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RESEARCH OF INFLUENCE OF DESIGN PARAMETERS
UPON NOISE CHARACTERISTICS OF CENTRIFUGAL FANS

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In this paper the results of experimental research of the influence of some design parameters (in particular the casing of fan and the stationary blades of straightened vane) on the noise characteristics of the centrifugal fans are presented. The “specific” intensity noise characteristics of fans with same design of the impeller but different design parameters of the casing had been compared. As result it was established that in the spectrum of noise, radiated by the centrifugal fans, as levels of tonal noise components as levels of broadband noise (in the medium and high frequency range) depend on the design parameters of the casing.

In the centrifugal fan aerodynamic noise is generated because of the airflow stream propagation through the blade channels of the impeller thanks to such processes as the vortex formation and interaction of the vortexes with elements of the impeller and the casing

At the medium and high frequencies predominantly the broadband noise is excited. According to paper [1] the broadband noise generation is connected with the turbulent pulsations, which are excited thanks to the interaction of the flow stream with the solid surfaces: above all, with the blades (at the inlet of the blade channels) and also thanks to the interaction of the formed vortexes with the casing of fan. The acoustic dipole (with different possible directivities of its axis), located near the end of the blade and rotated with the same frequency as the impeller, can be used [2] as the model of the source radiating the broadband noise. According to this model in the specter of the broadband noise at the low and medium frequencies the level is constant and in the high frequency range (if frequency $f \geq f_{lim}$, where f_{lim} is the boundary frequency of this range, which is defined by means experimental research) the noise level decreases at the increase of the frequency. According to experimental research the value of the boundary frequency (f_{lim}) depends on the frequency of the rotation of impeller.

The influence of the design parameters of casing on the intensity of the noise generation had been defined on base of the comparison of the results of the experimental research of the noise characteristics of the several centrifugal fans (with different design parameters of the casing). These noise characteristics had been defined for next kinds of fan with radial impeller: the centrifugal fan (type VR-86-77-3,15) with the spiral (as “snail”) casing; the roof fan (type VKRM-3,15) with the straightened vane (stationary blades); the experimental model of the roof fan with the turning of the air stream at the outlet of the impeller on 90° (roof fan with the outlet stream directed upward); the experimental models of the “uniflow” (duct) fans with the rectangular and circular cross-section of casings. All these fans are completed with the centrifugal impeller of the same design: the impeller (with 13 backward-curved blades) rotating with the frequency 3000 1/min (the only impeller of experimental model of the roof fan rotates with frequency, which is equal to 1500 1/min).

For the experimental research of the aerodynamic and acoustic (noise) characteristics of tested fans the special test facility, which is described in detail in the paper [3], had been used. This test facility consists of: the tested fan, the ducts connected with the intake and the outlet sides of fan’s casing; the anechoic termination and silencers; the throttle device, which is used for the adjustment of the fan’s operating conditions. All measurements of the noise characteristics had been produced for fans operating near the best efficiency point [BEP], the microphone was placed in the several points at the hemispherical measurement surface in the special test room.

The “specific fan speed” (n_q) for tested fans, depended from the aerodynamic scheme of fan, is varied from 77 up to 90 because of the different design parameters of casing of fans of various types. The “specific noise intensity characteristic” [SNIC] can be used for comparison of the acoustical performance of such fans (with different values of “ n_q ”). For the outlet fan noise this characteristic ([SNIC]) is calculated by means next equation (if the tip speed of impeller V_i doesn’t exceed 60 m/s):

$$[L_{SNIC}]_{out} = L_{wi} - 10\lg[Q/Q_o] - 20\lg[H/H_o] - 10\lg[S_{out}/(D_{out})^2] \quad (1)$$

where Q is the volume flow (m^3/s); H is the total pressure (Pa); $Q_o = 1 m^3/s$; $H_o = 10 Pa$; L_{wi} is the level of sound power for the octave or 1/3-octave with number “i”; D_{in} is the diameter of the impeller at the inlet, D_{out} is the diameter of the impeller at the outlet; S_{out} is the cross-section area of the outlet of fan.

The results of measurements of [SNIC] for spectrum of noise, radiated by 6 tested fans from the outlet side of casing, are presented in the table 1.

Table 1. “Specific” noise intensity characteristics of fans with the radial impellers

One-third octave band centre frequency, [Hz]	“Specific” noise intensity characteristics (levels of sound intensity) [L_{SNIC}] _{out} , dB, for next types of the centrifugal fans:					
	Fan with spiral casing	“Uniflow” or duct fan with rectangular cross-section of casing	Duct fan with circular cross-section of casing	Roof fan with :		Roof fan with outlet stream directed upward
				serial impeller	impeller with “angle piece”	
200	36	34	38	32	39	37
250	36	36	39	34	40	39
315 [f_{BPF}] ₂	37	36	41	34	42	44
400	38	39	39	37	45	38
500	42	43	40	38	47	37
630 [f_{BPF}] ₁	47	47	42	40	49	40
800	43	45	40	38	48	39
1000	42	44	41	36	47	41
1250	40	46	39	37	47	39
1600	42	45	37	35	46	40
2000	40	44	36	34	44	41
2500	39	47	35	33	41	38
3150	38	45	35	32	39	37
4000	36	44	34	31	38	36
5000	34	42	32	29	36	35
6300	32	39	31	28	34	33

According to comparison of the results of measurements of noise characteristics of 6 tested fans, the boundary frequency f_{lim} is minimal in the broadband spectrum of the roof fan (VKRM-3,15), possibly because just in this fan really free impeller operates without casing. Correspond to results of the experimental research of the pressure pulsation spectrum, presented in the paper [1], as levels (or amplitudes) of the pressure pulsations as the broadband noise levels, generated thanks to the excitation of the pressure pulsations in the blade channels, are increased if the impeller is placed in the spiral casing (in comparison with free impeller). In the noise characteristic of the centrifugal fan with spiral casing the boundary frequency f_{lim} is shifted in the high frequency range (in comparison with the

spectrum of the broadband noise generated in the roof fan). In the noise spectrum of the “uniflow” (duct) fan with rectangular casing the boundary frequency f_{lim} is shifted significantly in the high frequency range (relative to the fan with the spiral casing). But at the same time in the broadband noise spectrum of the duct fan with the circular cylindrical casing the boundary frequency doesn't shifted in the high frequency range (with respect to the fan with spiral casing).

The significant shifting of the boundary frequency f_{lim} in the high frequency range possibly is connected with the features of the sound wave propagation through the waveguide (duct) formed by the blade channels of impeller and the rectangular casing of the duct fan. In this case waves are propagated through the duct with turn on 90° . At the low frequency range, limited from above by the critical or cut-off frequency $f_{crit} : f_{crit} = C/2b$ (where b is the size of the rectangular waveguide cross-section; C – the speed of sound waves propagation in the air), the only plane sound wave can pass through the duct and higher modes ($m, n \neq 0$) can't propagate because of attenuation in duct.

In accordance with the theory of sound wave propagation in waveguides (ducts), when the waves pass through the turn on 90° [4], the mode (0, 0) is transformed into the higher modes (m, n). As result in the section of the duct, placed behind the turn on 90° , as plane wave or mode (0, 0) as higher modes (m, n) can pass through the duct. In such case the pressure in the sound field, formed in the section of duct, placed behind turn (bend), is equal to (for two-dimensional duct):

$$P(z) = \frac{4A \sin q\pi}{\pi} \left[\frac{1}{2q} + \sum_{m=1}^{m \leq q} \frac{(-1)^m q}{q^2 - m^2} \cos \frac{\pi(mz)}{b} \right] \quad (2)$$

where A is the amplitude of the sound pressure in the wave, propagated through duct section ahead of the bend; z is the axis of duct section ahead of the bend; $q = 2b/\lambda$, λ is wavelength; $m = 0, 1, 2, \dots$

In the low frequency range only 0-mode can pass through turn of duct, but at the medium and high frequencies (if $f \geq f_{crit}$) higher modes also pass through turn of duct. As result the boundary frequency $(f_{lim})_{out}$ in broadband spectrum of noise, radiated from outlet, is shifted in the high frequency range.

Shift of the boundary frequency $(f_{lim})_{out}$ also is connected with the resonance phenomenon, caused by the increase of number of eigen frequencies (N_{eig}), excited within the volume of casing, with growth of frequency, according to [4]: $N_{eig} = (4\pi/3)f^3V/C^3$, where V is volume of the casing.

In the spectrum of broadband noise, radiated from the inlet of duct fan with rectangular casing, the boundary frequency $(f_{lim})_{inl}$ is shifted in low frequencies relative to the frequency $(f_{lim})_{out}$. Due to such shift in spectrum in the frequency range $[(f_{lim})_{out} - (f_{lim})_{inl}]$ the difference between levels of noise, radiated from the outlet and inlet sides of casing, is increased significantly. Possibly this result is connected with the special feature of sound field in duct fan. At first, boundary frequency $(f_{lim})_{inl}$ doesn't shift in high frequency range so far as sound waves, radiated from the inlet side, can't pass through turn on 90° . Secondly, the waves, radiated from the outlet of blade channels, can't pass through the blade channels in opposite direction (towards the inlet of casing) in the frequency range, limited (from above) by cut-off frequency, which is equal to: $f_{crit} \geq 2500$ Hz. As result in this frequency range only plane waves can pass through blade channels. Consequently in this frequency range (below cut-off frequency) only plane waves (0-mode) is radiated from the inlet side because of attenuation of higher modes in the blade channels. As result the level of broadband noise, radiated from inlet, are reduced (relative to level of noise, radiated from outlet) and the boundary frequency $(f_{lim})_{inl}$ is shifted in the low frequency range relative to frequency $(f_{lim})_{out}$.

In the broadband spectrum of noise, radiated from the outlet side of the duct fan with circular casing, the boundary frequency $(f_{lim})_{out}$ doesn't shift in the high frequency range, because of the specific design of its casing, which forms duct with sudden turn on 180° . The only mode (0, 0) can pass through duct with such turn on 180° , because of attenuation of all higher modes. As result in such duct fan in the spectrum of noise the boundary frequency doesn't shift in the high frequency range.

At the same time in the duct fans, manufactured by firm “Fantech” (Australia), the casing consists of the cylindrical circular element and confuser (placed at the outlet side of casing). As result in the broadband spectrum of noise, radiated from outlet side of this casing, the boundary frequency is shifted in the high frequency range. In the broadband spectrum of noise, radiated from the outlet of the rectangular casing (manufactured by this firm) the boundary frequency also is shifted in the high frequency range.

When the special impeller with “angle piece” at the ends of outer surface of blades (along normal to its surface) is used (for increase of total pressure in the air stream) in the roof fan (type VKRM), the specific intensity noise levels are increased (in comparison with [SNIC] of the same fan with usual impeller). Probably noise levels growth is connected with additional vortex formation, which is caused by air flow stream around the “angle piece” (which transform the backward-curved blade in forward-curved blade) and by stream separation from forward curved “angle pieces”, which causes increase of area of flow separation in the blade channels.

In the broadband spectrum of noise, radiated by roof fan (with outlet stream directed upward), the boundary frequency also is shifted in the high frequency range (relative to the spectrum of noise, radiated by roof fan VKRM-3,15). In this fan the shift of boundary frequency is caused by the changes in design of casing, which are connected with introduction of additional casing element, forming the channel with turn on 90° .

According to comparison of specific noise characteristics ([SNIC]) of roof fans (VKRM) with the usual and increased (in 2,3 time) size of the relative clearance δ between impeller periphery and air straightened vane ($\delta = \Delta r / R$, where Δr is distance between periphery of blades of impeller and stationary blades of the straightened vane; R - radius of the impeller at the outlet), the increase of clearance δ doesn't cause significant changes in noise characteristic ([SNIC]) of roof fan. Such result probably is caused by sufficiently significant size of the clearance δ even in the usual (serial) roof fan. As result the interaction of the “vortical wake” (trailing vortices in airflow, leaving impeller), which is formed behind the blades of impeller, with blades of straightened vane doesn't cause generation of the tonal noise components (“interaction noise”) with high degree of intensity.

Conclusion

According to results of the experimental research the influence of the spiral casing of centrifugal fan causes the growth of the specific noise intensity levels ([SNIC]) in the spectrum of noise (in comparison with levels of noise, radiated by the free impeller in the roof fan). Also thanks to influence of the spiral casing, the boundary frequency in the boundary noise spectrum is shifted in the high frequency range (relative to spectrum of noise, radiated by free impeller).

The influence of the rectangular casing (in duct fan) causes more significant changes in the spectrum of broadband noise (radiated from the outlet side of casing): boundary frequency (f_{lim}^{out}) is shifted significantly in the high frequency range (relative to spectrum of noise, radiated by fan with spiral casing). Such shift of the boundary frequency is caused by transformation of the energy of the plane wave (0-mode) into the energy of the higher modes (m, n). This transformation of energy is connected with passage of sound waves through duct with turn on 90° . As result at the low frequency range (if $f \leq f_{crit}$) the only plane wave (0-mode) can pass through the turn of duct, but at high frequency range higher modes (m, n) also pass through turn of duct. Besides that the shift of boundary frequency is caused by more significant influence of the resonance phenomenon within casing of fan [3], connected with increase of number of the eigen modes, excited at eigen frequencies of casing. It's necessary to stress that number of eigenfrequencies (N_{eig}) is more for volume of rectangular casing, than of circular casing, because of N_{eig} is proportional to volume of casing V .

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