



Sound fracture analysis of Silencer used with absorbent materials of ICE engines

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Abstract

Sound is one of the forms of mechanical energy and the two main characteristics of sound are intensity or power and frequency or wavelength.

Regarding their performance against the incoming sound wave, industrial silencers can be divided into two general groups: intensifying and absorbing silencers.

The main goal of this article is to design and present a Silencer based on the breaking of sound frequencies resulting from the movement of fluid in the exhaust output of heavy vehicles, which leads to a reduction of at least 50 decibels of sound, and the operator has enough peace and concentration when performing the mission. In this article, after examining three types of Silencers, absorbent Silencers that use the properties of porous absorbent material to absorb passing sound and are the simplest form of Silencers, have been selected, analyzed, and examined and are suitable for the OM457 engine of Idem Industrial Company. It is designed

Keywords: Silencer, design, acoustics, internal combustion engine, noise reduction

Introduction

To respond to the strict environmental laws, engineers are looking for new types of muffling elements that can take measures to suppress the sound caused by various types of elements that exist in the flow channel and produce sound. The muffling effect is usually achieved by introducing sound reflection and absorption, which generally Silencers are made in various shapes and dimensions according to their application, which can be divided into four main categories: reactive, reflective, absorbent, and dispersive. In this article, the absorbent Silencer Has been studied.

To achieve good sound absorption in a wide frequency band, various fibrous materials such as wools, including stone wool, are usually implemented, which are resistant to heat and ignition, and the main and obvious part of the sound muting action in this type of Silencers is to change Sound energy is converted into heat energy, and this conversion occurs in layers of absorbent material, the quality of which is the main reason and basis for the successful design of the Silencer [1].

The literature research concerning the subject is as follows:

Pavlo et al. developed a Silencer with noise reduction and hydraulic characteristics, they should have the main parameters for basic data as well as for indirect evaluation of the proposed technical solutions for sound insulation, so parameters such as the acoustic and hydraulic parameters of the internal combustion engine of the low-power exhaust system [1]. Cabral et al. focused on the modern type of absorption acoustic element which is a micro-perforated element, where the absorption in the micro-perforated element mainly originates from the dense effect inside the openings, nonlinear acoustic vortex shedding, and flow repetition. The results show a good potential for the developed microporous elements and it was also found that this type of absorbent element can effectively replace conventional designs containing fibrous materials [2]. To provide an alternative to traditional fibrous and porous absorbers, micro-perforated panels (MPP) are generally reliable and effective solutions for absorption silencing for in-duct applications. This model calculates the MPP absorption coefficient as a function of four parameters: cavity diameter (d), panel porosity (σ), panel thickness (t), and cavity depth [3]. Yari et al investigated the effect of adjacent air cavity partitioning on MPP transmission loss properties and the effect of these settings on MPP absorption coefficient was discussed. The test results for the reverberation sound absorption coefficient show that the absorption characteristics of MPP can be improved by using a paper honeycomb panel. [4]. Tao et al. considered a more complicated case where the partitioned cell walls were also made of porous materials, then they concluded that the change in porosity has a significant effect on the acoustic attenuation of the MPP [5].

In this article, the goal is to design an absorbent Silencer using acoustic knowledge for the OM457 piston combustion engine, which is specific to Idem Industrial Company, in the design of this system, the properties and characteristics of the porous absorbent material to absorb passing sound and the perforated pipe, which are the sound absorbing ducts Help has been received.

The innovation of the article is in the use of a logarithmic algorithm in the design of pipe holes, which has the soundest absorption, and with the help of porous absorbent material, it reduces the sound by at least 50 dB. Another advantage is the design and simulation in the ANSYS-Fluent environment to detect temperature and pressure at any point, and the ability to change dimensions and weight according to the type of operation.

materials and methods

The technical specifications used in this article are stated in Table (1) that the acoustic design of the Silencer is suitable for the maximum inlet exhaust temperature and maximum engine power, and for homogenization with standard atmospheric pressure to prevent suffocation and shutdown of the engine with maximum pressure The ratio of discharge and the maximum relative pressure of the input have been optimized and also the minimum pressure drop has been calculated so that this Silencer can give the engine the ability to have the least noise inside the cabin with the lowest pressure drop and the possibility of measuring pressure and flow at any point. A Silencer should be provided.

Table (1) used technical specifications

The maximum inlet exhaust temperature	520 degrees Celsius
The maximum engine power	315 kW
The maximum relative discharge pressure	185 mbar
The maximum relative inlet pressure	400 mbar
The minimum pressure drop	50 mbar

Level difference (LD), placement loss (IL), and transmission loss (TL) are among the sound transmission characteristics of a structure, respectively, level difference means the arbitrary two-point difference inside and outside the structure in sound pressure levels, and placement loss, is the acoustic power emitted without the presence of the structure and the most important of them, which is the transmission loss, is a principle to show the efficiency of the acoustic behavior for engineering use, which indicates the amount of sound energy passing through the structure and is calculated as follows:

$$IL = 10 \log\left(\frac{W_1}{W_2}\right) \quad (1)$$



$$LD = 20 \log\left(\frac{P_1}{P_2}\right) \quad (2)$$

$$TL = 10 \log\left(\frac{W_i}{W_t}\right) \quad (3)$$

In equation (1), $1W$ and $2W$ represent the acoustic power without and with the presence of the structure, respectively, and in equation (2) P_i and P_o represent the pressure inside the structure and outside it. Also, in equation (3), W_i and W_t are specified. It is the input power and transmitted power from the structure.

In this article, due to the high accuracy and low computational volume of the boundary component method, this method has been used to calculate the number of sound transmission losses in silencers that have a simple design, which provides the possibility of two-dimensional instead of three-dimensional networking. Also, the existence of faster and easier solutions with high solution accuracy due to the use of integral operators instead of derivatives is one of the other advantages of the existing method with the finite element method.

In general, by using this method, the acoustic analysis of the sound wave propagated inside the geometry of the object is done, and the differential equation with partial derivatives for each of the components is calculated by considering the geometry and its boundary in Laplace form according to equation (4).

$$\sum_{i=1}^N \frac{\partial^2 \varphi(p)}{\partial p_i^2} \quad (4)$$

where N is the maximum dimension change. The above relation is summarized for each component of the geometry in the form of relation (5):

$$\nabla^2 \varphi(p) = 0 \quad (5)$$

Figure (2) shows the internal view of domain D of the whole surface, whose integral form is in the form of equation (6).

$$\int_S \frac{\partial G}{\partial n_q}(p, q) \varphi(q) dS_q + \frac{1}{2} \varphi(q) = \int_S G(p, q) \frac{\partial \varphi}{\partial n_q} dS_q \quad (6)$$

In the above relation, (p, q) is Green's function, which expresses the function at the point q and relative to the main coordinate p .

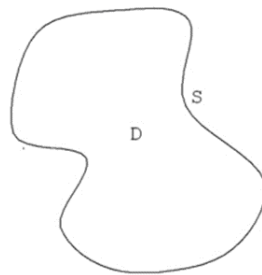


Figure 2: A view of the internal domain [6]

In integral functions, notation is a necessary and useful thing that makes it easy to determine the relationship between the integral equation and the linear system of equations, so for all points p that are on the surface S , the function can be written as equation (7).

$$\int_S G(p, q) \zeta(q) dS_q = V(p) \quad , \quad (p \in S) \quad (7)$$

In equation (7), $(P)V$ is the velocity of particles and by placing L as an integral operator, equation (7) can be rewritten as equation (8).

$$\{L\zeta\}_s(p) = V(p) \quad (8)$$

Now, after the relationships related to the calculation of the sound transmission loss were extracted and extracted, the time-dependent wave equation is simplified by using the Helmholtz equation, and for this purpose, it is assumed that the fluid in the acoustic domain is isotropic and homogeneous, and it should be kept in mind that Regardless of its geometry and range, the linear wave equation given in equation (9) is used in the acoustic analysis of the problem.

$$\nabla^2 \psi(p, t) = \frac{1}{c^2} \frac{\partial^2}{\partial t^2} \psi(p, t) \quad (9)$$

$\psi(p, t)$ is the speed of sound propagation and (p, t) is the time-dependent speed potential, which can be calculated as the sum of the potentials for each particle in the form of equation (10).

$$\psi(p, t) = \text{Re}[\varphi(p)e^{-i\omega t}] \quad (10)$$

In equation (10), ω is the angular frequency and it is calculated based on the formula $\omega = 2\pi f$, where f is the frequency in Hertz. (p) speed potential is independent of time, so the Helmholtz equation is in the form of equation (11) when (p) is the speed potential of sound and p is the coordinates of the desired point in the range.

$$\nabla^2 \varphi(p) + k^2 \varphi(p) = 0 \quad (11)$$

Finally, the sound pressure level and sound transmission loss in decibel scale can be measured using the logarithmic function of relations (12) and (13) that the sound pressure level includes sound pressure and reference pressure (p) which is approximately equal to 2×10^{-5} Pasgal and the sound transmission loss relationship includes the pressure ratio at the inlet and outlet levels.

$$SPL = 20 \log_{10} \left(\frac{p(p)}{p_*} \right) \quad (12)$$

$$TL = 10 \log_{10} \left(\frac{p_{in}}{p_{out}} \right) \quad (13)$$

Computing software

The software that has received attention in this field and has been important in the expansion of the boundary element method is the Fluent software, which is used to check the level of sound transmission loss of silencers because the Fluent software is multi-purpose and uses advanced numerical solution methods. Modeling and simulating physical problems.

This program provides the possibility of integrating this simulation with other computational methods and two-dimensional and three-dimensional design software (CAD) in the same environment, and also in the field of acoustics, this program is partially capable of solving partial and complete differential equations for analysis and Investigating the behavior of linear and non-linear systems and boundary conditions.

Governing boundary conditions

In the boundary component method, the boundary condition appears as equation (14), which includes the velocity potential $\varphi(p)$ and normal velocity $V(p)$.

$$\alpha(p)\varphi(p) + \beta(p)V(p) = f(p) \quad (14)$$

In the above relationship, α & β & f are complex values defined on the surface, and this relationship depends on the selected boundary surface.

For the surfaces that the sound wave does not pass through at the moment of impact and is completely reflected, it is called the wall boundary condition, which can be used for the external surface of the expansion chamber and the internal exhaust pipes, and this boundary condition is obtained from equation (15).

$$\left(-\frac{\nabla \varphi(p)}{\rho} \right) \cdot n = 0 \quad (15)$$

Results and discussion

In this article, with the help of Fluent software, the sound transmission loss level was investigated in the exhaust warehouse with porous structures. For this reason, the geometry of the exhaust manifold was modeled in the Catia software, and then the level of sound transmission losses was calculated for the mentioned model using the boundary component method and applying boundary conditions to the problem as well as accurate meshing.

The investigated exhaust tank includes inlet and outlet pipes, perforated pipes and sound absorbent materials, the purpose of this modeling is to investigate the effect of perforated pipes and porous plates on sound absorption and



finally the results obtained with the laboratory results that were conducted using the transfer matrix method was compared and an acceptable overlap was observed.

Silencer design

Considering the boundary conditions as well as the technical specifications of the mentioned engine, the Silencer was designed, the final and optimal dimensions of which are shown in table (2).

The use of a logarithmic algorithm for perforated pipes was an innovation that was used in this article because this algorithm is the most optimal of its kind and has the most sound absorption.

Table 2: Dimensional specifications of silencer

Length	230 mm
Width	105 mm
Height	1890 mm

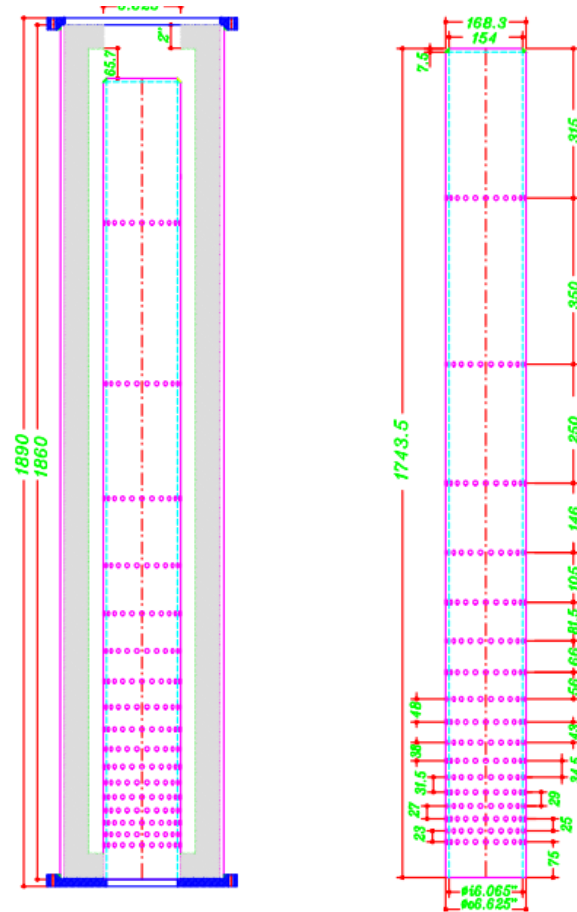


Figure 3: Finished dimensions of the Silencer

Conclusion

Absorbent materials that are made of porous materials and prevent the sound from escaping are often used in layers to reduce the level of passing noise. The use of absorbent materials in vehicles such as cars and airplanes plays a very important role, so in this regard, the acoustic damping function of silencers In the presence of sound absorbing materials, it was discussed that the Silencer with the shape and dimensions according to figure (3) was investigated, the sound absorbing material in this analysis was rock wool, whose density is equal to 5000 microns per meter.

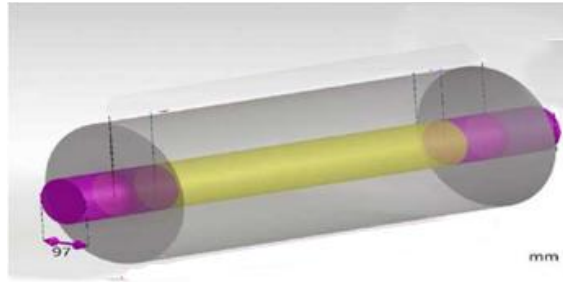


Figure 4: Silencer with sound-absorbing material

In this modeling, the airflow is considered an ideal fluid, which enters the expansion chamber through the perforated tube along the inlet tube and collides with the absorbent material.

The perforated tube has holes with a diameter of 5 mm, a thickness of 1.5 mm, and a percentage of porosity of 25. The absorbent material completely covers the expansion chamber like a cover, and the meshing of this geometry is visible in Figure (5). The perforated meshing was chosen due to the previously mentioned three-dimensional algorithm, and the important point in the analysis, due to its axial symmetry in the geometry of the shape, and to reduce the volume of calculations, it was checked in one-fourth form.

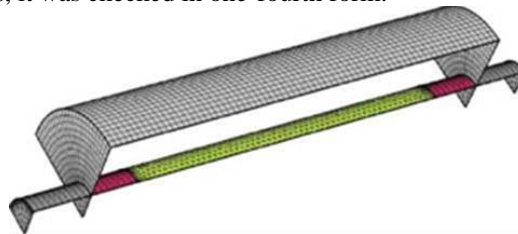


Figure 5: Meshed geometry with absorbent material and perforated pipe

The comparison of the results obtained from the analysis of boundary components with the laboratory method is given in graph (1). In this diagram, the analysis of the boundary parts of the geometry when it contains absorbent materials and when it does not contain absorbent materials is compared with the laboratory method, and a relatively good agreement is shown.

In addition, it can be concluded from the graph that adding absorbent material to the geometry creates a wider bandwidth, and a more coherent graph is obtained. The results also show that these materials can increase the level of sound transmission loss at high frequencies.

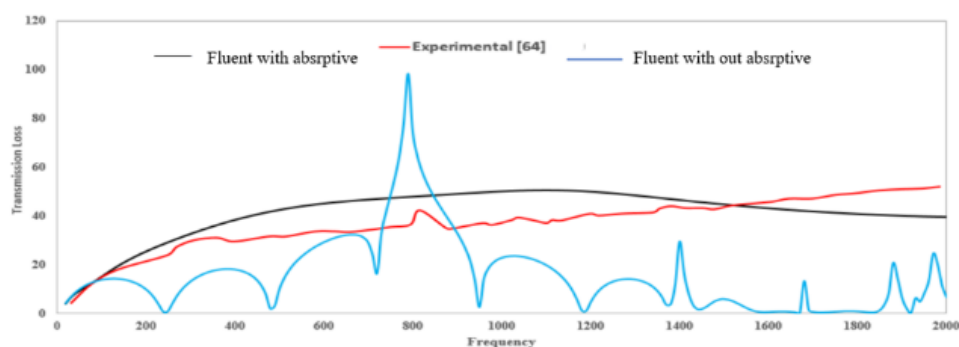


Diagram 1: The amount of sound transmission loss with and without absorbent material

In general, in this article, the types of silencers were briefly discussed and it was determined that sound is converted into heat in acoustic energy-absorbing silencers during an air path in perforated tubes. Absorption Silencer destroys the acoustic energy caused by the movement of acoustic waves by using the properties of absorbent material. Also, absorbent Silencers have a simpler structure, and one of the acoustic characteristics of Silencers is the level of sound transmission loss in them, which is logarithmically proportional to the pressure ratio entering the expansion chamber. It is defined as the pressure at the exit of the expansion chamber, which is measured in decibels.

In this research, due to accuracy in solving and reducing the number of calculations, the boundary component method was used to calculate the sound transmission loss level of silencers with simple structures.

Also, the amount of sound transmission loss was calculated using the boundary component method using Fluent software for Silencers with a circular cross-section, and the results indicate that the results of the boundary component method are in good agreement with other methods such as the laboratory method; Therefore, this method is efficient and useful in calculating the amount of sound transmission loss in silencers with any internal geometry. Finally, among these models, a model that has a simpler structure and a better sound transmission loss graph in terms of frequency bandwidth was used as an example for detailed design.

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