An Efficiency Study of the Aerodynamic Sound Generators Suitable for Acoustic Particle Agglomeration

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Abstract—**The object of this study is the acoustic field generated by aerodynamic acoustic generators of various types and designs. Six types of aerodynamic acoustic generators were studied experimentally and theoretically to determine the parameters of their generated acoustic field. It was established that the aerodynamic Hartmann type sound generator produces the necessary for acoustic particle agglomeration acoustic field and can be used in acoustic air cleaning equipment. It was established that classical theoretical calculation methods underestimate the design features of aerodynamic acoustic generators and cannot be used to calculate their characteristics.**

Keywords-acoustic generator; frequency; sound pressure level

I. INTRODUCTION

Studies show that the efficiency of air cleaning equipment can be significantly improved if the distributed particles in the air being cleaned are treated by an acoustic field. Authors in [1, 2] established that the relative air humidity measured above an open surface tank is decreased up to 1.6 times in the presence of an acoustic field when compared with the humidity obtained from the conventional push-pull air removal system. Authors in [3] increased the average cleaning efficiency of cyclone separator from 87.2% to 97.5% by placing an aerodynamic sound generator at the bottom of the conical part of the cyclone separator. Authors in [4] improved significantly the fine particle removal efficiency with the combined effect of acoustic agglomeration and vapor condensation, reaching up to 80% with a sound pressure level of 150dB. An acoustic agglomeration process promoting the formation of particle clusters to enhance particle capturing efficiency without adding flow resistance in the air distribution ductwork provides an energy-efficient solution [5]. However, this method requires reliable, energy-efficient sound generators that can operate in various environments including aggressive ones. Such generators should be able to generate high-intensity sound fields with sound pressure level above 100dB [5], which is typically required to produce efficient acoustic agglomeration in several seconds. The most efficient are sound generators which emit acoustic waves at the ultrasonic frequency range [6]. In order to design a suitable sound generator, it is necessary to ensure that the acoustic field characteristics correspond to the characteristics of dust or aerosol particles exposed to that field [7, 8]. Increased radiation intensity causes increased relative speed of the particles. Particle adhesion is characterized by the characteristic frequency of the acoustic field. In case of 1μm size particles the characteristic frequency equals to 7.2MHz [7]. If the particle size is increased to 10μm, the characteristic frequency is decreased to 72kHz [7]. However, at very high frequencies with respect to the characteristic frequency, particle amplitude becomes independent on the frequency, but only on the ratio of densities of particle and environmental medium. Therefore, in order to investigate the acoustic characteristics of the designed sound generator, it is necessary to analyze the pressure of the generated sound.

II. OBJECTS OF RESERCH AND EXPERIMENTAL SETUP

Six aerodynamic acoustic field generator prototypes (Figures 1-6) were designed and manufactured. The prototypes were experimentally studied to determine the considered parameters of generated acoustic field: sound pressure and frequency.

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The first acoustic generator AAG-1 is shown in Figure 1. Compressed air flow enters into the generator through coupling 1 and then is distributed to the central 5 and peripheral channels 6, which direct the air into the resonance chamber 7. After the pressure in chamber 7 reaches a certain critical pressure, compressed air flow breaks through the air flow passing the channel 5 and leaves through the nozzle 4. After the outburst air pressure in the chamber 7 is decreased, air flow starts to pass through channel 5 and comes out through the nozzle 4 until the pressure in chamber 7 reaches certain value. Then the described cycle is repeated creating air flow pulsation and acoustic field as a result.

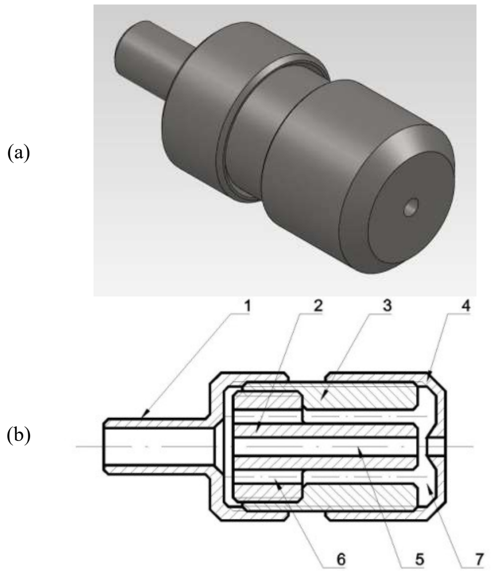

Fig. 1. Acoustic generator AAG-1: a) 3D model, b) longitudinal section

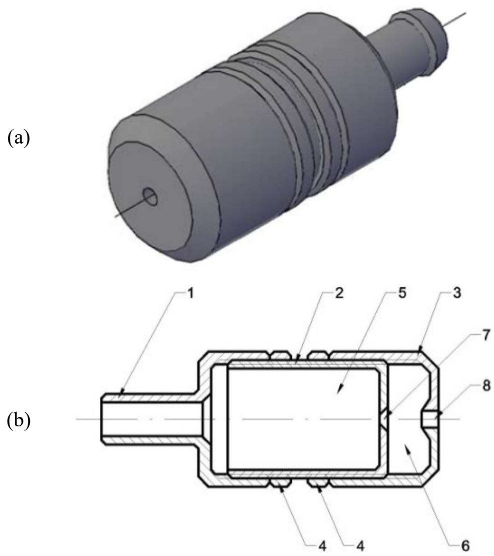

Fig. 2. Acoustic generator AAG-2: a) 3D model, b) longitudinal section

The second acoustic generator AAG-2 is presented in Figure 2. Compressed air flow is fed through coupling 1 into the primary chamber 5. Then the compressed air enters into the secondary chamber 6 of the acoustic generator through the diverging hole 7. Due to the hole with increasing diameter 7, air vortexes and pressure fluctuations are created in the chamber 6. Two air flows (primary and secondary) are created in the chamber 6 resulting from the turbulence. These flows come out through the hole 8 of the nozzle 3. Pressure fluctuations of outgoing compressed air flow generate high-frequency acoustic field.

The third acoustic generator AAG-3 is shown in Figure 3. Compressed air flow is supplied through coupling 1 into the diffuser 2. Then air flow bypassing the tab 5 of the diffuser enters into the nozzle 7 through slots 4. Due to the holes 6 additional air flows are ejected into the nozzle 7 which are mixed with the main flow of compressed air. Tab 5 and stepped narrowing of the nozzle 7 cause the turbulent flow. Mixed air flow generates acoustic field passing through the nozzle 7.

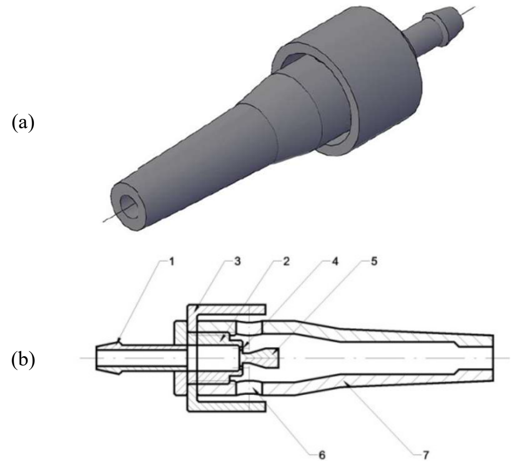

Fig. 3. Acoustic generator AAG-3: a) 3D model, b) longitudinal section

The fourth acoustic generator AAG-4 is shown in Figure 4. Compressed air flow through the coupling 1 enters into the central channel 4. In addition, the secondary compressed air flow is supplied through coupling 3 which flows the channel 5 and cross the main flow near the end of the nozzle 2. The intersection of two compressed air flows causes the pressure pulsations which generate high-frequency acoustic field.

The fifth acoustic generator AAG-5 is shown in Figure 5. Compressed air flow is supplied through coupling 1 into central channel 5 and is directed toward the nozzle 4. In addition, the secondary air flow is supplied through coupling 2 into the housing 3. This air flow enters the channel 5 through the inclined channels 6 that direct it opposite to the main flow. The intersecting opposed flows create pressure pulsations and generate high-frequency acoustic field leaving the nozzle 4.

The sixth acoustic generator AAG-6 is shown in Figure 6. Compressed air flow coming out of the nozzle 1 periodically fills the resonator 2. Then the air bursts coming out from the resonator collide with the compressed air exiting from nozzle 1. Density fluctuations are generated as a result and generate a high-pressure acoustic field. Aerodynamic acoustic generators of this type are known as Hartmann type generators.

(a)

(b)

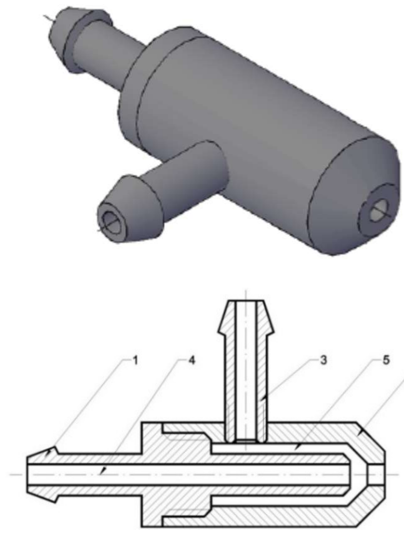

Fig. 4. Acoustic generator AAG-4: a) 3D model, b) longitudinal section

(a)

(b)

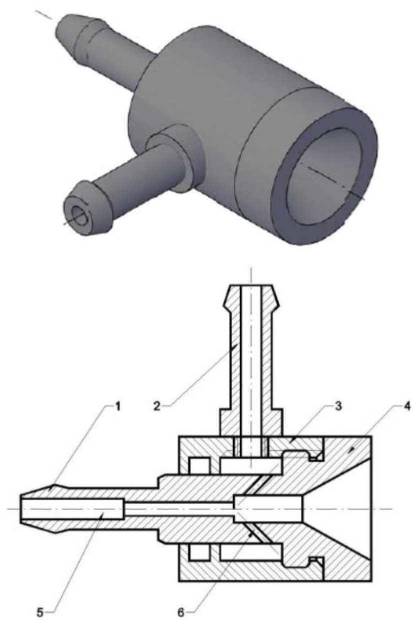

Fig. 5. Acoustic generator AAG-5: a) 3D model, b) longitudinal section

A Bruel & Kjaer compact sound level meter type 2250-S with frequency analysis software BZ-7222, BZ-7223 and sound recording option BZ-7226 were used for the measurements of sound pressure level and frequency analysis. The experimental setup is shown in Figure 7.

III. Results and Discussion

The results of parameter calculation of the aerodynamic acoustic generators are presented in Table I. The graphical representation of the results is shown in Figure 8. The calculation results show that air flow rate and generator's outlet diameter have the greatest influence on the frequency and power of acoustic field emitted by the aerodynamic acoustic generator. AAG-2 and AAG-4 sound generators with small diameter holes theoretically generate an acoustic field of 47.2kHz frequency. This frequency is more than exceeds the human hearing threshold, being more than the double of its upper limit. Calculations show that these two generators are the most powerful. AAG-6 generator with large outlet theoretically should emit a low-frequency (138Hz) acoustic field. Its power is respectively the lowest.

(a)

(b)

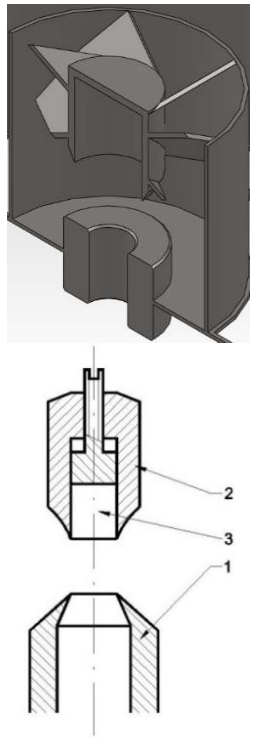

Fig. 6. Acoustic generator AAG-6: a) 3D model, b) longitudinal section

Fig. 7. Experimental setup. 1: sound level meter/analyzer, 2: acoustic chamber, 3: compressed air port

The experimental results are presented in Figure 9, which contains a comparison of the acoustic characteristics of the manufactured generators. It can be seen from Figure 9 that AAG-6 acoustic generator is the most powerful. It can be also noticed that the sound pressure peak generated by the acoustic generator is repeated every 8kHz, i. e. at 8 and 16kHz.

TABLE I. THEORETICAL PARAMETERS OF THE AERODYNAMIC ACOUSTIC GENERATORS

Generator	Frequency, Hz	Sound power, W		
		W_M	W_D	W_K
AAG-1	1.99E+04	3.13E+01	4.51E+01	6.50E+01
AAG-2	4.72E+04	1.76E+02	8.01E+02	3.65E+03
AAG-3	3.71E+03	1.09E+00	1.67E-01	2.57E-02
AAG-4	4.72E+04	1.76E+02	8.01E+02	3.65E+03
AAG-5	2.49E+03	4.89E-01	4.40E-02	3.97E-03
AAG-6	1.38E+02	1.49E-03	2.84E-06	5.38E-09

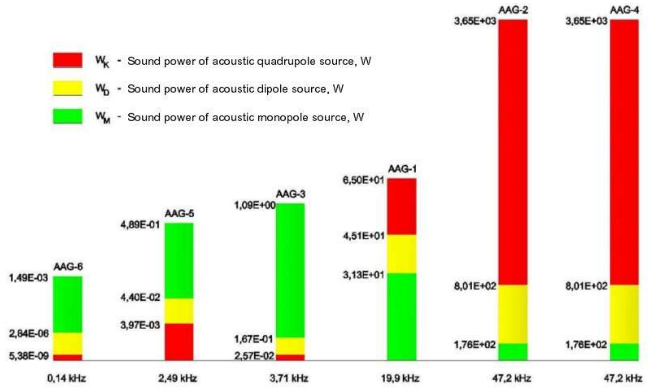

Fig. 8. The theoretical results of the aerodynamic acoustic generators

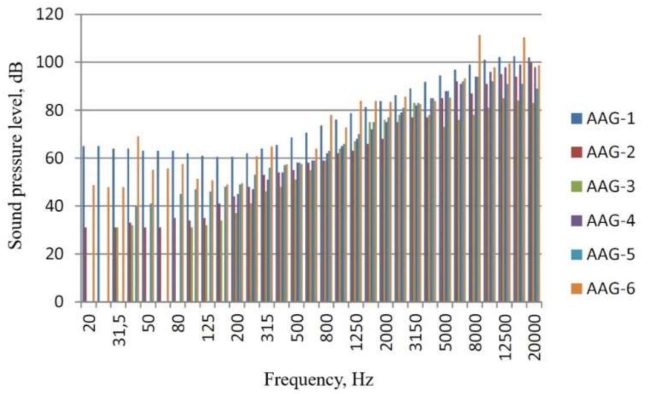

Fig. 9. The sound pressure levels of acoustic field generated by acoustic generators

IV. CONCLUSIONS

The results of the theoretical calculations of the prototypes of the acoustic generators differ from the experimental data as classical theoretical calculation methods underestimate the design features of aerodynamic acoustic generators. Therefore, it is necessary to formulate the assumptions and determine the empirical correction factors evaluating design peculiarities of aerodynamic acoustic sources. The experimental studies have shown that the aerodynamic efficiency of the generator is influenced not only by the principle of operation and the ratio of dimensions of its structural elements, but also by the technological fulfillment of the acoustic source.

The experimental studies have shown that the most powerful aerodynamic generator is AAG-6. Its resonant chamber was the largest compared to the other prototypes and the edges were sharpest, i.e. chamfers were not removed. The AAG-6 acoustic field generator exhibits the clearest sound pressure pulsations. Sound pressure peaks are repeated every 8kHz, i.e. at 8 and 16kHz and exceed 100dB. Therefore, such prototype was chosen to be used to generate sound waves in an acoustic cyclone separator.

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