# A Review of NVH Testing of Engines

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***Abstract:*** *The presented work establishes benefits of using various intrusive as well as non-intrusive methods to analyze pressure, noise and vibrations signals from a dual cylinder diesel engine. This work investigated the effects of change in various injection parameters on development of in cylinder pressure, noise emissions and engine block vibrations. Various contributing NVH sources in engines include flow noise, combustion based noise, mechanical noise, etc. Amongst these sources, the contributions due to combustion based noise and piston lateral motion are of prime importance. Hence, a major portion of this work was dedicated towards discussion of these two aspects of engine acoustics.*

***Keywords:*** *Noise, vibro acoustic*

## 1. Introduction

Diesel engines constitute a major source of power for various ships, buses, trains as well as road machinery. About one fifth of the total energy consumption in U.S.A. goes towards operating these engines [1], and hence demand for these engines is growing fast as compared to gasoline engines [2]. Sales of vehicles using diesel engines reached peak during the decade of 1980′s in U.S.A. due to major oil crises as depicted in figure no 1 [1].

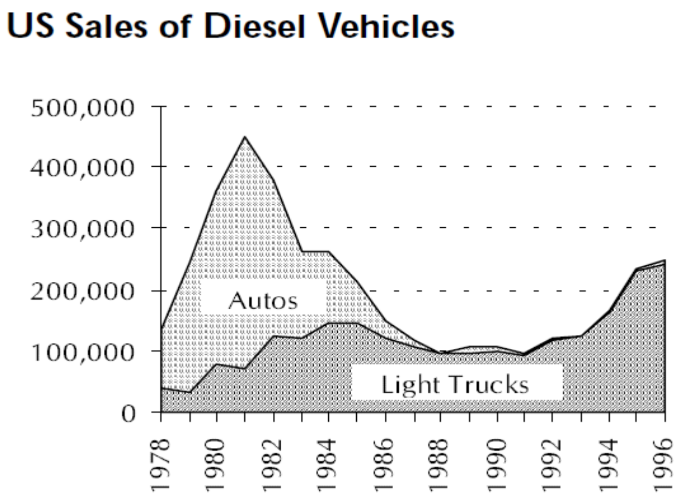


**Fig. 1.** Trends in sales of various diesel engine based automobiles in U.S.A.

Various projections at that time had predicted that an increase of about 20% in sales would be achieved at the end of decade [3]. However, due to variations in the fuel costs, falling prices of petrol and various problems associated with operations of diesel engines led to fall in their overall sales [4, 5].

Gasoline engines use spark ignition system for initiation of fuel reaction when compared with diesel engines (which are based on the compression ignition of fuel-air mixture). Diesel engines operate at higher compression ratios, thus allowing more useful work output during course of their operation. Combustion in these type of engines can be made to take place away from chamber walls, thus helping in reduction of overall heat release rate. In addition, there are various throttling as well as pumping losses associated with operation of petrol engines. These are some of the major reasons for their lesser cycle efficiency when compared with diesel engines. Overall fuel efficiency of a diesel engine may pass over 40% in case of medium sized engines and 50% for larger ones (which are generally used in marine propulsions) [6].

The above-discussed factors have hence led to renewal of interest of various automotive companies towards development of diesel engines. Sales data of diesel engines based automobiles in Europe have indicated that about a quarter of new automobiles were powered using these engines [7, 8]. In France, diesel engines accounted for almost half of total engine sales [9]. Sales of diesel engine based cars in Japan have almost tripled in past [10]. Several commercial vehicle suppliers have now started to manufacture their own diesel engines. Table no 1 shows the market share of diesel engines supplied by various automotive manufacturers in U.S.A.

**Table 1:** Supply of diesel engines by various manufacturer, Year-2013 [11]

| Automotive Make | Engine Make | Market Share |
|---|---|---|
| Hino | Hino | 100% |
| Freightliner | Cummins | 62.3% |
| | Detroit Diesel | 37.0% |
| | Mercedes Benz | 0.7% |
| International | Cummins | 7.2% |
| | Navistar | 92.8% |
| Volvo | Cummins | 13.6% |
| | Volvo | 86.4% |
| Western Star | Cummins | 21.2% |
| | Detroit Diesel | 78.8% |
| Mack | Cummins | 6.0% |
| | Mack | 94.0% |
| Peterbilt | Cummins | 65.2% |
| | PACCAR | 34.8% |

Recently several key technologies like direct injection (D.I.) systems, recirculation of exhaust gas as well as turbocharging are being introduced for further development of diesel engines [12]. Other methods include use of pre-mixed and homogenous charge compression ignitions systems [13-15]. However, higher period of pre-mixed combustion in these methods may lead to higher noise emissions from engines. Hence, various merits of using a diesel engine may be lost over their poor performance over various noise, vibration and harness benchmarks.

## 2. Summary of various sources of noise in combustion engines

Vehicle noise and vibrations can have a bad effect on overall performance of automobiles. These aspects also form important benchmarks for perception of customers while choosing a vehicle as parameters of comfort levels and vehicle reliability. In automotive collective term of noise, vibration and harness (NVH) is used to indicate the unwanted sounds and vibrations [16]. NVH is a term commonly used for the branch of engineering related to vehicle refinement in terms of sound and vibration performance as experienced by its occupants. A layout of vehicle consists of several units which includes chassis, power train, heating, ventilation and air conditioning systems (HVAC) as well as various electronics systems [17].

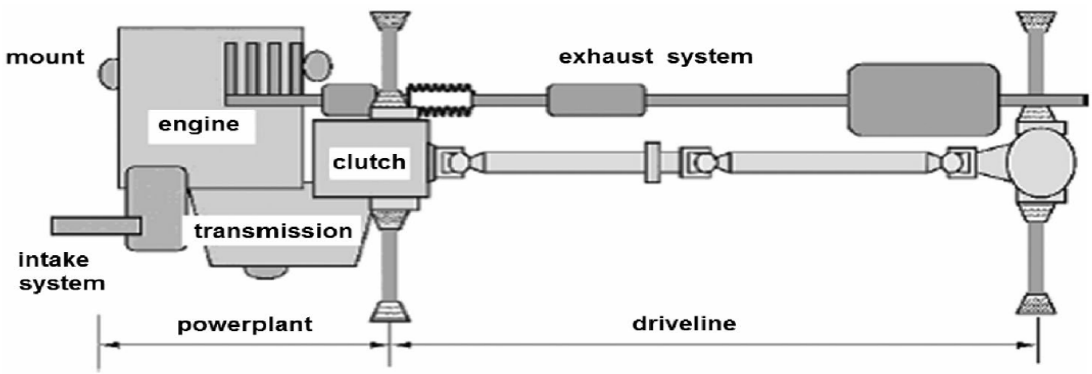


**Fig. 2.** Powertrain system

Figure no 2 depicts powertrain showing an engine block, transmission systems, clutch, driving systems as well as intake and exhaust systems.

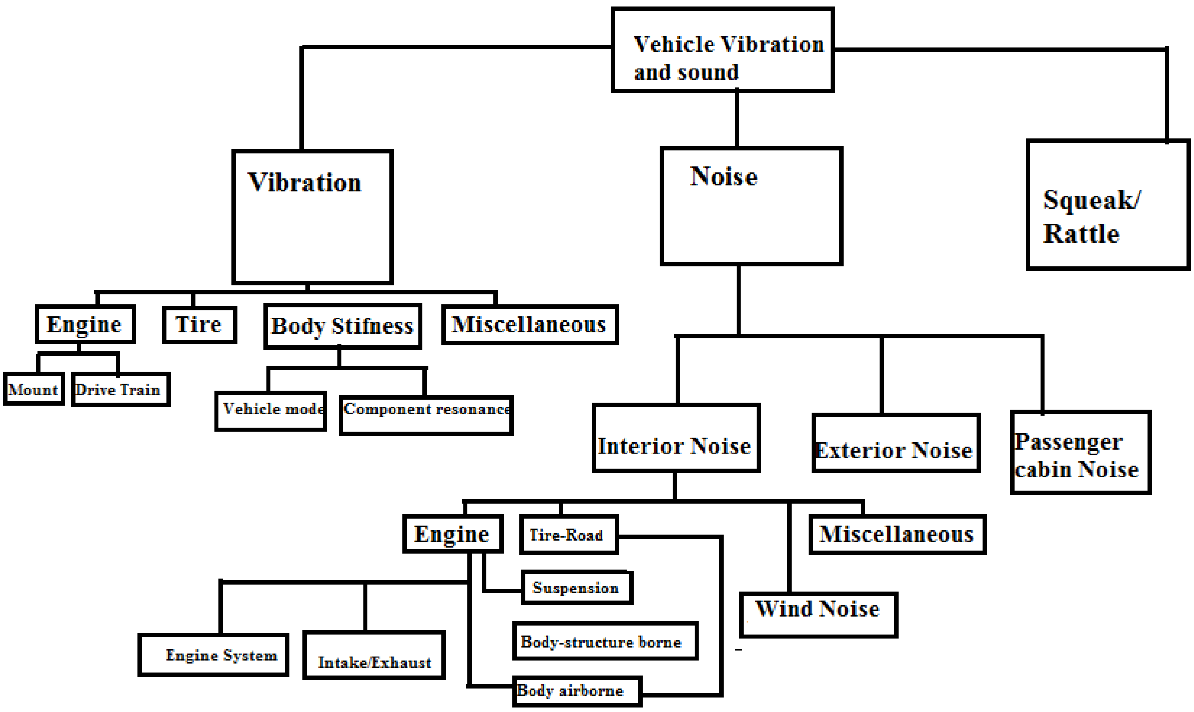


**Fig. 3.** Noise and vibration sources in an engine

Various sources of vibrations in an automobile may be further classified as external or internal one as depicted in figure no 3. The internal sources are due to variable pressure acting on piston head as well as inertia of various moving parts. The external ones refer to vibrations due to unbalanced moments and variable engine torque. Further various sources of noise in an engine may be classified as motion dependent noise, combustion based noise and aerodynamic noise etc. as shown in figure no 4 [18].

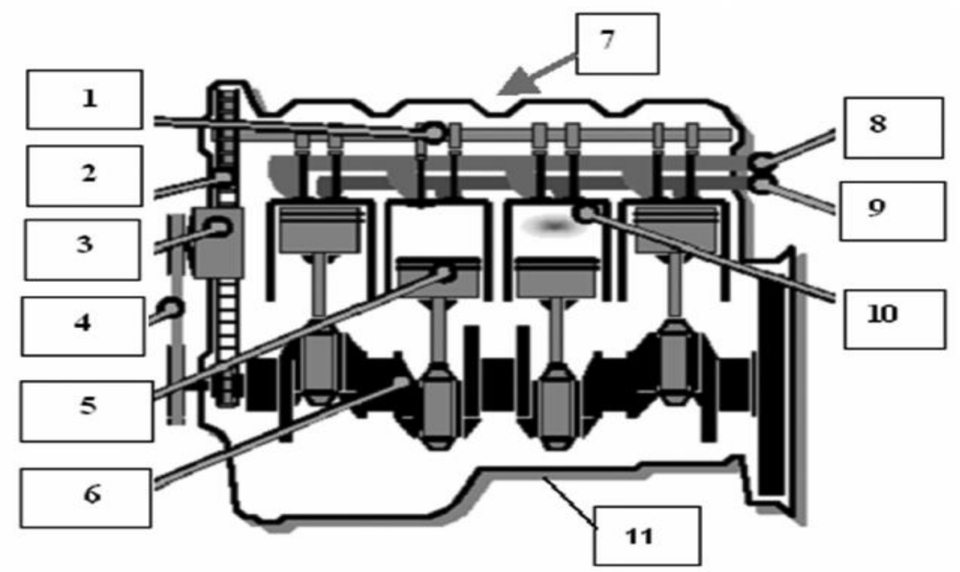


**Fig. 4.** Schematic representation of various sources of noise (1:valve train, 2:chain drive, 3-4:acessory noise, 5:piston slap, 6:bearing noise, 7:cover noise, 8:intake noise, 9:exhuast noise,10:combustion noise,11:oil pan noise)

Combustion based noise can be analyzed by monitoring the speed of combustion process taking place inside combustion chambers, crank angle positions corresponding to 50% mass fraction burnt (CA50), 100% mass fraction burnt (CA100), location and amplitude of maximum in cylinder pressure developed ($P_{max}$) and maximum value of its derivative $(\frac{dP}{d\phi})_{max}$.

Combustion based noise is generated as an impulsive pressure wave due to combustion process impacts on the wall of liner and piston head [19]. The intensity of this noise is proportional to the square of in cylinder pressure developed. This noise can be further classified as direct or indirect type [20]. Direct one is related to the development of in cylinder pressure, whereas the indirect part refers to portion that is transferred to structure from the combustion chamber.
Motion based noise which is proportional to operational speed of engine arises due to relative motion of parts or various inertial forces resulting in impacts. This includes noise due to piston motion, bearing noise, cam noise, oil pump noise, timing belt and chain noise as well as structural noise of cover [20]. This type of noise can be estimated by running engine under motored condition assuming that other components such as flow-based noise are neglected.

Aerodynamic noise includes contributions due to intake noise, exhaust noise and noise due to motion of fan. Various vibrations due to transmissions and driveline also contribute separately. There are also other noise sources, which include squeak and rattle of engine body system. Noise levels experienced by passengers inside the vehicle are not only dependent on various sources but also on the engine structure and acoustic transfer functions. Various sources have typical frequency ranges as shown in table no 2 [20]. Wind and road tire noise lie in the medium frequency ranges [20].
Range of various frequencies not only depends upon operational conditions, but also on the configurations of engines. Hence, identification and estimation of specific frequency must be done by proper testing procedure. By comparison of fundamental frequency and harmonics of individual noise sources, contributions of each source can be estimated. A typical beak up of contributions from various engine surfaces for a V6 engine using this technique is shown in table no 3 [22].

**Table 2:** Frequency ranges of various noise sources

| Noise source | Approximate frequency range | Effecting factor |
|---|---|---|
| Combustion Noise | 500-8000Hz | In cylinder pressure |
| Piston Slap | 2000-8000Hz | Speed, piston design |
| Valve Operation | 500-2000Hz | Valve type ,Engine speed |
| Fan Noise | 200-2000Hz | Speed, number of Blades |
| Intake Flow Noise | 50-5000Hz | Turbulence |
| Exhaust Flow Noise | 50-5000Hz | Turbulence |
| Injection Pump Operation | 2000Hz | Pump features |
| Gear Noise | 4000Hz | Speed, Number of teeth |
| Accessory Belt-Chain Noise | 3000Hz | Engine speed, misalignment, number of teeth |

**Table 3:** Noise analysis from a V6 engine

| Part | dB Sound Pressure Levels |
|---|---|
| Engine Block | 78.7 |
| Cylinder Head | 76 |
| Crank Case | 79 |
| Engine Base | 78 |
| Intake Manifold | 77 |
| Cam Cover | 78 |
| Front Cover | 77 |
| Exhaust Manifold | 74 |
| Oil Pan | 73 |

Its effects can lead to temporary or permanent hearing damage and can impair workers' efficiency. Individuals suffering from poor hearing, whether it is due to their age or illness, can have their problems made worse by exposure to higher levels of noise at work. It can also lead to accidents due to limited speech communication, misunderstanding oral instructions and masking the sounds of approaching danger or warnings.

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