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Research Article

INVESTIGATING NOISE SOURCES FOR A HEAVY VEHICLE

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A B S T R A C T

Although the problem of NVH is a well-known topic and studied by researchers, the persistence of noise of different frequencies, in the range of 16-16kHz, in the environment, in this case in heavy-duty vehicles, remains a topic of interest that must be adapted to new technical innovations. Major vehicle manufacturers are investing exhaustible resources of time and money to improve the vibro-acoustic performance of vehicles, which have evolved from simplistic mechanisms to complex systems with multiple functions. In a complex dynamic system, such as the cab of a truck, a number of variables come into play in the interior noise problem. This paper presents a starting point in combating noise inside and outside heavy-duty vehicles, by presenting the main sources of noise, in order to obtain an initial picture of the cumulative impact due to noise and vibration generated by acoustic sources from vehicle operation.

INTRODUCTION

Globally, there is a tendency for the automotive industry to move into a new phase of development, characterized mainly by the evolution of traditional vehicles into complex, complete electric systems. Electric vehicles, recognized by researchers as the vehicles of the future, generally exhibit superior NVH performance to traditional vehicles. They have a better vibration behaviour, with a structural hardness superior to traditional vehicles, due to the evolution of material manufacturing technology, they also present superior acoustic properties, mainly due to the electric motors and their ancillary systems, which are relatively silent. The electrification of the transmission and propulsion system has also led to changes in the sources and transmission path of vibrations, in particular noises[1,2].

Until now, the major market leaders of the vehicle manufacturing industry (such as: Tesla, Chevrolet, Volkswagen, Audi, Porsche, Aston Martin, Mercedes-Benz, Ford, Volvo, Nissan, Hyundai...etc.) are making efforts to creation of own production lines of electric vehicles. Also globally there is an emerging market in electric vehicles, where competition is increasing[3].

Currently, however, natural gas, oil and coal provide 84% of all world's energy and oil still powers nearly 97% of all global transportation. As a result, the transport industry is forced to modernize, traditional vehicles must be improved, to become more comfortable and quieter, to meet customer requirements and face market competition.

Beyond engine performance, safety and comfort have become the benchmarks for most customers in the heavy-duty vehicle market. Comfort, safety and performance are the three selection criteria of major customers that make significant differences in heavy truck sales performance. Based on these requirements, noise, vibration and harshness - NVH performance, have been a hot topic of research over the last decade[4,5].

Many sources can cause an increase in sound pressure the level that affects the comfort inside the passenger cabin. These sources are classified into two broad categories: noises from the vehicle structure and noises from interaction with the external, airborne environment.

Analyzing the issue of noise in the context of the vehicle manufacturing industry, it can be stated that a special interest is given to the acoustics of the passenger compartment. According to research in the field of acoustic comfort in the vehicle cabin, the driver is the most exposed to noise emissions[6].

Moving on to the analysis of the interior comfort of vehicles, it can be stated that the driver is part of a vehicle-steering wheel-pedals-chassis vibroacoustic system. The sounds transmitted inside the passenger compartment come from acoustic sources on specific transfer paths for each source. The most important of these, in the process of operation, which contribute to the generation of noise emissions are: the engine and its ancillary systems, the interaction with the roadway and the interaction with the air environment.

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The objective of the present study is to demonstrate a methodology which can be used to identify key contributors to interior noise in a heavy vehicle. During the heavy truck design phase, the approach noise and vibration problems are very difficult, time-consuming, and expensive due to the complexity of the problem.

Acoustic Sources and Acoustic Systems

Sound waves can be produced by natural phenomena (electrical discharges, volcanic eruptions, ocean waves - which fall under high-intensity sound sources), by living things, machines and man-made devices. In almost all cases acoustic waves are radiated into space due to the vibrations of a body, fluid or even case[6].

Consequently, a sound source can be defined as a radiator of acoustic energy in space, which changes the pressure of the environment in which it is located.

Acoustic radiators are found in various forms, from the strings, tubes, or vibrating surfaces of musical instruments, to solids in oscillating motion, to liquids or gases in turbulent flows, to sudden pressure vibrations due to percussion, detonations or explosions. In this thesis, an exhaustive study of acoustic sources and systems is not proposed, but only a review of some common types of acoustic radiators, used in practical applications related to the generation of sound signals with the aim of studying the acoustics of the vehicle interior. Among them are: pulsating sphere, pulsating cylinder, vibrating piston, point acoustic sources (solid nail, point acoustic sources arranged linearly), simple acoustic systems (inertial systems - acoustic inertia, capacitive systems - acoustic capacity, dissipative systems - acoustic resistance) , complex acoustic systems (Helmholtz-type resonators, membrane resonant cavities), sound tubes (sound tubes with constant section, tubes with discontinuous variable section), acoustic filters, acoustic funnels[7].

Since noise is produced as a result of the vibration of a body, noise sources they can be divided, according to the forces that produce the respective vibrations, into the following categories: Sources producing noise through mechanical action (collision and friction); Sources producing noise through aerodynamic action (laminar and turbulent flows of fluid through the holes);

Sources producing noise through electromagnetic action; Sources producing noise through thermal action[8,9,10,11].

Noise produced by collision. By collision bodies vibrate. Massive bodies with appreciable rigidity vibrate as a unitary whole, all its points moving in phase. If, following the collision, the body vibrates as a unitary whole, then the intensity of the sound produced is proportional to its surface area and to the square of the velocity of the particle of the body. Bodies of low stiffness such as plate or bar, whose dimensions are large in relation to the wavelength of the sound produced, produce bending waves by collision. In bodies where bending waves are produced by collision, the intensity of the sound produced depends on the nature of the material from which the body is made (since the internal damping of the material also plays an important role), on the mass of the vibrating body and on its dimensions. The influence of the thickness of a vibrating plate on the intensity of the sound produced is greater than that of its mass. Thus, in the case of a floor that vibrates, doubling the thickness of the floor leads, due to the increase in bending stiffness, to a reduction in the noise level by 10 dB, while doubling the mass of the floor, by doubling the density of the material from which it is made, leads to a reduction in the noise level by only 3 dB. In the category of sound sources that produce collision noises are included: ordinary hammers, pneumatic hammers, stamping machines, weaving looms, gears, plates subjected to shocks, etc.

Noise produced by friction. In this case, the vibrations are produced as a result of the action of the frictional forces that arise both during translational and rotational movements between two bodies in contact. The intensity of the sound produced varies with the size of the frictional forces and torques, depending, therefore, on the value of the friction coefficients (of sliding, rolling, pivoting, etc.) and on the size of the normal reactions between the bodies in contact. So, the rougher the surfaces of the bodies in contact are, having greater asperities, the greater the intensity of the noise produced. Due to friction, the body vibrates with its own frequencies, which determine the spectrum of the noise produced. And in this case (of vibrations due to friction) the intensity of the noise produced depends on the internal damping of the materials from which the bodies in contact are made. They produce frictional noises: the running of wheels on rails, the processing of materials on planing machines, the processing of materials by filing, the rotation of spindles in bearings, etc[9,10].

Noise produced by aerodynamic action. Noises of an aerodynamic nature (also called siren noise) are produced both due to the flow of fluids through rigid, fixed elements (nozzles, suction ports, discharge ports, pipes, etc.), and due to the flow of fluids through moving elements (rotors with vanes, propellers, etc.). In both cases, the intensity of the noise produced depends on the geometric shape of the elements through which the fluid flows, on its flow rate and speed, and on its dynamic viscosity. If the noise is like a sound produced by a siren, it has a predominant frequency. When the air coming out of an orifice hits an obstacle, vortices are alternately formed on its two sides, which produce pressure variations. The frequency of the generated fundamental sound is equal to that of the vortices and is determined by the relationship:

$$f = kx\frac{v}{d} \tag{1}$$

where k is a coefficient that depends on the flow conditions; v – air speed, [m/s]; d – body thickness, [m].

If the flow is turbulent, a noise with a continuous spectrum is produced. The shape of this spectrum depends on the size of the pipe through which the fluid flows, the speed of the fluid current, the state of turbulence, etc. In the case of jet noise, in addition to the sound spectrum, the analyzes also highlighted the existence of infrasonic and ultrasonic spectra[9].

Noise produced by magnetic action. Magnetic noise is specific to electrical machines (generators, motors, transformers). This type of noise is due to the periodic forces that are exerted in the interspace between the rotor and the stator, the so-called magnetomotive forces, due to the winding of the stator and the rotor. When the motor is running at idle, the only force that is taken into account is that due to the stator, and when the motor is running under load, the predominant force is that produced by the rotor. The tangential components of the magnetomotive forces give rise to the total torque that produces the useful mechanical work of the motor, and the radial ones (which do not produce useful mechanical work) act on the component elements of the electric machine and drive them into vibrational motion, thus generating noise. The intensity of the produced noise depends on the size of the radial components of the magnetomotive forces and is lower than that of the aerodynamic noise. Thus, the removal of the fan of an electric motor with a speed of 3000 rpm caused the generated noise level to decrease by 30 dB, therefore the aerodynamic noise was predominant. Magnetic noise is made up of a fundamental sound, having the frequency of the electrical network (50 Hz) and a series of its harmonics. The amplitudes of the harmonics decrease as the frequency increases[10].

From the point of view of acoustic sources, noise emissions can be classified into: air-borne noise and structure-borne noise. Airborne noises (wind turbulence) are radiated by acoustic sources external to vehicles and are transmitted into the passenger compartment through openings in the vehicle structure (door leaks, weld seams, connecting elements of subassemblies, etc.), because the sound pressure waves it propagates along the path of least resistance.

Noise produced by thermal action. During the process of burning fuels (natural gas, pulverized fuel oil, pulverized coal dust) in thermal installations, due to the interaction between the flame and the gases, self-oscillations that generate noise often occur. In the case of boilers operating with solid fuel, the noise is due to the formation of vortices in the hearth, the detachment of the vortices from the walls and the vibrations of the air in the hearth. Low frequency components (below 100 Hz) predominate in the spectrum of the noise produced. These vibrations generate both a rather intense and annoying noise, as well as the trepidation of the boiler and the incomplete burning of the fuel in its hearth. In boilers that operate with fuel oil injectors, the noise appears as a result of a rapid emission of heat, while in boilers with natural gas burners, the noise is produced by the detachment of vortices from the edge of the burner. In this last case, the low frequency components (65...250 Hz) predominate in the noise spectrum[11].

Characteristics of a Sound Wave

Sources that radiate acoustic energy in all directions in space are called omnidirectional (non-directional) sources, and those that radiate most of the energy in only one direction (the most common) are called directional sources. Examples of directional sources: human mouth, horn, radio, etc.

Depending on the frequency characteristic, the acoustic source produces: pure sounds, complex sounds or noises. Pure sound is due to a harmonic vibration, being characterized by a single frequency. The complex sound contains a number of pure sounds whose frequencies may or may not constitute a harmonic series. Such a sound is made up of a fundamental sound and a series of high frequency components. Noise is due to an acoustic vibration with a continuous spectrum, at least in a certain frequency band, and therefore has no well-defined components.

The characteristic sizes of sound sources are: loudness of the sound source, power of the acoustic source, directivity of the acoustic source and radiation impedance[12,13].

Loudness of the acoustic source. The acoustic radiator has a vibrating surface (Area>0), the strength of the source is defined as the instantaneous fluid flow that it oscillates in one second. If all points on the radiating surface, A, oscillate in phase with speed v_0, then the strength of the source, denoted by Q, is:

$$Q = AxV_0 \quad [m^3/s] \qquad (2)$$

The power of the acoustic source. The acoustic power P of a sound source represents the total acoustic energy radiated by the source in the unit of time and is measured in [W]. The acoustic powers of some common acoustic sources are presented in table 1:

Table 1 Reference acoustic powers of some sound sources

Source	Power of the source
Rocket to launch lamp	10^4 kW
Jet aircraft	10 kW
Pneumatic hammer	1 kW
Piano	0.3 W
Human voice	20 μW
Leaf rustle	0.001 μW

Directivity of the acoustic source. If the acoustic source has a point of symmetry or of a pulsating sphere in phase, the source will radiate acoustically in any direction with the same acoustic intensity. If the source has an axis of symmetry, it will preferentially emit in different directions, the generated acoustic field being non-uniform in three-dimensional space[13]. Radiation impedance. It is defined as the ratio between the force exerted by an acoustic source on an elementary surface and its movement speed (the particles that form this surface), being a complex quantity[13].

Case Study

Identification of noise sources

The noises generated by the structure come from the mechanical vibrations that propagate throughout the structure and are influenced by the characteristics of the roadway, the speed of the vehicle, the characteristics of the suspension, as well as the clearances resulting from the wear of the assemblies and various components of the vehicles (figure 1) [7,8,9].

The effects of shocks and vibrations, generated by the operation of motor vehicles, are manifested both at the level of the motor vehicle, by generating wear on the component assemblies or sub-assemblies, affecting their durability, and on the driver, affecting his physiological state (fatigue, health, attention), the cumulative effect manifesting itself in terms of road traffic safety, in the sense of reducing it.

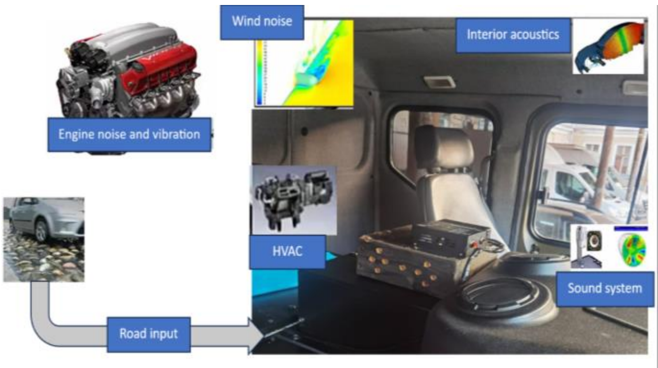

Fig 1 Acoustic sources responsible for noise emissions inside a truck cabin

The noises produced by the engine consist of: noises from the combustion process and mechanical noises. During the engine combustion process, the pressure in the engine cylinders increases suddenly (approximate pressure values: p=30-40 bar for MAS-spark combustion engines, and p=80-100 bar for MAC-compression combustion engines). The sound pressure level in this case can reach values over 200 dB. These forces are transmitted to the engine structure and lead to vibrations that are radiated as noise[14].

On the other hand, in operation, between the contact surface between the crankshaft and the bearings, a mechanical noise is generated through the oil film. The main causes of noise generation in internal combustion engines can be summarized as follows:

- The aerodynamic effects of exhaust gases and fresh air at intake;
- The forces produced by shock due to technological games or as a result of wear;
- The sliding friction forces in the couplings of the component systems;
- The vibrations of the crankshaft assembly, connecting rod, crank, piston under the influence of gas pressure forces in the cylinders, unbalanced forces and torques;
- Operation of auxiliary engine sub-assemblies such as: cooling system, injection pump, water pump, oil pump and others.

The noise coming from the interaction of the vehicle through the tires with the roadway being transmitted both through the air environment and through the chassis inside the vehicle. The indoor noise problem consists of low frequency noises (<1000 Hz).

Contributions are made by the noise transmitted through the vehicle suspension (<500 Hz) and the noise transmitted directly by air and originating from the tire-vehicle structure interaction (>500 Hz). At the frequency value of 250 Hz, the internal noise pressure level is approximately 60-65 dB. On the other hand, at frequencies above 1000 Hz, the sound pressure level is generally 15 dB lower than at frequencies below 300 Hz.

The interaction between the tire and the structure of the vehicle depends on the texture and type of the road, and the phenomenon consists on the one hand in the deformation and compression of the air in the tire compartment and on the other hand this interaction generates horizontal and vertical forces which are transmitted to the chassis in the form of vibrations, as a result of noises[15].

In the operation of the vehicle, another acoustic source generating noise is the wind passing over the structure of the vehicle. This depends on the speed of the vehicles and is included in the problem of interior noise, from speeds over 110 km/h. When the vehicle moves, the external environment (air) comes into contact with the structure of the vehicle, thus creating a layer of turbulent air at the contact surface, pressure fluctuations occur and thus sounds are generated.

Noises from the intake and exhaust processes of motor vehicles occur at low frequencies below 500 Hz. When the intake valves close and open, there are sudden movements of the air masses, when closing the air charge is stopped and in this way a pressure pulse results that generates a noise input. During evacuation, the exhaust valve opens, the residual gases flow with significant pressures that lead to the appearance of sounds[16].

As automobiles have evolved from simple to complex machines, the propulsion system is modernized and quieter, the heating, ventilation and air conditioning (HVAC) system located on board the automobile becomes a prominent source of noise in the passenger compartment. The pulsation of the refrigerant pressure, measured at the operating frequency of the HVAC system compressor piston to which are added the phenomena produced during the suction through the air flow intake pipe, propagates as audible noise in the passenger compartment, located in the frequency range 16-16000 Hz, significant in studying the problem of interior noise of motor vehicles[17].

NVH researchers divide the problem of indoor noise into two categories: the problem of high-frequency noise and the problem of low-frequency noise. In the case of heavy-duty vehicles, the problem of low-frequency noise boils down to noises and vibrations radiated into the passenger compartment, caused by vibration constituent parts as part of the vehicle structure, which not only seriously affects the comfort of the driver and passengers, but they also have a big impact on driving safety and the life of the vehicle[18].

CONCLUSION

In the operation of vehicles on public roads, to the noise emissions of the permanent sources, analyzed in this paper, are added the emissions generated by the transient sources (such as traffic) which will contribute significantly to the cabin noise profile perceived by the passengers, leading to values that exceed the permissible limits. The impact created by the noise contribution associated with traffic, in a transitory way, on the values in the passenger compartment of the heavy vehicle, can create discomfort for the passengers over time and with exposure for a long time becomes harmful.

Analyzing the specialized literature, it was possible to define the main sources of sound that contribute significantly to noise emissions both in the passenger compartment of the vehicle, affecting the passengers and outside, affecting the external environment.

This paper presents a strategy for making cumulative preliminary estimates for the level of noise emitted by noise sources for a heavy vehicle, both stationary and moving, in order to obtain an initial picture of the cumulative impact due to noise and vibrations generated by acoustic sources originating from the operation of vehicles heavy.

At the same time, a monitoring strategy is presented to select the main sources of noise as well as important data on the acoustics of the vehicle interior, together with the selection of the best available techniques, with the aim of contributing to the further mitigation of the potential noise impact. on the passengers, as well as the implementation of a strategy that leads to the improvement of the interior acoustic comfort level.

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