Paper No.367/2021

IMPROVEMENT OF ACOUSTIC FEATURES OF CATALYTIC MUFFLERS

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Abstract: *This article describes an experimental method of designing mufflers based of finite element modelling and the results of experimental study. We have presented the results of studies, including in the form of sound pressure distribution over the internal volume and transmission losses of the developed designs of the muffler. Based on the results of these studies, a design with the best vibroacoustic features was selected. The results of experimental testing of the developed and manufactured design of a catalytic silencer in a car are presented.*

Keywords: *Finite-element model, exhaust system, muffler, transmission loss*

DOI: *10.36336/akustika202139230*

1. INTRODUCTION

In recent years, the requirements for external noise from vehicles have become stricter. A car equipped with an engine must meet the current noise standards, which are regulated by UNECE Rule No. 51 with amendment 03 (for Europe and Russia). To achieve the required external noise levels of vehicles, it is necessary to develop modern low-noise mufflers that meet the requirements for toxicity and backpressure. In particular, there has been tremendous progress in developing mufflers. This is due to the use of modern materials, technologies, and testing/calculation methods.

The acoustic performance of an exhaust muffler can be measured using several parameters such as the installation effect, insertion loss, and transmission loss.

The installation effect is determined by measuring the sound pressure or sound power of the noise at the test point before and after installing the muffler. Usually, the effect of installing a muffler in a so-called basic system is determined during bench testing of the external noise, which helps you to determine the effectiveness of a muffler. However, this value depends on many factors during testing and allows only an approximate estimate of a muffler's efficiency.

Insertion loss is determined by testing the entire exhaust system, where the noise of a system with a muffler is measured and compared to the noise of an exhaust system in which the muffler is replaced with a straight piece of pipe. However, this parameter depends both on the design of the muffler and the features of the engine and exhaust system; that is, the insertion loss for the muffler installed in one vehicle may differ significantly from the insertion loss for the same muffler installed in another vehicle with a different engine or a different muffler.

To assess the efficiency of both the entire muffler and its elements, the most informative parameter is the transmission loss, or ***TL***. It is calculated as follows:

$$\boldsymbol{TL = 10\, lg\, (W_{in} / W_{out})} \tag{1}$$

where
$\boldsymbol{W_{in}}$ - sound wave power at muffler's input,
$\boldsymbol{W_{out}}$ - sound wave power at muffler's input output.

When designing an exhaust system, the main objective is to achieve the installation effect that provides the standard noise valuesat a control point. However, the system can consist of several elements connected in series and / or in parallel by means of connecting pipes. A change in the design of one element leads to a change in the boundary acoustic conditions for the operation of another element, which affects the entire system. At the first design stage, the interaction of various elements of the system is not taken into account. Instead, the transmission loss is used. This parameter determines the attenuation of acoustic energy by each element. The second stage involves the calculation of the entire exhaust system, taking into account the interaction of individual elements, which is a second-order value of smallness compared to the impact of the design features of each muffler element.

2. DESIGNING 3D-MODELS OF CATALYST MUFFLERS

The ANSYS software package is used to create three-dimensional FEM of the muffler. Finite element modeling allows to analyze the required number of muffler designs, taking into account the boundary conditions and select the most effective ones based on acoustic indicators.

Based on the size and layout constraints, the three best designs of mufflers (shown in Fig. 1) were selected from a variety of options.

The muffler construction (Fig. 1a) consists of:

1. Pipe with a inlet cone;
2. Catalytic unit;
3. Outlet cone with a pipe;
4. Internal volumetric chamber;
5. External volumetric chamber;
6. Outlet pipe.

The second muffler construction (Fig.1b) additionally consists of:

7. Volumetric chamber;
8. 8 holes with diameters of 30 mm.

The third muffler construction (Fig.1c) additionally consists of:

9. Volumetric chamber.

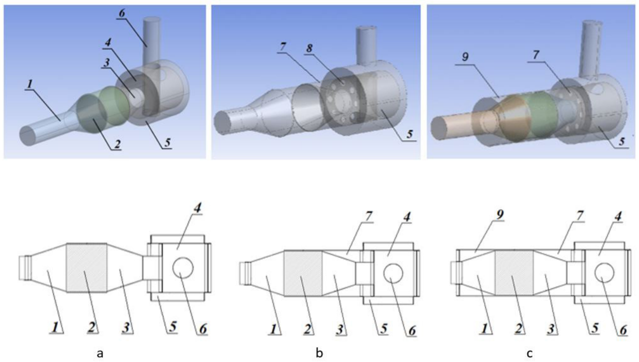


Fig. 1: Muffler construction: a – first construction, b – second construction, c – third construction

Finite element models (FEM) were developed in Ansys and exported to LMS Sysnoise. In Fig. 2 shows the models of the first two muffler constructions imported from Ansys.

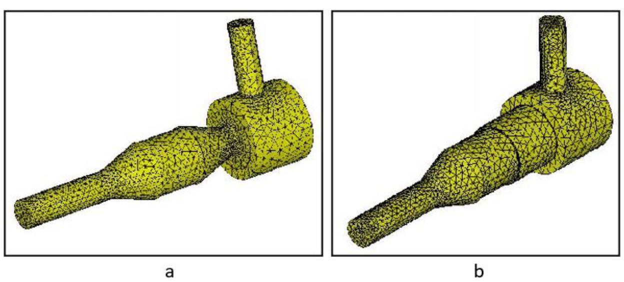


Fig. 2: A catalytic muffler with two volumetric chambers in the LMS Sysnoise software

3. THRESHOLD CONDITIONS IN THE ANALYSIS OF DESIGNS OF EXHAUST SYSTEMS, ANALYSIS OF THE RESULTS OF EXPERIMENTAL STUDIES

For the calculation in the Sysnoise software package, we set the boundary conditions (BC) – piston excitation at input and matched load at output. In Fig. 3a, they are marked in red and green, and in Figs. 3b and 3c, they are marked in red and blue, respectively.

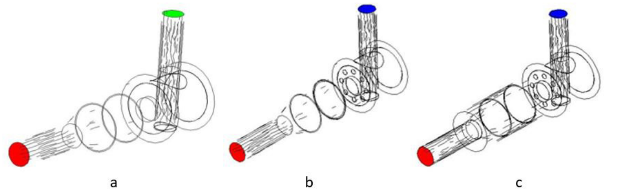


Fig. 3: BC for muffler constructions: a – first construction, b – second construction, c – third construction

It should be noted that the parameters of the density and speed of sound propagation in the catalytic block were determined experimentally according to the developed methodology and used for three designs of mufflers (Fig. 4a, 4b).

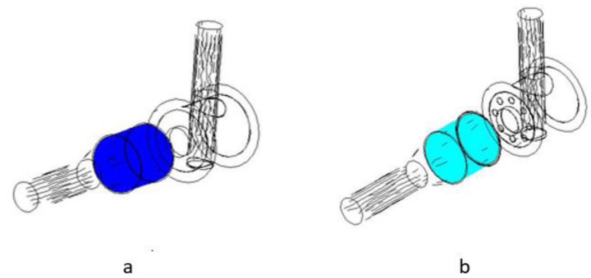


Fig. 4: BC of the catalytic block for muffler constriction: a – first construction, b – second construction

In fig. 5 shows an example of the distribution of sound pressure over the volume at different frequencies (first catalytic muffler design).

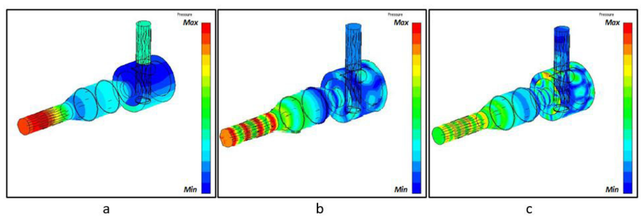


Fig. 5: Volume distribution of sound pressure first construction: a - 250 Hz, b - 1500 Hz and c - 2500 Hz

Taking into account the described scenarios of the distribution of sound pressure in mufflers, one can see a specific distribution of maximum and minimum at each frequency. This is due to the standing waves both in the inlet pipeline and within the muffler itself (Fig 5 a,b,c).

Fig. 6 shows the transmission loss (TL). Three constrictions of the mufflers are presented in the following order: Ver_1 – construction 1 (Fig. 1a); Ver_2 – construction 2 (Fig. 1b); Ver_3 – construction 3 (Fig. 1c)

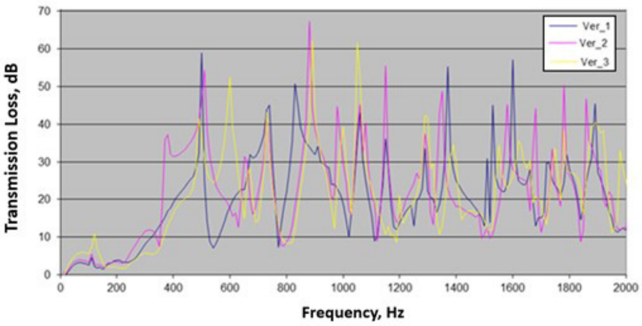


Fig. 6: Transmission loss of catalytic mufflers with three designs

Taking into account the described scenarios of the distribution of sound pressure in catalytic mufflers, one can see a specific distribution of maximum and minimum values at each frequency. This is due to the standing waves both in the inlet pipeline and within the catalytic muffler itself.

As seen from the above results, in the mid and high-frequency range all designs have approximately the same average efficiency of 20 to 40 dB, which is sufficient for efficient operation of the muffler. The effectiveness of reducing the sound pressure at frequencies up to 150 Hz is provided by the third design of the catalytic muffler thanks to the addition of the fourth volumetric chamber (Fig.1c).

The developed calculation and experimental methods for designing and studying mufflers based on finite element modeling makes it possible to design a muffler with the required acoustic parameters.

4. EXPERIMENTAL RESEARCH ON EXTERNAL NOISE OF THE DEVELOPED CONSTRUCTION OF THE EXHAUST SYSTEM

The third construction of a catalytic muffler proved to be the most effective (Fig. 7). Its efficiency was evaluated using a truck.

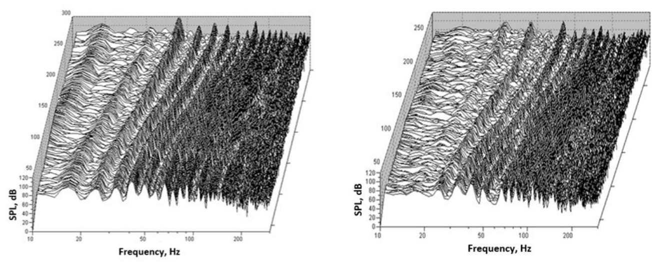
a b

Fig. 7: The optimal construction of a muffler

This muffler was compared to a standard one using a stationary vehicle in accordance with the recommendations of GOST R 41.51-2004 at the testing ground of the State Research Center of the Russian Federation FSUE "NAMI" (Fig. 8). The sound pressure level (SPL) measurement point was located at a distance of 0.5 meters from the exhaust pipe cut at an angle of 45 degrees.

Fig. 8: Testing the muffler at a FSUE "NAMI" testing ground

The results of comparative measurements are shown in Figs. 9 and 10.



a b

Fig.9: SPL at the cut of the exhaust pipe: a-serial muffler and b--catalytic muffler

It follows from Fig. 9 that, at all high-speed modes of engine operation in the low-frequency region (up to 150 Hz), the spectral components of the catalytic muffler are significantly lower than those of the serial muffler.

Fig. 10 shows the noise spectra of both mufflers when the engine is running at full load and at a crankshaft speed of 2,000 min^{-1}.

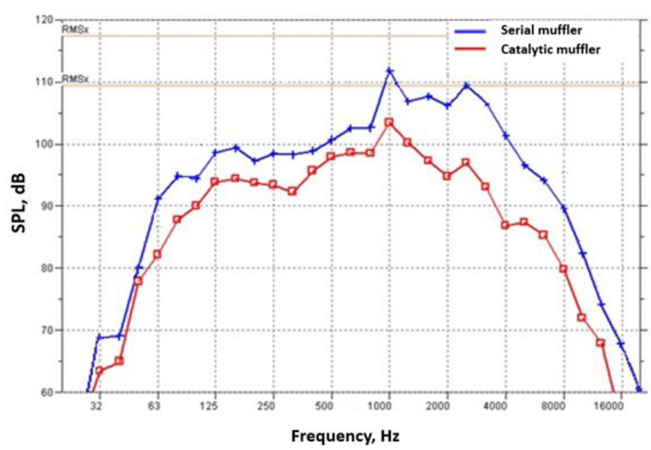


Fig. 10: Sound pressure levels at the cut of the exhaust pipe of (a) a serial muffler and (b) a catalytic muffler at a distance of 0.25 m at an angle of 45 degrees

The maximum sound pressure at a frequency of 1,000 Hz was 113 dB for the serial muffler and 104 dB for the catalytic muffler, which is 9 dB less. In the low-frequency range, the sound pressure levels of the catalytic muffler are 2 to 11 dB lower than those of the serial muffler. In the mid- and high--frequency range, the reduction in sound pressure achieved by the catalytic muffler is between 9 and 20 dB. If necessary, the efficiency of reducing the sound pressure in the mid- and high-frequency ranges can be increased by introducing a dissipative element.

5. CONCLUSION

1. Finite element modeling allows to analyze the required number of muffler designs (taking into account the boundary conditions) and select the most effective ones in terms of vibroacoustic properties.
2. Bearing in mind the overall-layout restrictions, three optimal designs of the muffler were selected, and finite element models were created for them.
3. For further research, the third design of the catalytic muffler was selected as the most effective in reducing sound pressure, especially in the frequency range up to 150 Hz due to the addition of the fourth volumetric chamber.
4. The catalytic muffler with the third design was compared to the serial muffler on a stationary car in accordance with the recommendations listed in GOST R 41.51-2004.
5. The catalytic muffler allows to reduce the maximum value of sound pressure by 9 dB at a frequency of 1,000 Hz at a distance of 0.5 m from the pipe cut. In the low-frequency range, the sound pressure levels of the catalytic muffler are 2 to 11 dB lower than those of the serial muffler. In the mid- and high-frequency range, the reduction in sound pressure achieved by the catalytic muffler is between 9 and 20 dB.

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