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ON CONTROL OF A PRESSING FORCE APPLIED TO ACOUSTIC LINER SAMPLE IN A NORMAL INCIDENCE IMPEDANCE TUBE

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Abstract: *The study considers the influence of control of the pressing force applied to an acoustic liner sample in a normal incidence impedance tube on the spread of acoustic characteristics of the tested sample. The design of a normal incidence impedance tube with a control system of a sample pressing force is presented. This system is implemented as a piston in a pneumatic cylinder with a pressure control unit. The measurements were taken on days when the characteristics of the environment were different from each other. This made it possible to better track the influence of the pressing force on reducing the spread of acoustic characteristics. In total, 10 measurements of the acoustic liner sample were carried out on a normal incidence impedance tube with and without control of the pressing force. The measurements were carried out for six months. As a result, the study has shown that the control of the pressing force applied to the acoustic liner sample provides a smaller spread of the obtained acoustic characteristics.*

Keywords: *Normal incidence impedance tube, impedance, sound absorption coefficient, acoustic liner sample, spread of acoustic characteristics*

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1. INTRODUCTION

Determination of the acoustic characteristics of liners based on measurements in a normal incidence impedance tube (NIIT) and processing the data obtained in the experiment using the 2-microphone transfer function method [1] is a widespread method. However, there are some disadvantages in this method. For example, in [2], various errors are considered that can occur during measurements with NIIT and affect the transfer function. Another parameter that can affect the acoustic characteristics of the liner sample is the distance between the microphones and the distance between the microphone and the sample, which is considered in [3]. Nevertheless, the experiments on NIIT are in demand, since this make it possible to evaluate the acoustic characteristics of a liner sample under simple experimental conditions.

Undoubtedly, each NIIT has its own design features, which can also affect the accuracy of obtaining acoustic characteristics. One of these features is the way of fixing the acoustic liner sample in the NIIT. It is known NIITs, in which a piston presses a sample, and the piston, in turn, is fixed with a binder bolt. There is a variant when a sample is fixed between flanges [4]. There are also variants when the piston is pressed to the sample by a hand and remains during the experiment in an unfixed state [5]. In addition, the NIIT duct can end with a rigid cover, to which the sample is simply attached without pressing [6].

When carrying out measurements on the NIIT, the pressing force affects sample rigidity. In its turn, this affect the values of the obtained acoustic characteristics. In all the above cases, NIIT does not control the pressure force applied to the sample. Thus, when repeating tests of the same sample on NIIT without a control system of the pressing force, a spread of acoustic characteristics can be observed. This spread is especially wide for cases when the samples are measured on the days at different atmospheric pressures. In this work, it is considered the design of NIIT with a control system of pressing force applied to acoustic liner sample. In addition, it is presented the results of determining the acoustic characteristics of the same sample tested on conventional NIIT and NIIT with a control system of pressing force.

2. NORMAL INCIDENCE IMPEDANCE TUBE WITH CONTROL SYSTEM OF PRESSING FORCE APPLIED TO ACOUSTIC LINER SAMPLE

The acoustic interferometer from [5] was used as NIIT with a conventional system of the sample fixing, the diagram of which is shown in Fig. 1. The impedance tube has thick steel walls, which allows measurements at high sound pressure levels (150 dB and above). The sample 3 is pressed by the piston 4 to the support ring 2 and fixed from the side with a binder bolt (not shown in the figure).

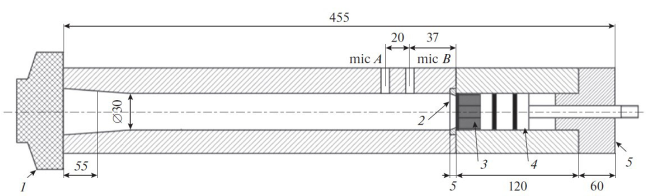

Fig. 1: Scheme of the conventional NIIT: 1 – sound driver, 2 – supporting ring, 3 – acoustic liner sample, 4 – piston, 5 – end cap

The NIIT with control system of the pressing force (Fig. 2) is a modification of the interferometer shown in Fig. 1. This is the same impedance tube 2, in the walls of which flush microphones 3 are installed and sound driver 1 is attached to one side of the tube. The rest of the interferometer is modified.

A pneumatic cylinder 5 is inserted into the sample holder 4 (Fig. 2) and controlled through the pressure control unit 6.

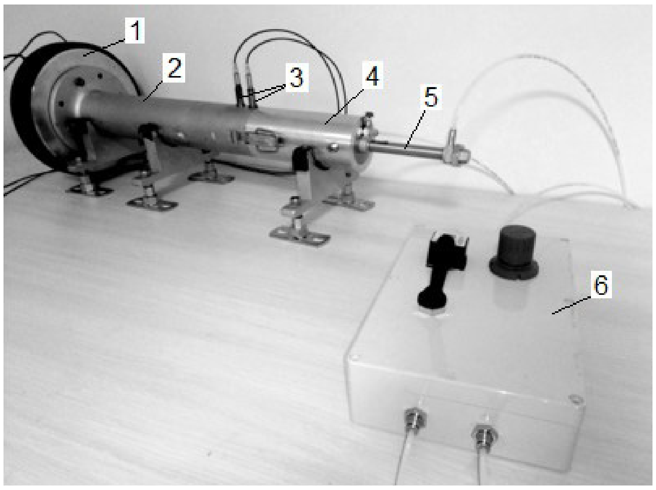

Fig. 2: NIIT with control system of pressing force

The test sample 8 (Fig. 3) is pressed by piston 9 to supporting ring 7, which in turn abuts against the impedance pipe 2. The piston is seated in the sample holder 4 through the sealing rings 10 (o-rings). The pneumatic cylinder 5 is screwed into the end cap 12, which is fixed in the sample holder 4 with the binder bolt 11. The piston motion towards the sample is caused by supplying air through the channel 18, which presses the rod 16 connected to the piston 9. In this case, the air from the cavity 17 moves through the gap 15 into channel 13 and through the adjustable throttle 14 is squeezed out into the control unit 6 (Fig. 2), where it is vented through the muffler-1 19 (Fig. 4). This solution provides a smooth piston motion so that it does not hit sample 8 when pressed. The piston motion from the sample 8 is caused by supplying air through the throttle 14 into channel 13, then air through the gap 15 moves into the cavity 17 and presses on the back side of the rod 16. In this case, the air from the cavity 17 through channel 18 is squeezed out into the control unit 6 (Fig. 2), where it is vented through the muffler-2 20 (Fig. 4).

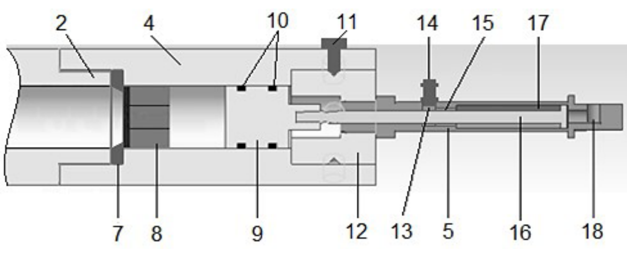

Fig. 3: Design of the sample holder with pneumatic cylinder

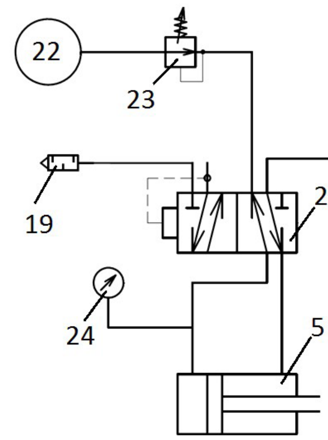

Fig. 4: Scheme of the pressure control

The air supply to channel 18 or 13 (Fig. 3), and, accordingly, the pressing or unloading of the sample 8 is operated through the manually operated valve 21 in the pressure control unit (Fig. 4). The pneumatic line is loaded with pressure from a stationary compressor 22. Using the pressure regulator 23, the required pressure is set in the pneumatic line, the value of which is displayed on the digital pressure gauge 24.

A mini-cylinder brand Camozzi 16N2A12A060 is used as a pneumatic cylinder. The pressure control (number 6 Fig. 2) unit is a sheet metal box containing: manually operated valve Camozzi 358-900; digital pressure gauge Camozzi PG010-PB-1/8; precision pressure regulator Camozzi M004-R15. There are also two mufflers G1/8 (numbers 19 and 20 Fig. 4) installed inside the unit to quietly release pressure from the pneumatic line.

3. STUDY OF INFLUENCE OF THE PRESSING FORCE APPLIED TO ACOUSTIC LINER SAMPLE ON THE SPREAD OF ACOUSTIC CHARACTERISTICS

The quality of production of acoustic liner samples is important for the results of the experiment [7]. The production of the samples from composite materials for carrying out experimental study is a rather laborious and time-consuming process. For research study, it is rational to produce acoustic liner samples of various configurations using 3D printing. The accuracy of such production of the test samples is much higher than the manufacturing from composite materials. This makes it possible to create resonators with a complex geometric shape [8] for verifying the calculation techniques [9-12].

For experimental study, a sample of ABS plastic with a standard cell size was printed (Fig. 5). The perforation of the sample was 8%, the height of the resonator was 20 mm, and the perforated sheet thickness was 1 mm. The sample was tested in a frequency range of 500-6000 Hz with sound pressure levels (SPL) of 130, 140 and 150 dB. Acoustic characteristics were determined based on the standard transfer function method [13].

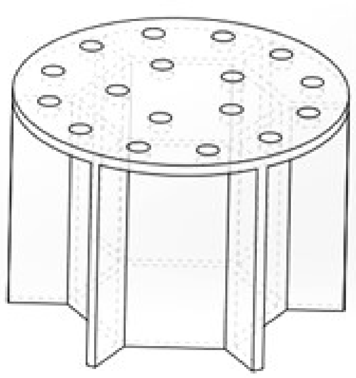

Fig. 5: Test sample

Since the characteristics of the environment (temperature and atmospheric pressure) can strongly influence on the obtained acoustic characteristics of the test samples, the experiments were carried out specifically on days when the characteristics of the environment were different from each other. This made it possible to better track the effect of the pressing force control on reducing the spread of acoustic characteristics. In total, 10 measurements of the sample were carried out on each NIIT configuration (without and with control system of the pressing force). The measurements were carried out for six months. The characteristics of the environment for these measurements are presented in Tab. 1.

Atmospheric pressure [bar]	Temperature [°C]	Humidity [%]
0.998	24.5	16
0.987	25	16
1.006	28	17
1.016	24	10
0.976	20	17
0.992	18	25
0.993	23	45
0.997	23.5	42
1.001	23.2	40
0.988	23	28

Tab. 1: Atmospheric conditions on the days of the experiments

The obtained acoustic characteristics of the sample at different SPL are shown in Fig. 6-8. It can be seen that the ranges of changes in acoustic characteristics, especially in the high-frequency region, are higher for conventional NIIT than for NIIT with control system of pressing force. It is also seen that as the SPL increases the range of changes in acoustic characteristics becomes narrower.

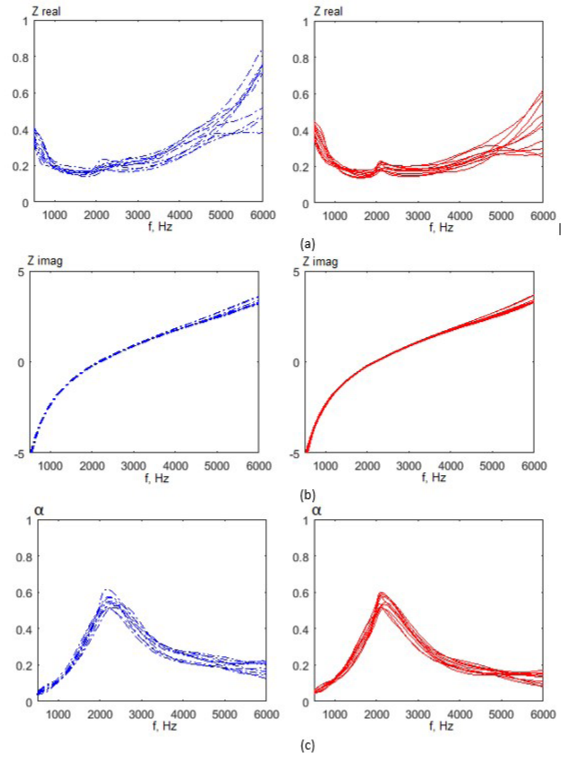

Fig. 6: Acoustic characteristics of the liner sample at 130 dB: (a) – real part of impedance, (b) – imaginary part of impedance, (c) – sound absorption coefficient, at the left of the figure – conventional NIIT, at the right of the figure – NIIT with control system of pressing force

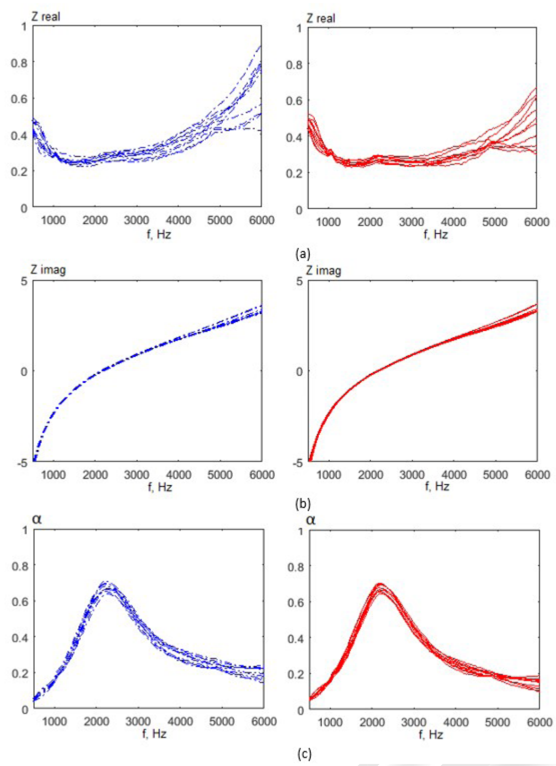

Fig. 7: Acoustic characteristics of the liner sample at 140 dB: (a) – real part of impedance, (b) – imaginary part of impedance, (c) – sound absorption coefficient, at the left of the figure – conventional NIIT, at the right of the figure – NIIT with control system of pressing force

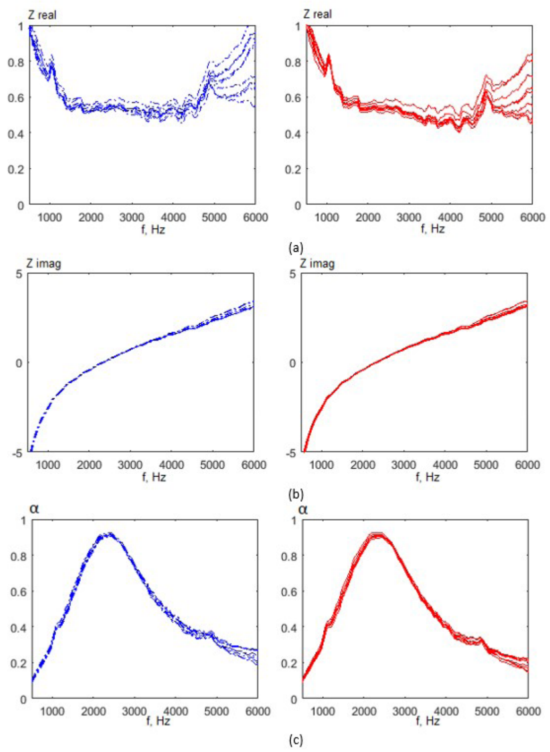

Fig. 8: Acoustic characteristics of the liner sample at 150 dB: (a) – real part of impedance, (b) – imaginary part of impedance, (c) – sound absorption coefficient, at the left of the figure – conventional NIIT, at the right of the figure – NIIT with control system of pressing force

To estimate the spread, the standard deviations of the acoustic characteristics were calculated using the formula:

$$\sigma(f) = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i(f) - \bar{x}(f))^2}$$

where
x(f) is acoustic characteristic at a given frequency f,
$\bar{x}(f)$ is acoustic characteristic averaged over the number of tests at a given frequency f, n is a number of tests. The obtained standard deviations are shown in Fig. 9. It can be seen that NIIT with control system of pressing force provides a smaller spread of acoustic characteristics as compared to a conventional NIIT.

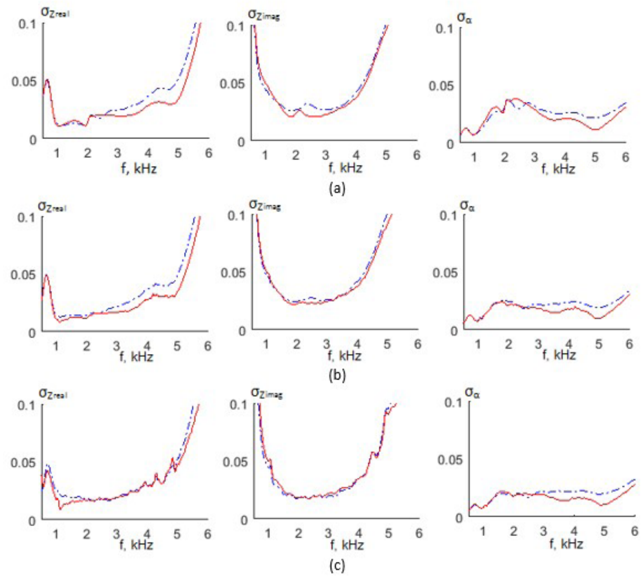

Fig. 9: Spreads of acoustic characteristics: (a) 130 dB, (b) 140 dB, (c) 150 dB, ‐·‐·‐·‐·‐ conventional NIIT, ——— NIIT with control system of pressing force

4. CONCLUSION

In the study, it has been demonstrated that the control system of pressing force applied to the sample in the NIIT allows one to reduce the spreads in the obtained acoustic characteristics. It is noted that as the SPL increases, the spreads naturally decrease, and at high SPL (more than 150 dB) there are practically no differences in the acoustic characteristics of the liner sample obtained with the conventional and modified configuration of a NIIT. Nevertheless, many acoustic liners of building structures are operated and, accordingly, tested at much lower SPL (no more than 120 dB), and the spreads in this case can be quite noticeable. Thus, one can conclude that the design of the NIIT with a control system of pressing force presented in the article is relevant. It also can be noted that design of this NIIT is patented [14].

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REFERENCES

[1] Chung, J.Y., Blaser, D.A.: Transfer function method of measuring in-duct acoustic properties. I. Theory. II. Experiment // Journal of the Acoustical Society of America, Vol. 68, No. 3. p. 907-921, 1980
[2] Boden, H., Abom, M.: Influence of errors on the two-microphone method for measuring acoustic properties in ducts // Journal of the Acoustical Society of America, Vol. 79, No. 2. p. 541-549, 1986
[3] Brian, F., Katz, G.: Method to resolve microphone and sample location errors in the two-microphone duct measurement method // Journal of the Acoustical Society of America, Vol. 108, No. 5. p. 2231-2237, 2000
[4] Polyakov O.L., Kornilov V.D.: Flowing acoustic interferometer, Patent for invention, No. SU-868370, September 30, 1981

[5] Fedotov, E.S., Kustov, O.Yu., Khramtsov, I.V., Palchikovskiy, V.V.: Comparative analysis of acoustical interferometers based on experiment-calculated research of sound-absorbing liner samples, PNRPU Aerospace Engineering Bulletin, No. 48, p. 89-103, 2017
[6] Mueller, D., Schulz, H.-J., Zitouni, G., Baumann, W.: Europe's largest aero acoustic test facility for aero engine fans – The Development and operation of the AneCom AeroTest anechoic chamber // AIAA Paper, No. 3050, p. 26, 2005
[7] Kustov, O.Yu., Khramtsov, I.V.: Estimation of the influence of incomplete side cells of a liner sample using numerical simulation, Scientific and Technical Volga Region Bulletin No.11, p. 137-140, 2019
[8] Kustov, O.Yu.: Influence of geometric errors on acoustical characteristics of the liner samples produced by 3D-printing technology, Scientific and Technical Volga Region Bulletin No.11, p. 21-23, 2018
[9] Fedotov, E.S., Khramtsov, I.V., Kustov, O.Yu. : Numerical simulation of the processes in the normal incidence tube for high acoustic pressure levels, AIP Conference Proceedings, Vol. 1770, No. 030120, 2016
[10] Khramtsov, I.V., Kustov, O.Yu., Fedotov, E.S., Siner, A.A.: On numerical simulation of sound damping mechanisms in the cell of a sound-absorbing structure, Acoustical Physics, vol. 64, No. 4, p. 511-517, 2018
[11] Khramtsov, I.V., Kustov, O.Yu., Palchikovskiy, V.V.: Determination of acoustic characteristics of full-scale sample of single-layered honeycomb liner based on numerical simulation, Akustika, Vol. 32, p. 182-188, 2019
[12] Khramtsov, I.V., Kustov, O.Yu., Palchikovskiy, V.V., Bulbovich, R.V.: Determination of acoustic characteristics of the double-layer honeycomb liner sample based on numerical simulation, Akustika, Vol. 34, p. 30-34, 2019
[13] ISO 10534-2: Acoustics – determination of sound absorption coefficient and impedance in impedances tubes. Part 2: Transfer-function method, 1998
[14] Kustov, O.Yu., Palchikovskiy, V.V., Burdin, N.N.: Acoustic interferometer, Patent for invention, No. RU2730041C1, January 27, 2020

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