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Review on Vibration and Noise emitted by Automobiles

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Abstract:The IC engine is made up of reciprocating and rotating parts and they produce unbalanced forces during their operation and produce the vibratory output at the vehicle supporting members. The vibration reduction will be possible by minimizing unbalanced forces and by providing the anti vibration mounts at the engine-vehicle interface. Many researches were made to find the causes for the vibration and to reduce the vibrations at the engine supports. But still there is a research gap on the vibration modeling and vibration isolation of the engine. In this work, an attempt is made to represent the state-of-the- art for the engine vibrations and its isolations and to provide a gate way for the future work on it. It reveals the various work carried out on the engine multibody modeling of the IC engine components and different engine mounts and their orientations. The present work describes various automotive noise & vibration sources and their contribution, engine vibrations and engine mounting areas and revealed the gaps and untouched parts that requires further research.

Keywords – Engine vibration, Noise, Engine mount, Energy flow path, Stationary Noise, unbalanced forces.

I. INTRODUCTION:

Noise and vibration play an important role in the sound quality of the vehicle. It describes the dynamic behavior of vehicles in the whole frequency range. It comprises the sensible low frequency vibrations of structures, the sensible and audible range of perceived acoustical comfort as well as the audible high frequency range of noise limited by the perception ability of the human ear [1]. Noise, Vibration and Harshness (NVH) as a field of vehicle technology has two different aspects: firstly, interior NVH aspects, which include the improvement of the interior vibro-acoustic environment for the drivers and passengers and the protection against occupational health issues for the professional vehicle driver and, secondly, exterior NVH aspects, aimed at the control and reduction of environmental noise emission by road vehicles but aiming also at a sufficient acoustic noticeability of electric vehicles at low speeds for the safety of vulnerable road users. Many techniques have been developed to reduce the vibrations.

The internal combustion (IC) engine is the concentrated mass in vehicle and if not properly designed it will cause vibrations and transfer to the supporting structures ride comfort, driving stability and drivability are important factors for the performance of a vehicle and are affected by the engine vibrations. Because of the environmental considerations, as well as changes in consumer preferences regarding vibration induced must be reduced. Vibration behavior of an IC engine depends on unbalanced reciprocating and rotating parts, cyclic variation in gas pressure, shaking forces due to the reciprocating parts and structural characteristics of the mounts. Engine vibrations are caused due to the reciprocating and rotating masses of the engine. The variations of inertial forces are due to the combustion and the compression differences of the piston cylinder arrangement during their operation. The engine inertial forces leads to the unbalanced forces of the engine and they are quiet varying with respect to speed, fuel supply and combustion characteristics of the fuel. To predict the vibration output of an engine and to minimize the possible durability and consumer perceived quality problems associated with engine vibration, a robust and accurate design and simulation model is needed. To reduce the engine vibration proper mounting must be provided as dampers at the interface of the engine and chassis.

The aim of this study is to evaluate the noise emitted by motor vehicles, depending on the type of road surface and driving speed. The results give an answer if the type of road surface has a significant impact on the volume of a moving car or rather it is caused by other factors that are directly related to the movement of the car at a given speed.

One way to eliminate traffic noise is to reduce the speed of traffic. This method is mainly used in urban areas, where other methods of reducing the noise propagation are not feasible. Two questions were the aims of the study. The question of what effects of noise reduction will be achieved by reducing the speed of movement of vehicles and by how much will the noise level change if it is emitted by the passenger car, van and truck depending on the type of road surface.

II. SOURCES OF NOISE & VIBRATIONS IN AUTOMOBILE:

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 vehicles running at higher level of noise and vibrations.

2.1 Engine Vibrations:

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. Many researchers and engineers have worked, and are currently working on noise and vibration reduction in automobile. Some of the highlighted works have been used in the survey and the brief description of those works is as follows:

Engine produces the vibratory forces due to the unbalanced forces from the engine parts during the operation. The vibration caused by the engine at the supports is torsional vibration and the longitudinal vibration. The torsional vibration is caused at the crankshaft due to the fluctuating engine combustion pressures and engine loads. The longitudinal vibrations are caused at the block and the mounts by the reciprocating and rotating parts of the engine. Studies have shown that the noise reduction can be achieved by the reduction of the speed of movement of vehicles. The type of road surface has a significant impact on the noise level of a moving car or it is rather caused by other factors related to the movement of the car at a certain speed. Noise measurements were carried out using a controlled pass-by method (CPB) [3]. The research consisted in comparing engine vibrations measured in specific and representative points. In order to determine the vertical component vibrations, the measurements were performed via a mirror.

A laser Doppler vibrometer made by Polytec was used to measure vibration velocities. The vibrometric system directly measures two quantities: displacement and velocity. In the investigated case, vibration velocity is the variable which supplies better diagnostic information. Vibrations were measured for the car standing on its wheels and for the car jacked up to reduce the influence of the car vibration damping systems on the measurement results. The latter are presented in the form of comparative diagrams. Moreover, the fast Fourier transform was used to determine the frequency distribution. Prior to that signal was subjected to conditioning operations using parametric windowing and filtering. Vehicle suspension system consists of innovatory Vacuum Packed Particles controllable dampers which allow controlling the vehicle body vibration. The control in the vehicle suspension system can be realized by controlling the under pressure resulting in various jamming mechanisms in the granular core [4].

For a vehicle body Finite Element (FE) model, a reduced formulation has been achieved by using the WBS (Wave-Based Substructuring) technique. A modification approach has been applied that is based on the generation of bead patterns on a subcomponent that has been identified as critical for the NVH behavior. By combining the reduced structural model with an efficient ATV (Acoustical Transfer Vector) approach to predict the interior acoustics performance, one can efficiently evaluate the effect of structural modifications on the interior NVH levels, such that the global NVH behavior can be optimized, the optimization of vehicle vibro-acoustics by making use of a structural optimization software in combination with an acoustic target function [5]. The MR (Magneto-Rheological) engine mount is a semi-active hydraulic engine mount, containing MR fluid that can alter its dynamic behavior as a result of applying a magnetic field. The modeling of a new semi-active MR engine mount has been conducted. It was shown that by increasing the magnetic field, the dynamic stiffness of the engine mount can be changed [6].

The seating design reduced both contact pressure and amplitude of vibrations transmitted through the body, the reduction in WBV (whole body vibration) allows more sustained driving than permitted by conventional seating devices the seating devices implemented in high-vibration vehicles, may reduce the risk of WBV-related musculoskeletal disorders among drivers [12].

Vehicle vibration insulation measures include: vehicle weight reduction, radial bogie, axle configuration optimization, vehicle suspension systems resilient, flexible wheel, damping wheel, grinding wheel tread, novel rolling stock; track vibration insulation measures include: rail grinding and oiled, pasting damping materials on rail, seamless rails, elastic fastener [18].

The implementation and experimental investigation of the applicability and efficiency of an active vibration control (AVC) concept for vibration reduction in an automobile passenger compartment, the floor panel of a medium-class test car has been studied as test case for an AVC implementation based on the use of piezoelectric actuators. A preliminary numerical activity has been performed for the correct evaluation of the dynamic behavior of the system under the specific external disturbance spectra; based upon this information, a procedure for the correct positioning of sensors and actuators devices has been implemented of both SISO (Single Input Single Output) and SIMO (Single Input Multiple Out-put) feed forward control applications, under simulated conditions of external disturbance field [19].

The complete solution to the noise and vibration problems can be obtained by integration of passive and active systems; the actuator component of the active technology needs major advancements to reduce the overall system complexity and cost, as well as to enhance performance [20].

Considering C, I and Box type cross sections, is analyzed by employing a polymeric composite heavy vehicle chassis for the same load carrying capacity, with a reduction in weight of 73% to 80%. The results of the steel and polymeric composites material with cross section C, I, and Box are performed. Based on the results it was inferred that steel with 'I' section has superior strength to withstand high load and induced low deformation and stress distribution when compared to S-Glass Epoxy composites material [8].

Amplitude vs. frequency graph is generated from harmonic analysis is utilized to determine the resonance frequency. The highest amplitude occurred in the third natural frequency with amplitude of 0.375 mm. The outcome of this analysis can be used as a reference in improving the chassis design and performance against dynamic behavior of the structure by introducing stiffener on part of the chassis imposed with the highest displacement [10-11]. From this study one can conclude that there is need of more research in this area of chassis vibrations for the comfort during ride, the stability of the whole vehicle.

2.2 Noise Sources:

In chassis NVH, chassis acts as the main frame of the body structure of the vehicle. It is one of the most important part to be considered when designing a vehicle. There are three types of chassis structure which is the ladder chassis frame, space frame chassis and monocoque chassis. Elements that always been considered during the design of the chassis structure is such as the strength and the stiffness of the chassis. Chassis built for vehicle has to be strong because it tends to be subjected to static stress, strain and also vibration due to various dynamic excitations. Static analysis of the chassis structure is important in determining the safety of the chassis structure. This assembly may be a single welded structure, multiple welded structures or a combination of composite and welded structures [2]. Vibration on the chassis can affect the comfort during ride, the stability of the whole vehicle as well as the safety of the vehicle, it causes high stress concentration at certain part of the structure, fatigue on the structure and loose in the joints of the structure also vibrations are transmitted to the human body, resonance may arise this may result in the dislocation of an organ and in the extreme case, in its damage.

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 into 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 1 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.

2.3 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.

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. 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. 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. Table 1 and 2 shows various noise/vibration sources.

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.

Figure1. Propagation of tyre noise of an automobile at frequency of 600 Hz

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Table 1 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.

Table 2 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

III. MOUNTINGS:

The unbalanced forces produced from the engine are transferred to the engine supporting members and causes the structure borne vibrations. To reduce the vibratory forces from the engine to the structures, the engine is supported by the damping members called vibration isolators (engine mountings). The mountings are the final most sources to reduce the vibratory forces by its damping property. Mounts are designed to satisfy two important criteria the first is the support function, reduction of the large amplitude vibration, at lower resonance bands. It requires the mountings to have higher stiffness and damping. The other is noise control; the mountings have to reduce the noise in the supporting structures induced by small amplitude vibration of the engine, at higher bands. It requires the mountings to posses lower stiffness and damping. These two requirements are contradictory, and the main aim in the design of engine mounts is to stabilize these two different conflicting requirements.

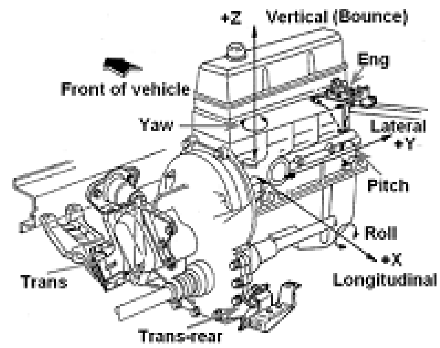

Fig.2 Engine model

Both the decoupler mechanisms were used to control the amplitude dependent behavior of the mount. In the first type, the fluid is forced through the inertia track due to relative motion between the engine and the chassis and this design relies upon the appropriate combination of inertia track and decoupler gap size. In the second type, the decoupler directly connected to the engine mount and its motion is directly controlled by the engine motion of the engine and the chassis. The linear and non-linear mathematical models of the both type were simulated and from the results it has been identified that the direct decoupler mount exhibits the lowest transmissibility in low frequency domains whereas the floating decoupler shown better performance as the excitation frequency increases.

The non-linear response solutions of the both mounts were validated by direct comparison with the linear counter parts and it has been identified that the similarity between the solution regions sufficiently removed the resonance in the non-linear modeling They also experienced difficulties in the mathematical modeling of the direct decoupler when using the new method, energy-rate method, for the analysis of stability of the parametric system. The hydraulic mount with inertia track and decoupler has variation in property based on the disturbance frequency range and is small at higher excitation. For that they developed two linear models, one is low high frequency range and the other for high frequency range. The combination of two models also was used in optimization of the hydraulic mount. For the optimal design of the non-linear fluid engine mount with inertia track and decoupler they used sequential quadratic programming (SQP) technique to minimize the transmissibility of the fluid mount. The frequencies used in the SQP for low frequency range model and high frequency range model were calculated from the simulation of the mathematical model. To obtain effective vibration for the high and low frequency range models the SQP was combined with low and high frequency range models.

The design parameters that greatly affect vibration isolation effectiveness were considered as design variables such as the effective piston area, inertia track, inertia of decoupler, inertia track resistance, decoupler resistance, rubber stiffness and compliance in top and bottom chambers. focused on the performance enhancement of engine mount rubber(EMR) by adopting a form a design optimization approach. The optimal design was arrived by considering the material stiffness and fatigue strength of a rubber. The objective of the optimal design was made to minimize both the weight and the maximum stress of the EMR and to maximize the fatigue life cycle subjected to constraints on static stiffness of rubber. The number of life cycles associated with the fatigue strength should be increased as much as possible under the acceptable material stiffness behavior. Such design requirements made possible through multi objective optimization method. In the context of approximate optimization a back propagation neural networks was used to construct global response surface between input design variables and output responses of objective functions They made Enhancements on the existing non-linear models to include a continuous function that follows a simple and effective approach to capture the switching effect and leakage through the decoupler, and upper chamber bulge damping. The developed model also showed appropriate system response over the full range of loading conditions. From the experimental set up initially the individual components of the mount model was verified and then the behavior of the whole assembly was verified. The data obtained from the results gave the relative importance of several damping, inertia and stiffness terms and the measured responses of the mounts at various frequencies and amplitudes are compared with the results of the mathematical model.

A Multi-Body Dynamic Simulation (MBDS) of the engine was carried out by simulating an engine to estimate the forces acting on the cylinder block. The dynamics of the engine is described taking into account the effects of the gas pressure and the inertia forces of the moving parts. In this work to identify the real engine operating behavior, both the crank and the block have been considered as flexible bodies. The cylinder block excitations were used to evaluate the engine radiated noise with the MATV methodology.

Developed controlled equilibrium mounts (CEM) for an aircraft engine which is much smoother than usual mounts to isolate the engine vibration. The CEM uses the additional control effect of equilibrium position of mount by the by-pas air from the engine. The Equilibrium position of mounts can be obtained by pressurizing and exhausting of air in to the mounts by the control valves. They developed a CEM simulation model considering the thermodynamic effects and heat transfer characteristics of air, valve control logic and equation of motion. The model consists of parts like conventional mount, expandable volume, control-valve and supply system. The electrometric part of the mount provides the basic isolation and the expandable volume provides the additional isolation by pressurized/exhausted air, supplied from the engine, with help of control valves. The simulations were made to find mount displacements during taxi, climp, cruise and decent conditions of the air craft.

They used a bush type engine rubber mount model for a passenger car. The developed model was considered as basic model and modification were made for the large deformation and endurance analysis of the rubber mounts. The model was simulated in the bush type rubber mount for optimization of the shape of the mount and subsequently for the desired stiffness values. The authors introduced a controllable inertia track and made considerable changes in the dynamic properties with respect to the area of inertia track. They identified that the dynamic properties were varied as the inertia track was changed. The results of the numerical simulations showed that the vibration isolation of the passive engine mount was affected by changing the inertia track area and the optimization, developed based on the frequency band and magnitude, of dynamic properties was made. The authors were also identified that many of the researcher were not considered the displacement of the mount in the reduction of dynamic stiffness to reduce the force transmitted to chassis.

IV. CONCLUSION:

Engine vibration sources resulting from various forces viz: Combustion, reciprocating and rotational is reduced by using in-plane and two plane balancing methods. Method to reduce the rotating and reciprocating unbalance is gives the designer a means to influence the noise and vibration characteristics. The contribution of each vibration source and its reduction technique is focused here. The noise sources; their contribution and the engine related noise and vibration phenomenon in the vehicle is tabulated. An attempt is made to co-relate the noise and vibration sources and further methods to reduce the same are provided which reduces the noise and vibration and improve vehicle ride comfort characteristics. The energy flow method’s four stages are used as a benchmark to reduce any vibration problems in automobiles arising from the random as well linear vibrations. It also helps in identification of the proper flow of vibrations and noise.

Noise one of the major concerns is taken care of here by identifying various noise sources and techniques to reduce the same are discussed which improves the vehicle ride quality and comfort level of passenger Interior noise is the major concern and is required to be taken care at the design stage itself. To reduce the vehicle interior noise manufactures prefer placement of sound absorbing materials, proper sealing of all openings and cavities present in the vehicle.

The problem of noise emission by moving vehicles on public roads with different types of surfaces in the literature was undertaken on several occasions. It is obvious that the noise levels of vehicles depend largely on the size and construction of vehicles (cars, trucks, special), traffic volume, speed of vehicle, type and characteristics of the road surface with which tires of different types and manufacturers cooperate [8-10].

An important result of the study is data that allow predicting changes in the level of noise emission by motor vehicles in the case of e.g. changing the surface of the paving stone to asphalt - bitumen surface. The applied research method and the results obtained allow assessing whether a change to a quieter road surface will bring the expected results of noise reduction, or whether restrictions should be imposed at the same time speed.

Reducing the speed can always reduce the level of noise emitted by road vehicles. An alternative method is to change the road surface. Such a treatment will increase the speed of movement of vehicles in areas with high traffic without increasing noise.

The results also allow to determine for what type of vehicles, the introduction of speed limits will bring the best results, while maintaining the required bandwidth for a specific (for appointed research) road surface.

For load carrying members, the design should first satisfy the strength and stiffness requirements over damping benefits. The noise limits for in-use vehicles are legislated as; highest noise levels permitted are 103 dB (A) as compared to the noise level of 96db (A) observed in new vehicles.

As per the present scenario noise and vibration is a major problems in the vehicles, so this research work is useful to minimize this problem. As per as the electronic parts are concerned it affects on the accuracy, repeatability, range and life of the electronic components. So with this regards this work is useful for increasing the performance of the vehicle. Engine vibrations and engine mounting areas and revealed the gaps and untouched parts that requires further research. More attention is required towards the noise and vibration reduction of automotive chassis considering different driving speed and road alignment.

The changing rotational speed results in the speed fluctuations of the crankshaft and the torsional vibrations at the crankshaft. The reciprocating and rotating components of engine have subjected to variation in inertial motion and the combustion pressure during the operation and the variation in the inertial motion of the parts during the upward motion and variation in the combustion pressure during the downward motion produce the unbalanced forces at the engine block and the unbalanced forces at the block are measured as longitudinal vibrations in the three orthogonal direction. Both the vibrations can be reduced by minimizing the unbalanced forces and by supporting the engine at proper mounts. The engine mounts should have characteristics of high stiffness and high damping in the low frequency range and of low stiffness and low damping in the high-frequency range.

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