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Structural techniques of reducing vibration and noise of axial fans

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Abstract

With the development of industry and technology, the overall noise level in urban areas increases. It leads to an increase in human noise exposure in everyday life: at work, in transport, residential premises, etc. The impact of noise has a negative effect on human health. It causes increased fatigue, decreased performance and activity. To combat this negative impact, it is necessary to reduce the intensity of noise sources.
The main sources of ventilation noise are fans. Since ventilation systems are an integral part of most structures, the reduction of fan noise is an important challenge in mitigation of domestic noise pollution. Ventilation noise control and measures to reduce the vibration and noise activity of fans were investigated in many research papers. This paper provides an overview of recommendations to reduce the noise from axial fans.

Keywords: Noise, noise control, axial fan, vibration;

1. Introduction

Under the influence of a constant periodic force, a mechanical system, which incorporates elements of elasticity and mass, enters the mode of oscillatory motion. A fan, as an electro-mechanical system, has an internal source of power generating a periodic effect on the entire structure. It leads to the appearance of areas of compression and depression of the medium provoking the emergence of sound.

When designing low-noise fans, it is necessary to achieve a minimum vibration and noise activity of the system. Thus a designer is faced with the task to minimize the amount of energy generated by the internal power source.

Periodic forces arising in the course of the fan operation have various origins.

2. Aerodynamic forces

Vortex formation in flow parts and boundary layer noise are among the main causes of fan noise. According to [6], the acoustic power of the vortex noise generated by the fan impeller is determined by the following equation:

$$W = \chi \frac{\rho}{c^3} U^6 D^2$$

where χ is the coefficient accounting for the geometric shape of the element in the air flow, the flow direction and Reynolds and Mach aerodynamic criteria;

U is the circumferential speed of the impeller;

D is the impeller diameter;

p is the medium density;

c is the speed of sound in the medium.

This equation shows that the main factors affecting the vortex noise are the circumferential speed of the impeller and its dimensions. It demonstrates that the most effective methods of reducing the noise level will be to increase the size of the impeller while decreasing its angular velocity.

At a peripheral speed of the impeller of approximately 20 m/s, the fan noise intensity corresponds to low-noise operating conditions. With increase of the speed, an increase in noise generation begins [6].

The formation of vortices in the flow of the operating medium is inextricably linked with the frontal aerodynamic resistance of the body. To reduce frontal resistance, fan blades are made curved (Fig. 1). The frequency of the vortex noise is determined by the frequency of the breakdown of the vortices, which in turn depends on the lateral size of the body and the pressure at its front edge. Modern modeling technologies allow to clearly illustrate the distribution of the pressure gradient throughout the body of the fan blade. It enables to optimize the shape of the blade, reduce turbulence and vortex noise, smooth the pressure gradient (Fig. 2) [1, 3].

Fig. 1 Fan wheel with curved blades

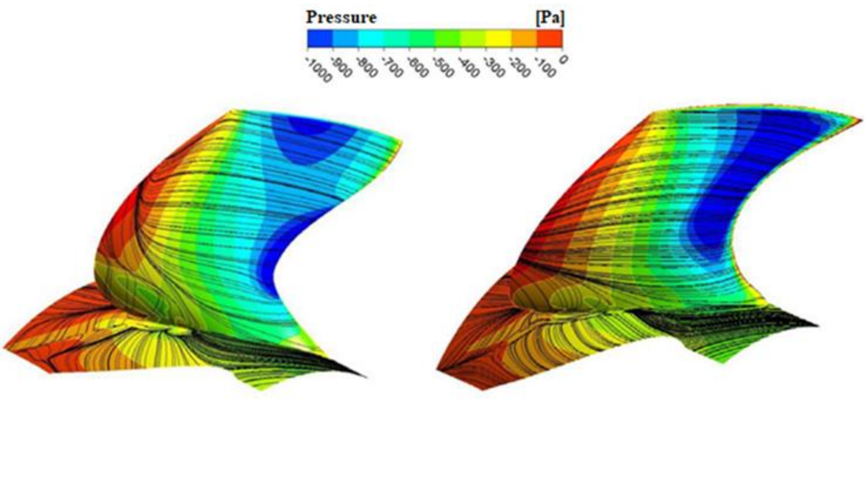

Fig. 2 Pressure distribution on the fan blade (left), optimized blade shape (right). Black lines show the air flow direction

Since the speed and direction of the flow in the fan continuously change along the blades, different parts of the blades emit sound of different frequencies ensuring a wide band of continuous noise spectrum. However, the noise on the boundary layer of the blade may have discrete components. To combat this phenomenon, blades with a sawtooth-shaped output edge are used (Fig. 3) [5].

Fig. 3 Sickle shaped blade with a sawtooth-shaped edge

Another way to “blur” the discrete components of the sound pressure is the use of blade wheels with uneven pitch of the blades. In this case, the blades generate sound pulses with an uneven period of time. With the increase in the number of blades of the impeller, the effect decreases [5].

Another cause of fan noise is aerodynamic losses owing to uneven air flow. In order to eliminate turbulence and ensure a uniform velocity profile, an Inlet Guide Vane Unit and an Outlet Straightener are installed at the fan’s inlet and at the outlet, respectively [4].

When selecting the number of blades for the Inlet Guide Vane Unit and the Outlet Straightener, one must comply with the following equation [2]:

$$\frac{k_m m}{i z_k} < \left(\frac{M_u}{\sqrt{1 - M_{ca}^2}}\right)$$

where $Mu = uk/co$;

$M_{ca} = Ca/Co$,

u_k is the peripheral speed of the ends of the blades;

c_a is the axial speed;

k_m is the wave parameter;

$m = |IZ_{PK} + KZ_{AP}|$;

k is the coefficient taking all integer values;

i is the harmonic number.

In axial fans, the noise level strongly depends on the degree of turbulence at the wheel inlet. Therefore, when designing a fan, it is recommended to provide a smooth inlet ring and aerodynamically clean bearing brackets. This will contribute to the creation of a uniform spectrum, without discrete components

3. Mechanical imbalance

Lack of balance of rotating parts is one of the main causes of fan vibration. Imbalance can be reduced by balancing the rotor and the blade wheel on a balancing machine. Also in the manufacture of the rotor monitoring, measures must be provided to achieve its maximum solidity.

The force arising from the rotation of an unbalanced mass is defined as follows:

$$F = me\omega^2$$

where *m* is the unbalanced mass;

e is the distance from the axis of rotation to the unbalanced mass t;

ω is the angular velocity.

4. Electromagnetic forces

These forces act in the air gap between the stator and the rotor of the driving electric motor of the fan and have the nature of rotating or pulsating force waves.

Vibration and noise can be reduced by manufacturing electric motors with beveled grooves. Theoretically, it raises the possibility of reducing the total electromagnetic force at a particular groove to zero [8].

Another cause of the increase in vibration may be the unevenness of the gap between the rotor and the stator. This phenomenon leads to the uneven distribution of electromagnetic forces in the motor, which in turn contributes to an increase in vibration and noise levels.

If the non-uniformity of the gaps does not exceed 10%, then these vibrations are practically absent with no resonance [7].

5. Rolling bearings

The amount of vibration made by this source depends on several factors:

- quality of manufacture of the bearings (ensuring minimal vibration of the outer and inner rings during the operation of the bearing);
- precision of manufacture of the bearings' fitting holes (ensuring alignment of bearing assemblies on the rotor shaft and in end shields);
- vibro-acoustics of end shields (in case of unfavorable structural shape, they can become intense sound emitters).

In [6] a recommendation is given to reduce vibration and noise of bearing assemblies by means of replacing rolling bearings with plain bearings, arguing this replacement by the noiselessness of the latter.

6. Forced vibrations of the fan casing

These oscillations are triggered by the whole variety of processes occurring inside the fan and transmitted to it, spreading further as surface noise. In this regard, the fan casing should be made with a high noise and vibration absorption coefficient. It also is recommended to increase the rigidity and weight of the fan casing. However, as an alternative to a heavy casing, the casing may be made of a composite material. This material can be a sheet of metal of a relatively small thickness with a layer of vibration-absorbing mastic applied onto it. Such a composite retains the properties of each of its constituent materials [6].

7. Conclusion

The causes of noise and vibration discussed above are inherent in any fan and cannot be fully eliminated. However, by following the recommendations below one can make a list of measures to reduce the vibration and noise activity of axial fans:

- Use a blade wheel of a larger diameter than is necessary for the fan to operate in the area of maximum efficiency;
- Provide the angular velocity of the blade wheel of about 20 m/s;
- Optimize the blade shape;
- Use blades with a sawtooth-shaped outer edge;
- Use an impeller with uneven blade pitch;
- Use guides and straighteners;
- Use a smooth collector at the fan inlet;
- Balance the rotor and the blade wheel;
- Use electric motors with beveled grooves;
- Reduce unevenness of the gaps between the stator and the rotor of over 10%;
- Toughen the tolerance for bearing misalignment;
- Replace rolling bearings with plain bearings;
- Design a casing with a high noise and vibration absorption coefficient.

Thus, it becomes clear that the task of reducing the noise of an axial fan is complex and requires a considerable study. Currently, research in this area to taking place in many countries. Thanks to the use of the latest modeling technologies, the study of noise control measures becomes more and more efficient contribution to the gradual reduction of the noise of the newly-designed fans.

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