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EXPERIMENTAL STUDY OF THE AIR-JET STEM GENERATOR

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ABSTRACT

Applications of sound and ultrasound air-jet stem generators became of great interest in heat and power engineering, in environmental protection, in the production of heat insulating material, extraction of poor uranium ore, in metallurgical production, in food industry for stabilization and clarification in beer production, in the agriculture sector for laying and fodder, for water disinfection, in medical treatments and in other fields[1]. Thus the aim of this paper was the assessment of construction, calculation method and acoustic parameters of air-jet stem generator. We determined the generator's acoustic parameters considering different distances between nozzle and resonator, but also by placing a disk perpendicular to the nozzle and inserting the generator into a cylindrical tube. We studied the influence of the resonator distance (Δ_R=0.7, 1.2 and 1.7 mm) and the pressure on acoustical field parameters (frequency and intensity level) produced by the air-jet stem generator. The results established the optimal parameters for the air jet stem generator in order to get maximal acoustical intensity.

KEYWORDS: circuit boards, vibration, stem generator

1. INTRODUCTION

The air-jet generator with stem was proposed in 1951 by Hartmann [2], considering that the stem allows changing the distance between the nozzle and the resonator. Research concerning this type of generator showed that the stem brings certain benefits such as the reduction of the working air consumption at random pressure variations. During the period 1960 - 1980 constructions of the injectors based on Hartmann air-jet generator with stem were patented. The countries with most patents are: USA, the former USSR, Germany and Japan [3]. It was noted the renewed interest for air-jet generator with stem in work [4]. Unfortunately, flow dynamics into Hartmann generator with stem has not been studied enough.

This paper presents synthesized results of gas dynamics and acoustic research of Hartmann air-jet stem generator. Investigation of any technological process relating to the application of ultrasound is to produce ultrasonic vibrations of a determined frequency and intensity. Sound and ultrasound air-jet generators could be used in both gaseous and liquid medium. The ultrasonic system transforms electrical power into vibrational or ultrasonic energy, mechanical energy. This mechanical energy is then transmitted into the sonicated reaction medium. The efficiency of the energy transformation depends not only on the equipment itself, but also on the ultrasonication conditions [5].

The purpose of this work is to develop working method to get maximal effect of sonic technology using the air-jet stem generator for food industry research and antibacterial treatments.

Food industry is a new area of application of sonic technology [1]. This offers a clear advantage in terms of productivity, yield and selectivity, with better processing time, enhanced quality, reduced chemical and physical hazards, and is environmentally friendly [6]. The properties of ultrasound are in direct relation with the propagation media [7] but their most important applications occur in liquid media due to the multiple generated effects: mechanical, optical, chemical and biological. It has been shown that ultrasound is suitable for water disinfection [8], [9], [10]. Based on the theoretical research, processing liquid media by ultrasound is influenced by the following parameters: wave pressure amplitude, frequency, acoustic power or acoustic intensity, temperature, viscosity and the treated medium.

2. EXPERIMENTAL SETUP AND PROCEDURE

2.1. Apparatus

A construction of the experimental air-jet stem generator is shown in Fig.1 and in Fig. 2.

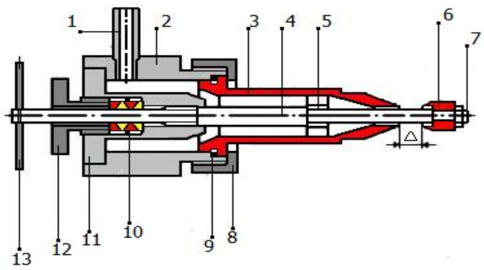

Fig.1. Experimental air-jet stem generator with variable resonator distance: 1- air connecting pipe; 2-base; 3-nozzle; 4-stem; 5-cross support; 6-resonator; 7- nut; 8 - fixing cap; 9-ring gasket; 10- triangular gasket; 11- cover; 12-locking nut; 13-handle; Δ- resonator distance

Fig.2. Experimental air-jet stem generator with variable resonator distance

Compressed air passes through the connecting pipe 1 and enters inside the nozzle 3, where it accelerates in the convergent part and leaves the nozzle with a speed equal to the speed of sound. In order to interact with resonator 6, inside the cavity appears a detached shock wave that oscillates between the nozzle exit section and the resonator, thus the detached shock wave transforms into high frequency sound waves. By varying the distance Δ_R between nozzle 3 and resonator 6, obtained by rotating the stem handle 13, we can adjust the air-jet stem generator acoustical parameters. The air-jet stem generator was designed and built with the dimensions [11] listed in Table 1.

Table 1. Air-jet stem generator dimensions

dimension	value	units
D_a	4.0	mm
d_t	3.0	mm
D_R	4.5	mm
l_R	2.0	mm
Δ_R	0.7÷ 1.7	mm
F	18÷ 20	kHz
$\dot{m}_a$	0.004	*kg/s*
p	0.1	MPa

2.2. Gas dynamics

The air-jet stem generator does not have moving mechanical parts and normally operates under its own oscillations. The use of air as working agent is necessary to generate ultrasounds. The air-jet stem generator pressure supply is controlled by an axial manometer with maximum value of 1 MPa and 1±0.05% measurement precision. Acoustic waves are produced due to local decomposition of primary jet border (that flows from the nozzle) and secondary jet (flowing from resonator), which occurs at periodic movement of the detached shock wave. For the participation of both jets in emission, primary and secondary, acoustic waves interference occurs and increases the acoustic intensity [12]. Thus, while dealing with both boundaries generation, the phase shift at interference is ¼ of oscillation period. This fact leads into error the supporters of the resonance hypothesis [13, 14], which confirmed that in this case it is a simple acoustic resonator with proper frequency equal to ¼ of oscillation period. Also, there is a size limit where the flow attachment to resonator internal lateral surface does not occur. The resonator will act as an obstacle plan leading to lower field intensity.

2.3. Calculation Procedure

The calculation method is presented in the paper. In accordance with this method, calculations for the air-jet stem generator are performed here. The dimensional scheme is presented in Fig. 3.[15].

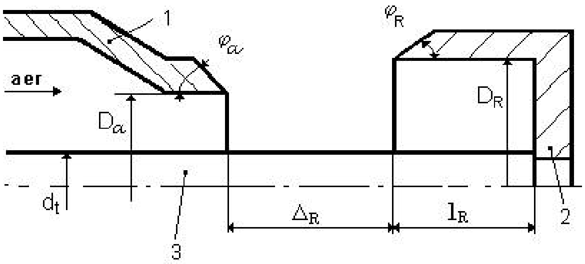

Fig.3. The dimensional scheme of air-jet stem generator

The calculation begins with the jet pressure number determination [16]:

$$n = \frac{P_0}{P_{ex}} = \frac{p + P_{ex}}{P_{ex}} \tag{1}$$

Starting from the calculated value of n we determined the resonator dimensionless geometric parameters [16]:

$$\overline{\Delta_R} = 0.74 \cdot n + 0.20 \tag{2}$$

$$\bar{l}_R = 1.1 \cdot \overline{\Delta}_R \tag{3}$$

$$\overline{D}_R = 0.34 \cdot n + 0.90 \tag{4}$$

$$\overline{D}_R < 5.25 \tag{5}$$

Using the working frequency chosen from the frequency area of f =18÷20 kHz, we calculated the nozzle slot [16]:

$$\delta = 0.075 \frac{a_0 \cdot n^{\frac{1}{2}}}{f \cdot \bar{l}_R^{\frac{1}{4}} \cdot \Delta_R^{\frac{1}{6}} \cdot D_R^{\frac{2}{3}}} \text{, [mm]} \tag{6}$$

where

$$a_0 = 331 + 0.59 \cdot (T - T_r) \text{ [m/s]} \tag{7}$$

and $T_r = 0^0$ C.

Using the selected parameters for working gas, namely $\dot{m}_a$, P_0 and T, we obtained the nozzle exit section area [16]:

$$F_a = \frac{P_0 \cdot \dot{m}_a}{\sqrt{T}} \cdot \left(\frac{k+1}{2}\right)^{\frac{k-1}{2(k-1)}} \cdot \left(\frac{k}{R}\right)^{\frac{1}{2}} \cdot 10^4 \tag{8}$$

Using the above data we got the nozzle and resonator geometrical parameters [16]:

$$D_a = \frac{2 \cdot F_a}{\pi \cdot \delta} + \delta \text{, [mm]} \tag{9}$$

$$d_t = \frac{2 \cdot F_a}{\pi \cdot \delta} - \delta \text{, [mm]} \tag{10}$$

$$\Delta_R = \overline{\Delta}_R \cdot (D_a - d_t) + d_t \text{, [mm]} \tag{11}$$

We obtain resonators distance and depth from the following relations [16]:

$$\Delta_R = \overline{\Delta}_R \cdot 2\delta \text{, [mm]} \tag{12}$$

$$l = \bar{l}_R \cdot 2\delta \text{, [mm]} \tag{13}$$

2.4. Experimental procedure

The main parameter that characterizes the acoustic power produced by a punctiform power issue experimentally determined is the sound intensity level [16]:

$$L = 10 \log \frac{I}{I_0} \text{, [dB]} \tag{14}$$

Acoustic parameters Frequency and sound intensity level were performed using Solo 01dB-METRAVIB, France device. This device is an instrument for acoustic measurements made in accordance with the noise emission standard SR EN ISO 3744/2009 measuring distance of 1 m, so that the microphone axis passes through the center of the air-jet stem generator working area.

The sound level meter has two analogue high-pass filters allowing for a programmable cut of the analysis frequency band. Measurements were performed only in the horizontal plane. Sound intensity level and frequency were determined according to air pressure at the generator entrance. The experimental air-jet stem generator was located at 2 m from the floor and 3÷ 6 m from the walls in a sound proof room. Background noise in the room during the research did not exceed 12 dB, which is much lower compared with the sound intensity produced by the sonic generator.

For the acoustic circular emission diagram determination, the acoustic parameters were measured in front of the air-jet stem generator by moving the microphone of 1 meter radius in the angles field of θ = 0 ÷ 180^0. The sound intensity level and frequency were determined at different emission angles according to the air pressure: at the generator entrance, with the reflective disk and with cylindrical tube (Fig. 4). The angle θ = 90^0 corresponds to the microphone axial direction. All experiments were performed in duplicate.

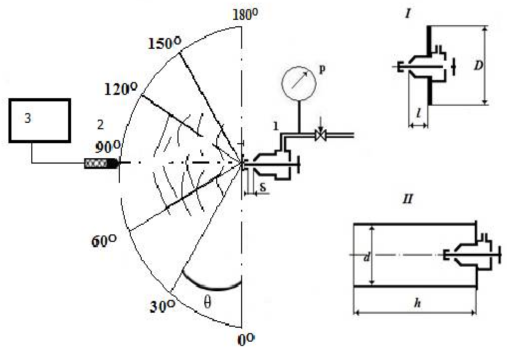

Fig.4. Pattern of performing acoustic measurements of air-jet stem generator at different emission angles: 1- air-jet generator; 2 - microphone; 3 - acoustical measurement system (Solo 01dB-METRAVIB device & Laptop); θ - angle of measurement; *I* - air-jet stem generator with reflective disk; *II* - air-jet stem generator into cylindrical glass tube.

3. RESULTS AND DISCUSSIONS

3.1. Air-jet stem generator with different distances between nozzle and resonator

Figure 5 shows the variation of overall intensity levels at different resonator distances, depending on supply pressure. At a resonator distance of Δ_R = 0.7 mm, the sound intensity level produced by the generator increased continuously with increasing supply pressure from p = 0.05 MPa to p = 0.35 MPa. A similar situation is for the resonator distance of Δ_R =1.7 mm. Instead, for the resonator distance of Δ_R=1.2 mm we can see the maximum level of overall intensity at a supply pressure of p = 0.1MPa. After that, the overall intensity level decreased.

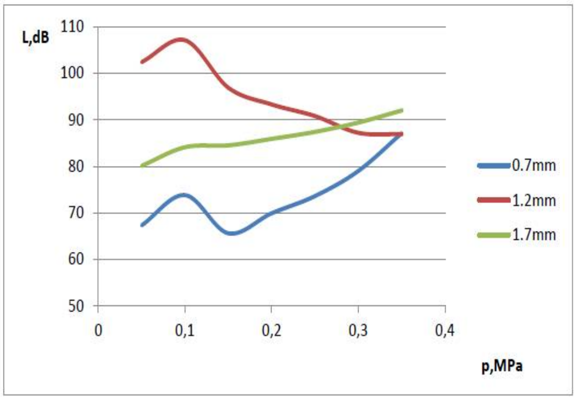

Fig.5. Overall intensity levels of air-jet stem generator at different resonator distances, depending on supply pressure

For Δ_R =1.2 mm and p = 0.1MPa, the overall intensity level is L=107.1 dB and the generator frequency is f=19.16 kHz, close to the calculated value of the generator (f =20 kHz).

3.2. Air-jet stem generator with disk placed normal on the nozzle

Measurements of air-jet stem generator with disk placed normal on the nozzle were performed at a resonator distance of Δ_R = 1.2 mm, p = 0.1MPa at different emission angles. These data are shown in Table 2.

Table 2. Sound intensity level for air-jet stem generator with disk placed normal on the nozzle at diferent emission angles (Δ_R=1.2 mm, p =0.1 MPa)

emission angles, θ	first frequency, kHz	sound intensity level corresponding to the first frequency, dB	second frequency, kHz	sound intensity level corresponding to the second frequency, dB	overall intensity level, dB
0	18.95	86.5	19.11	85.9	105.5
30	18.92	91.7	18.98	92.7	108
60	18.65	84.4	18.7	84.3	104
90	18.5	61.9	18.95	89.1	103.4
120	18.86	86	18.93	85.6	104
150	18.5	71.1	18.95	94.9	108
180	19	89.5	19.05	90.4	105.5

This table shows that the maximum overall intensity level is at 30÷150 emission angle. At 30 angular degrees we obtained the highest sound intensity level of 92.7 dB, corresponding to the second frequency of 18.98 kHz. At 150 angular degrees was measured the highest sound intensity level of 94.9 dB, corresponding to the second frequency of 18.95 kHz.
That means for the air-jet stem generator with disk placed normal on the nozzle that the best sound intensity level at p = 0.1MPa is obtained starting at 18.95 kHz frequency.

3.3. Air-jet stem generator placed into cylindrical tube

In Fig. 6 it can be seen that for the air-jet stem generator placed into a cylindrical tube, the best overall intensity level is at p = 0.1MPa.

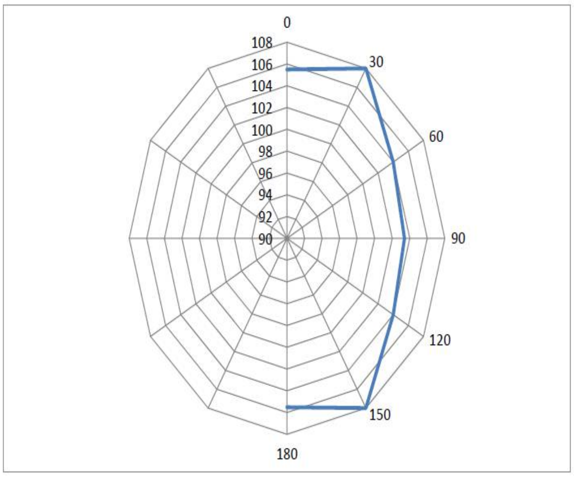

Fig.6. The angular diagram of air-jet stem generator with reflector disk: resonator distances Δ=1.2 mm and supply pressure p =0.1 MPa.

As pressure increases, the overall intensity level decreases. Table 3 shows that for air-jet stem generator placed into cylindrical tube at 90 angular degrees, the best sound intensity level is 98.7 dB for second frequency of 19.1 kHz.

Table 3. Sound intensity level for air-jet stem generator placed into cylindrical tube at 90 angular degrees

emission angles, θ	first frequency, kHz	sound intensity level corresponding to the first frequency, dB	second frequency, kHz	sound intensity level corresponding to the second frequency, dB	overall intensity level, dB
90	10	44.4	20	63.3	109.9
90	18.7	74.6	19.1	98.7	109.9
90	19.09	92.8	19.15	91.8	109.9

Technological liquids treated with air-jet stem generator will be in cylindrical containers. The air-jet stem generator placed into cylindrical tube is the desired version of the technological liquids treatment. The pressure at which the generator must operate is 0.1 MPa. The measured overall intensity at this pressure level is 109.9 dB. Also Fig.7 shows the acoustic spectrum of air-jet stem generator: resonator distances Δ=1.2 mm and supply pressure p =0.1 MPa.

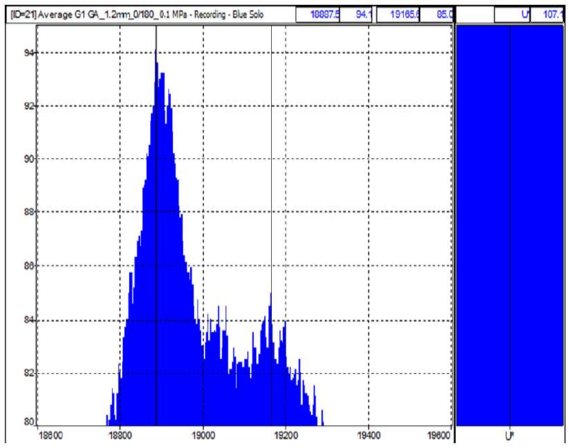

Fig.7. Acoustic spectrum of air-jet stem generator: resonator distances Δ=1.2 mm and supply pressure p =0.1 MPa.

4. CONCLUSIONS

Based on the calculation methods, the adjustable air-jet stem generator was designed. By changing the distance between nozzle and resonator, we established maximal acoustical intensity. Sound intensity level and working frequency of air-jet stem generator can be adjusted according to supply pressure.

The results of the three cases studied allowed us to conclude that:

- at a resonator distance of Δ_R = 0.7 mm, respectively Δ_R =1.7 mm, the sound intensity level produced by generator increased continuously with increasing supply pressure from p = 0.05 MPa to p = 0.35 MPa.

- at a resonator distance of Δ_R = 1.2 mm and p = 0.1MPa the overall intensity level is L=107.1 dB and the generator frequency is f=19.16 kHz, close to the one calculated (f =20 kHz);

- the air-jet stem generator with the disk placed perpendicular to the nozzle had the best sound intensity level at p = 0.1MPa from 18.95 kHz frequency;

- placing the generator into a cylindrical tube, at 90 angular degrees, the best sound intensity level is 98.7 dB for second frequency of 19.1 kHz.

Because air-jet stem generator uses as source mechanical energy of unsteady flow of gas or liquid jets, it is economically compared to the existing ultrasonic devices. Also it is the simplest construction in terms of technical achievement, to adjust acoustic parameters during technology process development.

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