Studying of the resonator depth influence on amplitude-frequency characteristics operating flow in the two-channel system

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Abstract. This paper is devoted to an experimental study of the characteristics of the operating flow in a two-channel system of an acoustic-convective dryer (ACD), developed at the Institute of Theoretical and Applied Mechanics (ITAM) SB RAS. A parametric study of cylindrical resonator depth and pressure in settling chamber influence on amplitude-frequency characteristics (AFC) of the formed flow is carried out. The influence of pressure in settling chamber and geometry of resonant cavity on AFC are considered. A tendency toward a decrease in Hartmann effect existence region with a decrease in cavity depth was found. A satisfactory agreement was obtained between the frequencies registered in the experiments and calculated using the Helmholtz formula for the natural frequency of resonant cavity.

1. Introduction

The idea of using high-intensity sound in drying of porous materials has led to development of acoustic-convective dryer (ACD) at the Institute of Theoretical and Applied Mechanics (ITAM) SB RAS. This device operating is based on the principles of a Hartmann-type gas-jet sound emitter operation (Hartmann whistle). Recently, increased interest in such applications has been shown in various applied fields. The study of physical processes occurring in the ACD two-channel system under the influence of a sound generator has a high priority in the development of acoustic drying technology, and also entails a number of fundamental discoveries related to the properties of deep resonators.

The use of ACD for drying porous materials allows one to avoid thermal effects on the drained material [1], which is a significant advantage for most materials: biological [2, 3], chemical [4–6], pharmaceutical and food [7–9]. An important advantage of the proposed drying technology is its higher intensity in comparison with the thermo-convective method [4]. At the same time, the structure of original material is not destroyed and its useful properties are preserved in the finished product. The relatively low energy consumption and simplicity of design makes the A CD attractive in economic terms [10].

A series of experimental [11] and numerical [12–15] studies is devoted to understanding the nature of the mechanisms occurring in the ACD system. The effects discovered during these studies require further research, including a series of physical and computational experiments.
2. Experimental setup
The experiments were carried out at ACD, the schematic diagram of which is shown in figure 1. The main elements of the setup are a settling chamber (1) subsonic narrowing conical nozzle (2) and a coaxially mounted resonant cavity of cylindrical shape (3). Elements (2) and (3) constitute a single structural element of the system — the primary channel. The nozzle and resonator are placed inside the secondary square section channel (4). The design described above forms the ACD two-channel system. Using a adjusting piston (5), the depth of the resonating cavity \( l \) was varied, and the maximum value of the depth is 31.5 caliber of the resonator. In this experiment, the cavity depth varied in the range from 23 to 31.5 with a constant nozzle diameter (0.5). The static pressure in the settling chamber varied in the range of 0-10 atm. The operating principle of the ACD consists in the periodic change of two processes: 1) filling an underexpanded supersonic jet from the nozzle into the resonating cavity, 2) outflow from the resonator of the jet reflected off the piston [16]. In the interaction of the jets flowing from the nozzle and from the resonate cavity, a seal region is generated, which is a source of sound fluctuations [17]. The formed acoustic-convective flow enters the operating section (4) and is recorded using the LH-610 highly sensitive piezoelectric sensor (6). The uncertainty in measurement of acoustic pressure is within ± 3%.

![Figure 1. Schematic diagram of ACD.](image)

3. The effect of pressure in the settling chamber on the AFC of the working flow
A series of experiments on recording the amplitude-frequency characteristics of the flow when pressure in the settling chamber changes, showed a number of patterns presented in figure 2. Firstly, depending on pressure in settling chamber, three formation stages of a high-intensity acoustic signal can be distinguished: generation and increase in the intensity of acoustic flow at low pressures up to 4 atm (figure 2.a); steady high-intensity mode of a operating stream (figure 2.b); attenuation of acoustic fluctuations in operating flow at high pressures of more than 9 atm (figure 2.c). Secondly, at low and high pressures, first harmonic dominates in spectrum, and second harmonic prevails in the interval between them. Of most interest is the high-intensity sounding mode, since nonlinear physical processes are realized in this mode.

At the second stage, at the high-intensity operation mode of the ACD, characteristic maxima in the AFC are clearly distinguished, which are the harmonic sequence of the main predicted frequency. The dominant second harmonic has a frequency of 250 Hz and an amplitude of 130 to 140 dB, while the amplitude of the first harmonic at 125 Hz is from 127 to 132 dB. Peaks in the spectrum with a frequency of 375, 500, 625, 750, 875, 1000 Hz are visible in figure 2b, which corresponds to 3–8 harmonics, but their intensity is much lower. The amplitudes of the 5th and 7th harmonics are low and almost comparable to background noise.
Figure 2. Characteristic acoustic emission spectra of deep resonators at a) 4.9; b) 6.9; c) 8.7 atm. In the settling chamber.
Figure 3. Comparison of the frequency (I) and intensity (II) of characteristic acoustic emission harmonics at different pressures in the settling chamber (black lines are the calculated frequency values of the corresponding harmonics).

The transition to the second harmonic is accompanied by a sharp increase in the frequency and intensity of all harmonics and persists until the end of the high-intensity operation mode, with a sharp decrease in all tones (figure 3). There is a slight increase in the oscillation frequency with increasing pressure in settling chamber (figure 3.I). At high pressure for 2-3 harmonics, the frequency rises before attenuation. Consider the change in intensity on the example of 3 and 4 harmonics, it can be seen that amplitude of high-frequency harmonics is much smaller than first and second in entire range of existence of the acoustic mode. The variation of harmonic intensity depending on pressure in settling chamber is nonmonotonic. In the interval between a) and c) the value of the fundamental harmonic goes almost constant, while the dynamics of the second, third, and fourth harmonics has a nonmonotonic character with a maximum.

4. The effect of cavity depth on AFC

In this experiment, the effect of resonator depth on frequency and intensity of generated acoustic-convective flow was studied. An analysis of the data showed that a decrease in cavity depth l leads to a shift in the fundamental frequency upward. In particular, maximum intensity is realized for second harmonic, at \( l = 31.5 \) and a frequency of 245 Hz, and for \( l = 23.5 \) at 310 Hz (figure 4.I). It is noted that the depth of resonator affects the intensity of generated sound. Larger depths correspond to greater intensity: as the depth of the resonant cavity decreases from 31.5 to 23.5, the intensity increases by 10 dB (figure 4.II).

High-intensity sound is observed at certain values of static pressure in settling chamber (4 - 10 atm.), called the region of existence of the Hartmann effect [18]. In this experiment, a tendency is observed to narrow the region of existence of acoustic emission with decreasing cavity depth. Thus, for the deepest cavities, reaching the mode of high-intensity oscillations (transition to the second harmonic) is observed in the pressure range from 4.4 to 9.7 atm, when high-intensity tones are observed for resonators with a smaller depth at 5.8 - 8.3 atm (figure 4.I).
Figure 4. Comparison of the frequency (I) and intensity (II) of acoustic emission harmonics for different cavity depth values l.

5. Verification
To verify the obtained experimental data, the basic frequency formula of the Helmholtz cylindrical resonator was used \( f = \frac{c}{2[l - 0.3d]} \), where \( c \) is the speed of sound of the working gas. The frequencies determined by this formula are in good agreement with the experimental data, and their change depending on the length of the resonator is shown in figure 5. Both the experimental data and the calculated values monotonically increase with decreasing resonator depth. The increase in the discrepancy between the curves is clearly noticeable, which was also observed in [11].

Figure 5. Comparison of the natural frequencies obtained in the experiment (points) with the calculated (lines).

6. Conclusion
As a result of an experimental study of deep resonators of an acoustic-convective dryer, it was shown that the generated acoustic flow has a series of harmonics with a dominant second harmonic at a frequency of 250 Hz, and its evolution with increasing pressure in the settling chamber of ACD is nonmonotonic.

The dependence of flow amplitude-frequency characteristics on cavity depth was established. It was found that with decreasing cavity depth, the frequency of flow increases and the intensity decreases. It has been experimentally shown that a decrease in cavity depth leads to a narrowing of the Hartmann effect existence region.
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References
[1] Gosteev Yu A, Korobeinikov Yu G, Fedorov A V and Fomin V M 2005 J. Appl. Mekh. Tech. Phys. 46 711–6
[2] Zhilin A A, Fedorov A V and Grebenshchikov D M 2018 Foods and Raw Materials 6 370 – 8
[3] Zhilin A A 2019 AIP Conf. Proc. 2125 030085
[4] Korobeinikov Yu G, Fedorov A V, Buluichevskii E A and Lavrenov A V 2009 J. Eng. Phys. Thermophys. 82 246–50
[5] Fedorov A V, Zhilin A A and Korobeinikov Yu G 2011 84 965–74
[6] Zhilin A A and Fedorov A V 2017 J. Eng. Phys. Thermophys. 90 1412–26
[7] Zhilin A A and Fedorov A V 2016 J. Eng. Phys. Thermophys. 89 323–33
[8] Yu G Korobeinikov, G V Trubacheev, Fedorov A V, Chu K M, Zheong D M and Kim Yu I 2008 J. Eng. Phys. Thermophys. 81 676–9
[9] Zhilin A A and Fedorov A V 2014 J. Eng. Phys. Thermophys. 87 908–16
[10] Korobeynikov Yu G, Nazarov A A and Fedorov A 2004 Energy Costs for Drying Wood by Acoustic Method Woodworking Industry No 4 6–7
[11] Zhilin A A and Golubev E A 2018 AIP Conf Proc 1939 020016
[12] Fedorov A V, Fedorchenko I A, An S B, Lee J H and Choo K M 2010 J. Eng. Phys. Thermophys. 83 72–82
[13] Fedorchenko I A and Fedorov A V 2013 J. Eng. Phys. Thermophys. 86 731–4
[14] Kravchenko A S, Zhilin A A and Fedorova N N 2018 AIP Conf. Proc. 1939 020018
[15] Kravchenko A S and Zhilin A A 2019 J. Phys.: Conf. Ser. 1268 012037
[16] Borisov Yu G 1967 Gas-jet sound emitters of Hartmann type Density matrix theory of coherent ultrafast dynamics Physics and Technology of Powerful Ultrasound ed L D Rozenberg, book 1 (Moscow: Nauka Publ.) pp 7–110
[17] V P Kurkin 1961 Akust. Zh. 7 442–5
[18] Glaznev V N and Korobeinikov Yu G 2001 J. Appl. Mekh. Tech. Phys. 42 616–20