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NOISE CONTROL FOR A BETTER ENVIRONMENT

Experimental research of nonlinear impedance of the orifices.

Komkin Alexandr[1] and
Bauman Moscow State Technical University
BMSTU, Department of Power Engineering, Moscow, Russia

Mironov Michael[2]
Andreev Acoustics Institute
Theoretical department, Moscow, Russia

Bykov Aleksei[3]
Bauman Moscow State Technical University
BMSTU, Department of Power Engineering, Moscow, Russia

ABSTRACT

The effect of sound pressure levels on the acoustic impedance of the orifices in the plate is investigated on the basis of measurements in an impedance tube using the two microphones method. A perforated diaphragms of 2 mm thickness with an orifices diameter of 4 mm were investigated. The dependences of the resistance on the number of the orifices in nonlinear modes are obtained. It is shown that in the nonlinear mode, the resistance of the orifice does not depend on their number in the plate and is determined by the oscillatory velocity in the orifece. An analytical approximation of the nonlinear resistance dependence on the oscillatory velocity in the orifice was carried out.

Keywords: Plate, Porosity, Measurement
I-INCE Classification of Subject Number: 26, 34

1. INTRODUCTION

Measurements and calculations take a great part in the impedance researches nowadays [1-3]. Reliable scientific data for architectural, medical and engineering designing are needed [4, 5].

This paper is a generalization of the results of an investigation of the characteristics of the Helmholtz resonator on the tube end wall, published in [6, 7], for high sound pressure levels in the tube when the resonator characteristics become significantly nonlinear. Studies of the nonlinear properties of the Helmholtz resonator take its place in a large number of papers, for example, in [8-20], which are mostly experimental. The main attention is commonly paid to the real part of the orifice impedance, defined as the acoustic resistance *R*. This issue was considered by Sivian [8], who stated that at high values of the oscillatory velocity in the orifice a transition to a nonlinear mode occurs and

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[1] akomkin@mail.ru
[2] mironov_ma@mail.ru
[3] alecksbykov@mail.ru

fraught with an intense increase in acoustic resistance.

In Ingard's works [9-11], for small neck thickness, that is way smaller than the diameter of the orifice, the value of the oscillating velocity in the neck that at some point determines the beginning of the nonlinear processes is proportional to its thickness, and with the increase of the throat thickness this dependence gradually decreases until it make no sense.

The influence of nonlinearities on the real part of the neck impedance (orifices in the septum) has been studied more accurately than the imaginary part. This question was considered in a large number of works by researchers later on [11-18]. It is shown that the real part of the impedance, which determines the dissipative losses, intensively increases with the increase of the oscillating velocity amplitude in the orifice, starting from the specific velocity value. The imaginary part of the impedance was investigated experimentally in [11,15-18] - with the increases of oscillating velocity amplitude the imaginary part decreases, which corresponds with the decrease of the orifice attached length. However, the limits of the attached length decrease with the increase of oscillating velocity are still unclear. In [18], descriptions of the real and imaginary parts of the acoustic impedance of the resonator neck by analytical formulas are also given, but it seems that the validity of formulas use is not sufficiently substantiated.

The latest publications on this issue are [19, 20], where the acoustic impedance of the orifices in the walls in the impedance tube was measured. At the same time, dimensionless acoustic impedance was considered, $\bar{R}_0 = R/(\rho c)$. In the course of the experimental studies, at first the acoustic impedance of the plate was determined, which was then converted to the impedance of the orifice as it was assumed that the law of conservation of volume velocity valid for linear acoustics is fulfilled. With use of this technique, it was found that the dimensionless resistance of the orifice on nonlinear modes increases in proportion to the diameter of the orifice, as opposed to linear resistance. However, this result does not have a clear physical interpretation, which necessitates additional researches in this direction.

2. MEASUREMENT SET-UP

In experiments there was used an impedance tube with an internal diameter d = 99 mm with two microphones 1 and 2 at distances of 153 mm and 281 mm, respectively, from the end of tube, where a partition with a certain number of an orifices were placed (Figure 1).

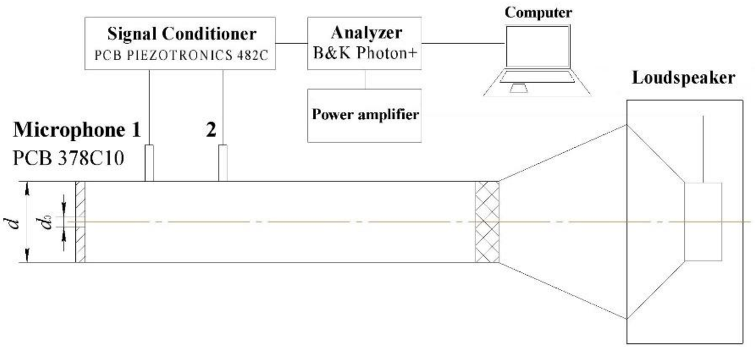

Figure 1 – *Experimental setup.*

The sound source is a Beyma 12MI100 speaker with a power of 450 W. To excite the speaker a sweep signal with a bandwidth of 10 Hz and a central frequency f_0 =150 Hz is used. The amplitude of the sweep signal varied, so that the sound pressure levels in the impedance tube could vary from 85 dB and 160 dB. The sound pressure was measured with a pair of 1/4" condenser microphones PSB 482C05. Then, the signals from the microphones were subjected to spectral analysis with the help of the B&K PHOTON + analyzer, which, by the transfer function method [20], determined the reflection coefficient of the sound wave from the partition *R*, and then the dimensionless acoustic impedance of the partition $\bar{Z} = (1+R)/(1-R)$.

Following Temiz [18], studies of perforated partitions with a thickness of 2 mm and orifices with a diameter of d_0 = 4 mm were carried out. Three perforated partitions with one, five and nine orifices were investigated (Figure 2). The parameter that characterize such partitions is porosity σ, defined as the percentage ratio of the total area of the orifices S_0 to the total area of the partition *S*: $\sigma = \left(S_0/S\right)100\%$. The porosity of the considered partitions was 0.16%, 0.82% and 1.47%.

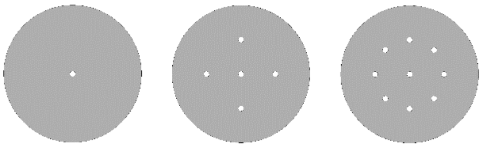

Figure 2 – *Investigated perforated plates with one, five and nine orifices of the diameter* d_0 = 4 mm

3. EXPRIMENTAL RESULTS

3.1 Impedance estimation based on calculated oscillating velocity in the orifice.

At the first stage, the effect of the oscillatory velocity U_0 on the impedance $\bar{Z}_0$ of the orifices on the perforated plates was determined. The oscillation velocity values were determined with the assumption that the law of conservation of volume velocity take its place during the transition of the sound wave from the impedance tube into the plate orifices on nonlinear operating modes: $U_0 = (S/S_0)U$,where *U* is the velocity measured in the impedance tube at the partition (not in the orifice but for tube diameter).

In this case, the orifice impedance $\bar{Z}_0$ is determined from the relationship:

$$\bar{Z}_0 = \bar{R}_0 + i\bar{X}_0 = (U/U_0)\bar{Z} . \tag{1}$$

Graphic dependences of the dimensionless resistance $\bar{R}_0$ on the velocity U_0 for the considered partitions are shown in Figure 3. Presented datas shows that the porosity of the plate does significantly affect its acoustic resistance, and the greater the porosity of the plate, the greater its acoustic resistance is.

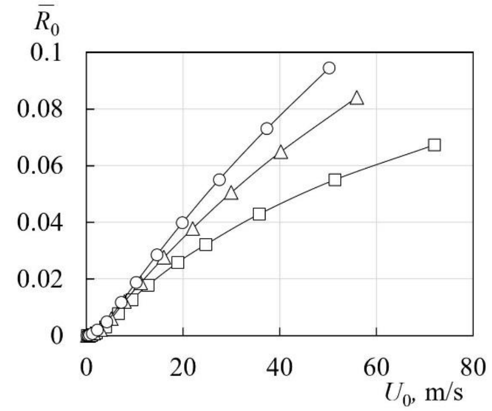

Figure 3. $\bar{R}_0$ *from* U_0 *for the plates with one (−□−),*
five (−Δ−) and nine (−○−) orifices.

Then the imaginary part of the orifice impedance $\overline{X}_0$, expressed in terms of the attached orifice length l_a, was determined. The dependence of the dimensionless attached length $\overline{l}_a = l_a / l_{alin}$, there l_{alin} – attached orifice length at linear modes, on the oscillation velocity in the orifice U_0 are given in Figure 4. It show that for the plate with small porosity (one orifice), the most smooth transition of the attached length to a new level is observed with U_0 increase. For the plate with five orifices, the attached length, goes to a new level and remains on it, and slightly increases further on with oscillation velocity U_0. For a nine-orifice plate, the attached length, reaching the minimum value and then begins to gradually increase with the increase of U_0.

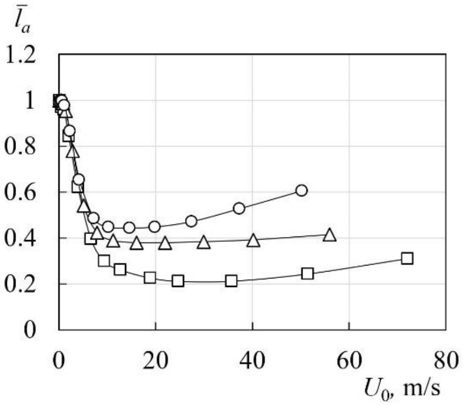

Figure 4. $\overline{l}_a$ *from* U_0 *for the plates with one (−□−), five (−Δ−) and nine (−○−) orifices.*

3.2. Impedance estimation based on measured oscillating velocity in the orifice.

Since the above-derived dependences of the resistance of perforated plates on the porosity did not have a reasonable physical interpretation, it was decided to estimate the oscillation velocity in the orifice by direct measuring with the Pitot tube (Figure 5).

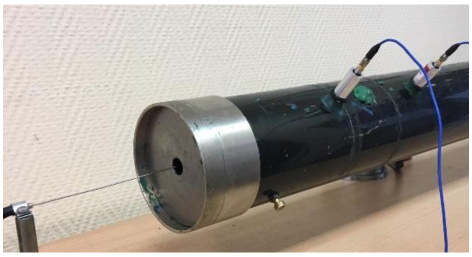

Figure 5. *Experimental setup with the Pitot tube fitted to the orifice in the plate.*

By measuring differential pressure Δp with the Pitot tube in the orifice the RMS oscillation velocity value can be determined: $\mathrm{v}_0 = \sqrt{2\Delta p / \rho}$. Taking into account that the Pitot tube measures the velocity for one direction motion that correspondes to a half-period of oscillations, we obtain that the total RMS value of the oscillatory velocity in the orifice is $V_0 = \sqrt{2}\mathrm{v}_0$. The sensitivity of the Pitot tube was found to be sufficient for measurements with sound pressure levels in an impedance tube greater than 125 dB.

The obtained experimental dependence of the measured velocity in the orifice V_0 on the sound pressure level at the partition L_p was approximated by the Equation 2:

$$V_0(L_p) = 0,02(L_p - 123)^2 + 3. \tag{2}$$

It should be mentioned that these V_0 values are in good agreement with the oscillation velocities measured by Ingard in [15] by mean of a hot-wire anemometer if we divide it by $\sqrt{2}$, as Ingard measured not the RMS, but the maximum values of the oscillatory velocity in the orifice.

At the second stage, the impedance of the orifices in the perforated plates was determined on the basis of the Pitot tube measured velocity in the orifice V_0. The dependences of the dimensionless resistance $\bar{R}_0$ of the orifices from the measured oscillation velocity V_0 are presented in Figure 6. As it was expected, the use of this approach changed the previously obtained analogous dependencies, shown in Figure 3. It turned out that the curves corresponding to plates with different numbers of orifices got into one line. Thus, the resistance of the orifices in the plates does not depend on the number of orifices, and this independence is manifested not only in the areas of developed nonlinearity, but also in the transition nonlinear mode. The last finding will be valid only for orifices of the same diameter.

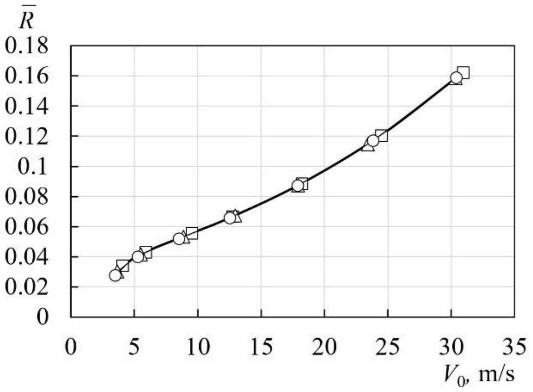

Figure 6. $\bar{R}_0$ *from* U_0 *for the plates with one (−□−), five (−Δ−) and nine (−○−) orifices.*

Unfortunately, we were not able to obtain reliable datas of the effect of the oscillation velocity V_0 on the attached length of the orifice in the partitions. This estimation turned out to be very sensitive to the V_0 measuring accuracy, so that for this purpose it was impossible to use the approximation Equation 2.

4. CONCLUSIONS

It is determined that in nonlinear modes, the law of conservation of the volume velocity during the transition of a sound wave through the orifice in the plates does not agree with the Bernoulli law. The velocity measurements with the Pitot tube showed that the oscillatory velocity in the orifice in the plate on nonlinear modes is determined only by the sound pressure at the plates and does not depend on the diameter of the orifices. It has been determined that the resistance of the orifice in perforated plates does not depend on the number of orifices of the same diameter both in nonlinear modes and in transition to nonlinear modes. Moreover, the dependence of the resistance of the orifice on the oscillatory velocity is nonlinear (close to quadratic).

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