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DETERMINATION OF ACOUSTIC FEATURES OF CATALYTIC CONVERTERS OF ESHAUST SYSTEMS

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***Abstract**: The object of the presented work are ceramic blocks and diesel particulate filters manufactured by CORNING and applied in the development and serial production of the exhaust gas aftertreatment systems for cars and trucks, providing the required emission standards and noise regulations. The purpose of the work is the definition of acoustic parameters of the blocks for the further use of these data in the design of the system components applying finite-element modeling. A set of the blocks with different model parameters (diameter, length, and the cell density) was tested on acoustic stand using previously developed methods. Acoustic wave parameters have been identified for each block (namely, the comprehensive speed of sound and comprehensive density). The technique of the test preparation on acoustic test bench, the methodology and results of testing, the methodology and the processing of the results are presented. The estimation of measurement and calculation of errors are presented.*

***Keywords:** Exhaust system; automobile engine; catalytic block; particulate filter; acoustic stand; acoustic wave parameters; calculation method of finite elements*

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1. INTRODUCTION

Recently catalytic converters have become an obligatory element of exhaust systems. These converters are installed either separately in metal casing or together with the exhaust pipe. In order to properly design the exhaust system, it is necessary to set the acoustic parameters of the unit, which, in addition to reducing the toxicity of exhaust gases (its main function), is also a fairly effective element of noise suppression.

The catalytic converter is installed in the exhaust system so that the entire gas flow passes through its cells and, acoustically speaking, is a parallel set of straight capillary fibers. Accurate analytical calculations of the transmission of a sound wave through a fiber require the values of the thermal conductivity of the walls and the viscous surface resistance, taking into account the fiber diameter [1]. The accuracy in solving this problem depends on the possibility of experimental calculation of the specified parameters of the catalytic converter's microtubes using complex tests and subsequent mathematical processing of the results. The end result depends on many factors and the method error is difficult to predict.

In this paper, the acoustic parameters of the converter were determined through calculation and experiments.

2. METHODS OF TESTING AND PROCESSING OF EXPERIMENTAL DATA

The entire catalyst converter unit is a homogeneous medium with inherent wave parameters. A sound wave which passes through the converter undergoes changes in amplitude and phase in the direction of wave propagation – in the same way as in any homogeneous medium. By measuring wave parameters before and after its passing through the converter, it is possible to determine any of its volume-averaged wave parameters, such as the speed of sound, wave number, volume impedance, etc.

The well-known method of four microphones is currently used to carry out acoustic bench tests of the exhaust system elements [2-6]. A sample of the material is installed in a pipe between two pairs of microphones M1-M2 and M3-M4. A speaker generating sound waves is placed at one end of the tube, and an acoustic load is applied to the other end. After having determined the spectra of sound pressures P1, P2, P3, and P4 at points where the microphones are located, the input/output incident and reflected waves of the sample are separated by calculation, and the spectra of sound pressures P and vibrational velocities V are determined for both sides of the test sample. The values of pressures and vibrational velocities are related to each other by a matrix equation which is a system of two equations with four unknown coefficients of the transfer matrix of the tested element (T11, T12, T21, T22). In order to calculate these coefficients, two more equations are needed, which can be obtained through additional measurements with a second load at the output of the measuring tube [see the second chapter of 1]. This is the so-called method of two loads.

The obtained results are then mathematically processed [7], and the desired wave parameters of the catalytic converters are obtained.

3. EXPERIMENTAL STUDY

To carry out the experiment, we have selected a set of ceramic blocks with various parameters specified in Tab.1.

#	Dimensions (in inches)	Cell density (amount per sq. inch)	Block type
1	4.662 x 4.662 x 4.000	400	Cellular ceramic block
2	4.662 x 4.662 x 4.000	600	Cellular ceramic block
3	4.662 x 4.662 x 4.000	900	Cellular ceramic block
4	3.543 x 3.543 x 3.740	400	Cellular ceramic block
5	5.662 x 5.662 x 5.000	400	Cellular ceramic block
6	13.000 x 13.000 x 14.000	200	Particulate filter
7	5.662 x 5.662 x 7.200	300	Particulate filter
8	10.500 x 10.500 x 6.000	400	Cellular ceramic LFA block
9	10.500 x 10.500 x 6.000	300	Cellular ceramic LFA block

Tab. 1: Characteristics of ceramic blocks

The blocks have been selected according to the following considerations:
- to determine the dependence of the acoustic parameters of catalytic converters on the cell density; blocks №1 to №3, №8, and №9 have the same geometric dimensions but differ in cell density; the sizes of the groups of blocks №1 to №3 and №8 to №9 differ significantly;
- to determine the dependence of the acoustic parameters of catalytic converters on the block size; blocks Nos. 1, 4, 5, and 8 have the same cell density but differ in geometric dimensions;
- to determine the acoustic parameters of particulate filters with different cell densities (blocks #6 and #7).

All specified catalytic converters have been "packed", i.e. prepared for testing on an acoustic stand (as shown in Fig. 1): inlet pipe with connecting flange; inlet cone; packed block; outlet cone; outlet pipe with connecting flange.

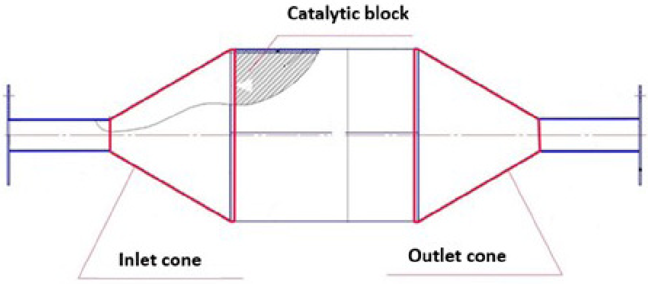

Fig. 1: "Packing" of catalytic converters for stand testing

In accordance with the test procedure, the following measurements and calculations have been carried out.

According to the results of measurements in four positions of the measuring microphones for each frequency range (two at the input, two at the output) at two acoustic loads for each packed block, the transmission loss (TL) parameters and the coefficients of the transmission matrix were determined. An example of the results of experimentally calculating the transmission matrix coefficients T11 ("acoustic pressure at the inlet – acoustic pressure at the outlet") and T22 ("sonic vibrational velocity at the inlet and at the outlet", real and imaginary parts) of the catalytic converter 1 in the frequency range between 0 and 3,000 Hz is shown in Fig. 2. A catalytic converter is symmetrical acoustically, and their T11 and T22 coefficients should coincide. As can be seen from the figure, this requirement is met with sufficient accuracy over the entire frequency range. By the deviation of the ripple of graphs from the general trend, one can give a general estimate of the error when determining the coefficients of the transmission matrix.

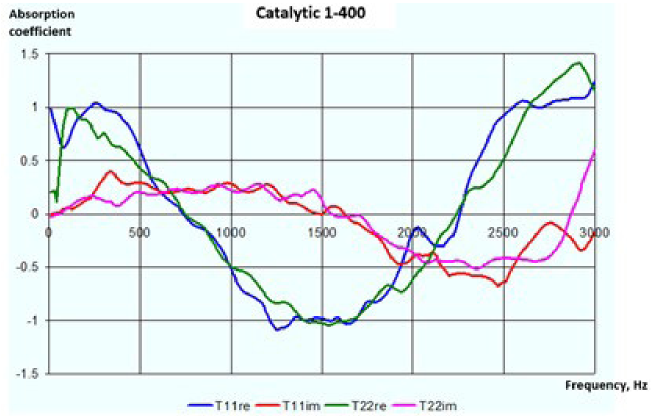

Fig. 2: Coefficients of the transmission matrix of a packed catalytic converter

Then, the parameters of transmission loss of the catalytic converter [***T***] were calculated according to the following matrix equation:

$$[\boldsymbol{TT}] = [\boldsymbol{T_{in}}][\boldsymbol{T}][\boldsymbol{T_{out}}] \quad (1)$$

where:
- the transmission loss matrix of a packed block [***T T***] is calculated experimentally;
- matrices of the transmission loss at the input [$\boldsymbol{T_{in}}$] and output [$\boldsymbol{T_{out}}$] cones are determined using the finite element model.

The obtained coefficients of transmission matrices were then used to determine the acoustic parameters of the blocks: ***W*** – wave resistance, ***k*** – wave number.

4. RESULTS OF THE EXPERIMENT

The results of experimental calculation of the acoustic parameters of catalytic blocks were determined in the form of spectra of the complex speed of sound and the complex density of the averaged medium of each catalytic converter. Fig. 3 and 4 show the superimposed spectra for units with the same geometric dimensions: 01_400 (cell density of 400 per sq. inch), 01_600 (cell density of 600 per sq. inch), 01_900 (cell density of 900 per sq. inch), diameter 4.662 inches, length 4 inches.

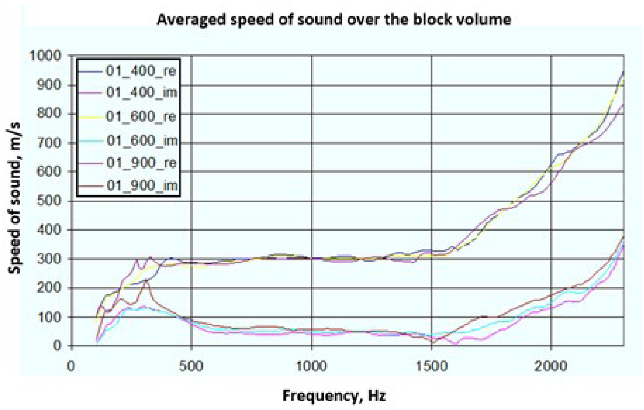

Fig. 3: Averaged speed of sound over the block volume

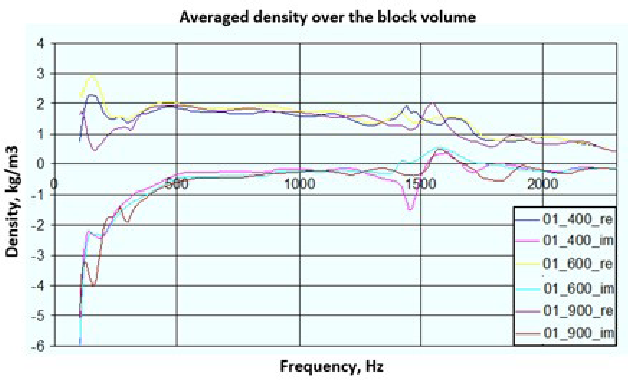

Fig. 4: Averaged density over the block volume

The analysis of the results helps to draw the following conclusions.

Catalytic converters (DOC) with the same diameter but various cell density:
- the real and imaginary parts of the block density, as well as the average real part of the speed of sound, does not differ in the entire frequency range for all blocks;
- the imaginary part of the speed of sound for frequencies above 500 Hz shows a small but stable difference; with an increase in cell density, the imaginary part (responsible for the absorption of sound) increases.

Catalytic converters with the same cell density (400) but various dimensions:
- the spectra of both the speed of sound and the density on average coincide in the entire frequency range.

Particulate filter units (DPF):
- the density spectra for DPF have a general trend similar to the trend of the density spectrum for the DOC block of the same diameter;
- the spectra of the speed of sound for DPF blocks have a general trend similar to the trend of the spectrum of the speed of sound for DOC blocks of the same diameter, but in the low frequency range;
- in the high-frequency range, there is a pronounced resonance in the sound velocity spectrum of DPF blocks: (at 740 to 760 Hz for a 13-inch block, 1,300 Hz for a 5.662-inch block). It should be noted that the ratio of resonant frequencies for the two DPF blocks corresponds approximately to the ratio of the lengths of these blocks (14 and 7.2 inches), that is, the peaks in the speed of sound spectra are determined by longitudinal resonance vibrations along the length of the blocks.

The developed method, if applied to particulate filters, makes it possible to determine the acoustic parameters for specific tested DPF samples (only of this size and density of cells). In order to find the acoustic parameters of particulate filters of any standard size, it is necessary to develop a new method of testing and calculation.

5. CONCLUSION

The tests carried out for a set of ceramic blocks with various typical parameters (cell diameter, length, and density; and particulate filters) made it possible to determine the wave acoustic parameters of the blocks in the form of reduced complex sound speed and density of the medium (based on the developed experimental method). The results obtained help to apply them in R&D for the development of exhaust systems using finite element modeling.

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REFERENCES

[1] Rakhmatov, R.I.: Improvement methods of research and design exhaust system vehicles on NVH parameters: PhD dissertation: 05.05.02 / Rakhmatov R.I. -M.: FSUE NAMI, 174 p., 2018
[2] Rakhmatov, R.I., Galevko, V.V., Nadareishvili, G.G., Yudin, S.I.: [Tendencies of development of exhaust systems of contemporary vehicles]. Natural and technical sciences, No. 6 (74), pp. 92-96, 2014
[3] Rakhmatov, R.I.: Improvement of acoustic characteristics of motor vehicle intake system based on calculation and experimental research / V.V. Galevko, G.G. Nadareishvili // Lecture Notes in Mechanical Engineering – 9783319956299. – pp. 2311-2322, 2019
[4] Rakhmatov R.I. Modern Vehicle exhaust system design dynamic analysis /AKUSTIKA, -03.2019, VOLUME 32. – pp. 351-354.
[5] Rakhmatov, R.I., Krutolapov,V.E., Zuzov, V.N.: Development of design solutions of exhaust system for gasdynamic noise reduction/Vibroengineering PROCEDIA-June 2019, Volume 25.-pp. 135-138, 2019
[6] Dickey, N.S., et all.: Time domain computational modeling of viscothermal acoustic propagation in catalytic converter substrates with porous walls // Journal of the Acoustical Society of America. v.118 (2), P. 808-817, 2005
[7] Song, B.H., Bolton J.S.: A transfer-matrix approach for estimating the characteristic impedance and wave number of limp and rigid porous materials // Journal of the Acoustical Society of America. V.107, № 3, P. 1131-1152, 2000

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