road noise and quality listening experience. The most popular parts would be the doors, interior and truck area.

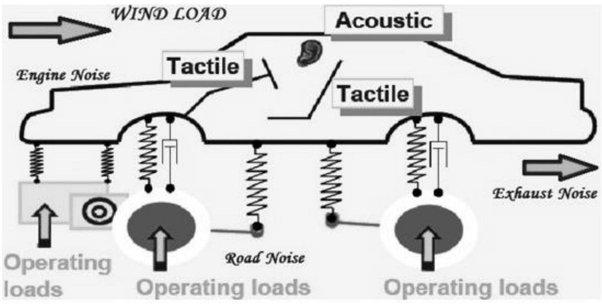

Fig.1. Noise Sources

Fig.2. Noise Sources

IV. UNITS

Interior noise in any vehicle reduces the users ride comfort. For today’s compact era the trend towards compact power units is substantially increased resulting in components /vehicles running at higher level of noise and vibrations.

The most fertile areas for roadway noise mitigation are in urban planning decisions, roadway design, noise barrier design, speed control, surface pavement selection and truck restrictions.

The definition of vibration is ‘low frequency disturbance producing physical movement in buildings or occupants’. It is the rolling of wheels on the road surface when passing over irregularities in the road that causes vibration. Vibration is expressed in terms of Peak Particle Velocities or PPVs. This is the maximum speed of movement of a point in the ground during passage of vibration.

V. NOISE SOURCES

Various noise sources in an automobile are induction noise, exhaust noise, noise from accessories, and noise radiation from engine sources. Induction noise is due to opening and closing of valves. In cylinder on opening the valve, the Inlet air column is set in to oscillation due to Intense pressure thump. Closing of the inlet valve produces forced undamped vibrations. Exhaust noise exists when exhaust valve opens and releases gas into exhaust system. Various accessories used generate unwanted sound. In this category engine fan is the main source of noise. It is used in addition to radiator for cooling, and operated by air during ride. Pressure fluctuations result in generation of noise. Transient vibrations are induced by periodic and a periodic distortion of engine due to combustion processes. Figure 2 shows Propagation of tyre noise of an automobile at frequency of 600 Hz. Alternating inertia loads and mechanical impacts of the engine mechanism produces noise. Often it is very difficult to sort out which force is the cause of excitation of engine structure. Table. 1 shows the percentage contribution of sources of the total noise.

TABLE I : PERCENT CONTRIBUTION OF SOURCES TO TOTAL NOISE

Sr.No.	Source	% Contribution
i.	Engine	22 to 30
ii.	Exhaust system	25 to 35
iii.	Intake system	05 to 15
iv.	Fan and cooling system	07 to 15
v.	Transmission	12 to 15
vi.	Tyres	09 to 15

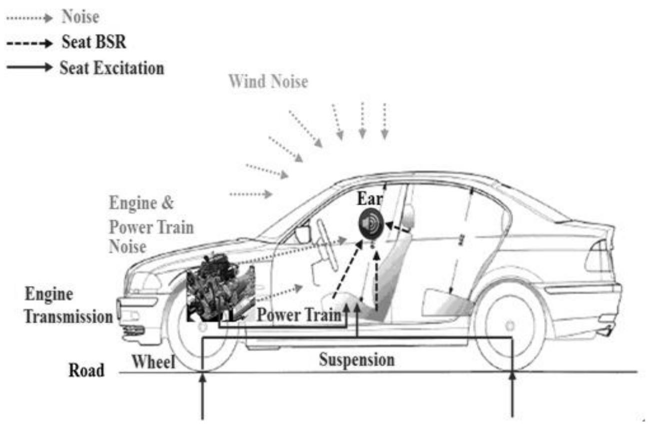

Fig..3. sources of noise from road traffic

VI. SOURCES

The sources of noise from road traffic can be separated into two components. The first is generated by the engine, exhaust and transmission and is the dominant noise source when traffic is not free flowing. (Fig.3)

This is particularly true for heavy vehicles, which contribute a significant proportion of low frequency noise. Noise levels will vary primarily according to engine speed rather than vehicle speed. The second noise source component is generated from the interaction of tyres with the road surface and is the dominant noise source under free flow traffic conditions at moderate to high road speeds and contributes a significant proportion of high frequency noise. Noise levels will vary depending on the vehicle speed, the road surface type and whether the surface is wet or dry. (Fig.4)

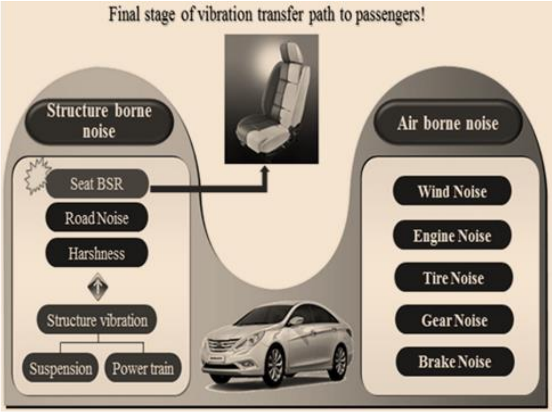

Fig..4 .vibration transfer path

The noise from a stream of traffic at a reception point at any one instant is an aggregation of noise from each of many vehicles at various distances. Among factors which influence a basic traffic noise level are traffic flow, speed and composition (percentage of heavy vehicles), road gradient and road surface characteristics. The noise level at a particular reception point will also be affected by other factors among which are distance from the noise source, the nature of the intervening ground surface and the presence of obstructions.

A. Engine:

Vibrations in engine are generated due to the reciprocating mechanism used for converting the energy into rotary motion. The forces producing the engine vibrations are: Combustion, Reciprocating and Rotational Forces. A downward force is generated during combustion stroke on the piston which due to geometrical construction of connecting rod and crankshaft generates a torque around crankshaft axis. Torsional vibrations are generated due to the torque variations. A multi-cylinder engine can be compared with a system of masses rotating on a single crankshaft in single and different planes. The primary & secondary forces as well as couples generate vibrations due to reciprocating unbalance. Significant inertia effects are generated due to small unbalance of rotating masses in high speed engines. Rotating unbalance generates unacceptable levels of vibrations and stresses in individual and supporting structures.

Engine noise is caused by various types of force generation within the engine and is transmitted to the radiating outer surfaces. The transmission path properties are determined by the vibration modes of the structure. The properties of the outer surface will also influence the sound radiation. Number of ways in which the final sound radiation may be influenced:

1) *Reduction at the source of combustion forces and mechanical forces.*
2) *Reduction of the vibration transmission between the sources and the outer surface.*
3) *Reduction of the sound radiation of the outer surface.*

B. Driveline Sources:

Noise and vibration in driveline are a consequence power transmission from engine to wheels.

Mechanical layout of front wheel drive and propeller shaft of rear wheel drive is the sources of noise and vibration in respective automobiles. The various sources are transmission gear noise, drive and propeller shaft, axle noise, tyre noise, aerodynamic noise, wind noise and interior noise. Generation of noise & vibrations from gears results due to improper bending dynamics of gear tooth and both torsional and bending characteristics of shafts. Propeller shaft generates excitation at elemental speeds. Due to large coupling angles, universal joints generate excitation. Also most of modern vehicles induct constant velocity coupling at the centre of two piece propeller shaft results into noise.

C. Axle noise:

Axle noise is due to response of rear axle to vibration generated by meshing action of the axle gear set. The so generated noise is annoying even at squat levels in passenger compartment of the vehicle. Tyre noise is due to tribology between tyre and road. Mechanics of tyre noise generation may be combination of squash vibration (primary noise source) exists due to rough road surface, tread squirm results lateral vibrations and generates noise spectra. Slick/aerodynamic noise is generated by chaotic flow of air around the tyre contributes to the tyre noise.

Fig .5(a) . Propagation of tyre noise of an automobile at frequency of 600 Hz

Tyre is excited by several means, which include non-uniform wear, radial or lateral run-out, road roughness, road surface irregularities, road surface discontinuities that induces impacts, bumps etc, which contribute to noise and vibration of automobiles.(Fig 5(a))

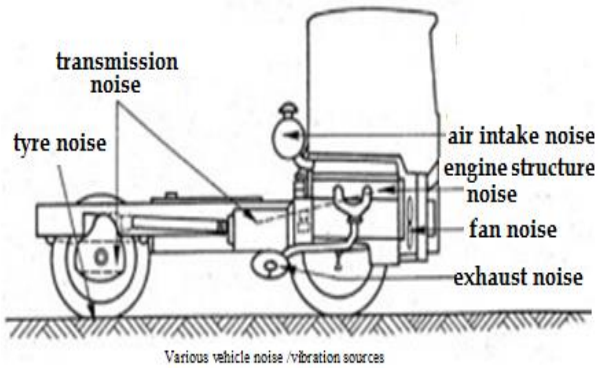

Fig. 5(b): Various vehicle noise /vibration sources

D. Wind noise:

Wind noise is superficial and is experienced at the interior of vehicle. Flow of air over the exterior of vehicle and the flow of air into and out of the cabin arising from imperfect sealing of door frames and glasses are the causes of wind noise generation. Ample number window and door seals ensure successful wind noise control. Figure 1,2,5(b) shows various noise /vibration sources and Fig .5(a*)* shows Propagation of tyre noise of an automobile at frequency of 600 Hz

E. Interior noise:

Interior noise is a prominent acceptance criterion of any vehicle in terms of comfort at the interior part. To identify interior sources of noise and diagnose them, the noise sources are quantified by determining sound power contribution from each vehicle component, panel acoustic leakages, panel vibrations gear shifting, and steering wheel vibrations.
Engine being the main source of noise, the noise from the engine is transmitted in two ways viz. direct infiltration & structural vibrations. Improper sealing, holes in lower dashboards, complicated geometry, worn out engine mounts leads noise from engine to reach directly into the cabin. Structural vibrations are due to rings in exhaust systems. These vibrations are transferred from engine to body through drive shafts supported on bearings, rear axle etc.

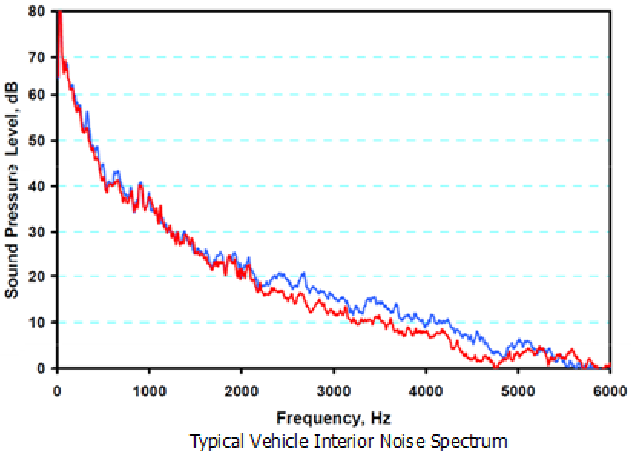

Fig. 6 . Typical Vehicle Interior Noise Spectrum

Table 2 depicts engine noise, vibration phenomenon and sources.

TABLE 2: ENGINE NOISE, VIBRATION PHENOMENON AND SOURCES

Sr.No.	Phenomenon	Source
i.	Noise during idling	High compression and cylinder pressure
ii.	Thriving Noise	Low order harmonics of inertia forces in multi-cylinder engines
iii.	Engine component reverberation	Harmonics of gas and inertia forces during respective compression and power strokes.
iv.	Vehicle component reverberation	Harmonics of gas and inertia forces.
v.	Airborne sound of engine	Mechanical impacts, combustion noise.

To estimate a change in the noise level, the ambient noise must be measured. Ambient noise can be put into one of three categories.

a) The first being dominated by traffic noise,
b) The second being dominated by undefined sources such as rural areas(watercourses, livestock, tree swaying etc.)
c) And the third being non traffic sources such as railways or aircraft.

TABLE 3 : ALLOWABLE SOUND LEVEL FOR ROAD VEHICLES ACCORDING TO EU DIRECTIVE 96/20 EC

Sr.No.	Type of Vehicle	Sound level dB (A)
i.	Personal car	74
ii.	Bus and truck weighing between3.5 to 2 tones and below	76
iii.	Bus with total weight above 3.5 ton and engine power below 15kW	78
iv.	Bus and truck weighing in between 2 to 3.5 to ton.	77
v.	For engine power 150kW or above	80

Vibration can be problematic because of : Its ability to affect precision tasks (for example in hospitals); Possible architectural damage, which affects the building and the occupants.
Table 3 presents the permissible noise levels according to EU directive 96/20 EC.

VII. NOISE CONTROL TECHNIQUES INCLUDE:

- Sound insulation: prevent the transmission of noise by the introduction of a mass barrier. Common materials have high-density properties such as brick, thick glass, concrete, metal etc.
- Sound absorption: a porous material which acts as a 'noise sponge' by converting the sound energy into heat within the material. Common sound absorption materials include decoupled lead-based tiles, open cell foams and fiberglass
- Vibration damping: applicable for large vibrating surfaces. The damping mechanism works by extracting the vibration energy from the thin sheet and dissipating it as heat. A common material is sound deadened steel.
- Vibration isolation: prevents transmission of vibration energy from a source to a receiver by introducing a flexible element or a physical break. Common vibration isolators are springs, rubber mounts, cork etc.

Noise nuisance is described by the World Health Organization as 'a feeling of displeasure evoked by noise'. It can affect people in houses, the street or even during recreational activities. New information suggests that human hearing is sensitive to a change in noise level of 1.0 dB(A). This is equivalent to a 25% increase or a 20% decrease in traffic flow. This sensitivity to new Schemes is an effect that can last for a number of years and will vary according to the sensitivity of hearing of the individual. There are also reported correlations between noise exposure and sleep disturbance, which can be important, even at low noise levels.

VIII. HEALTH EFFECTS FROM NOISE

Noise health effects are the health consequences of elevated sound levels. Elevated workplace or other noise can cause hearing impairment, hypertension, ischemic heart disease, annoyance, and sleep disturbance. Changes in the immune system and birth defects have been attributed to noise exposure. Noise exposure also has been known to induce tinnitus, hypertension, vasoconstriction, and other cardiovascular adverse effects. Noise has been associated with important cardiovascular health problems. In 1999, the World Health Organization concluded that the available evidence showed suggested a weak correlation between long-term noise exposure above 67-70 dB(A) and hypertension. More recent studies have suggested that noise levels of 50 dB(A) at night may also increase the risk of myocardial infarction by chronically elevating cortisol production. Research commissioned by Rockwool, a UK insulation manufacturer, reveals in the UK one third (33%) of victims of domestic disturbances claim loud parties have left them unable to sleep or made them stressed in the last two years. The U.S. Environmental Protection Agency authored a pamphlet in 1978 that suggested a correlation between low-birth weight babies (using the World Health Organization definition of less than 2,500 g (~5.5 lb) and high sound levels, and also correlations in abnormally high rates of birth defects, where expectant mothers are exposed to elevated sound levels, such as typical airport environs. Specific birth abnormalities included harelip, cleft palate, and defects in the spine. Children from noisy residences often possess a heart rate that is significantly higher (by 2 beats/min on average) than in children from quieter residences. Noise also is a threat to marine and terrestrial ecosystems.

IX. CONCLUSIONS

The noise from a flow of traffic at a reception point at any one instant is an aggregation of noise from each of many vehicles at various distances. Among factors which influence a basic traffic noise level, are traffic flow, speed, composition (% HGVs), road gradient and road surface characteristics. Speed control is effective since the lowest sound emissions arise from vehicles moving smoothly at 30 to 60 kilometers per hour. Above that range, sound emissions double with each five miles per hour of speed. At the lowest speeds, braking and (engine) acceleration noise dominates. Selection of surface pavement can make a difference of a factor of two in sound levels, for the speed regime above 30 kilometers per hour. Quieter pavements are porous with a negative surface texture and use medium to small aggregates; the loudest pavements have a transversely grooved surface, and/or a positive surface texture and use larger aggregates. Surface friction and roadway safety are important considerations for pavement decisions. The following improvement measures should be considered and incorporated to ensure that traffic related noise impacts are kept to a minimum. On roads which are fronted by residential properties, a textured thin surfacing product such as Stone Mastic Asphalt should be used. These can achieve noise reduction in the order of 3dB (A) compared with applied hot rolled asphalt surfacing.

REFERENCES

[1] Noise and Vibration Control of Combustion Engine Vehicles,by Mathias Winberg Ronneby, Doctoral Dissertation Series No. 2005:03,ISBN: 91-7295-062-5 ,Published 2005,Printed by Kaserntryckeriet AB,Karlskrona, Sweden.

[2] Automotive Noise Control: Thirty Years of Changing Perspectives, Jim Thompson, National Institute for Occupational Safety and Health

[3] Myer Kutz, *Handbook of Transportation Engineering*, McGraw-Hill (2004) ISBN 978-0-07-139122-1

[4] The Noise Pollution (Regulation And Control) Rules, 2000, Published In The Gazette Of India, Extraordinary, Pt.II, Sec. 3 (Ii) Dated 14th February, 2000.

[5] Environmental Noise Pollution and its Control, Proceedings of Specialist Course, Institution of Engineers, Roorkee, India 1992.

[6] Jeva, R. et al, Noise Impact Assessment - an approach, Energy Environment Monitor,Vol.: 12, September 96.

[7] Mathur, J.S.B., Noise Control : Legislation, Planning and Design, Industrial Effluent Treatment, Vol.:2, Applied Science Publishers Ltd., London, 1981 ed.

[8] 5. Rao, P.R., Noise Pollution and Control, Encyclopedia of Environmental Pollution and Control, Vol.-2, Environmedia Publications, India, 1995 ed.

Prof. Mahajan Sharad R. completed his B.E. In Automobile Engineering, M.E. In Energy Systems, From Karnataka University and Ph.D. In Mechanical Engineering. Presented and published 15 national level papers and 9 international journals. Taught various subjects in Automobile Engineering. He is having 24 years of teaching experience .

Shri. Rahul D.Rajopadhye, working Assistant Professor in Automobile Dept.at Rajendra Mane College Of Engineering, Devrukh,Mumbai University, having 10 years of teaching experience and presented , published many national papers in various conferences.