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Investigation of vibrations of a main centrifugal fan used in mine ventilation

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ABSTRACT

Operation of machines in resonance ranges is a great challenge for design engineers. The paper focuses on the analysis of centrifugal fan casing vibrations which during machine operation, particularly in unsteady states, are very strong. Within a series of investigations performed according to the experimental modal analysis natural frequencies of fan casing vibrations were specified. Additional numerical simulations helped to define theoretical values of the natural vibrations frequency and its mode shapes. The results were analyzed and the numerical model was adjusted. The information was later used in the analysis of vibration measurements in real operating conditions. The results achieved for a nine-blade impeller (new type) were compared to results of an old construction eight-blade fan impeller. New solutions, which shall facilitate casing operation beyond resonance frequencies vibrations areas, were proposed.

1. Introduction

Fan vibrations, both in steady and unsteady states, significantly influence durability of movable and fixed elements. One of the elements exposed to dynamic effects is an impeller steel casing, which is a part of an outlet scroll (Fig. 1). The fact that part of the scroll is constructed as a steel casing enables the impeller maintenance and potential replacement. However, design and placement of the casing exposes it to constant influence of dynamic effects resulting from flow phenomena occurring inside.

Proper casing operation requires limitation of losses resulting from leakage and vibrations which may damage or destroy the casing. Decreasing dynamic effects level reduces clearance resulting from vibrations and causing flow losses. This increases durability of casing elements and efficiency of the fan. The analysis of casing operation based on specifying the frequency of natural vibrations is made to avoid operation within a resonance vibrations range. Operation in this range is a significant problem not only from the point of view of durability but also the influence on safety of work in the fan surroundings. Work safety issues have to be taken into account and analyzed in order to develop various mechanical constructions [9,11,14].

Natural vibrations frequencies of a properly designed casing do not overlap characteristic frequencies of fan operation (i.e. rotational frequency of an impeller, blade

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Fig. 1 – The steel casing of the centrifugal fan used for mine ventilation.

passing frequency and their harmonic frequencies). The rotational frequency results from its angular velocity and is defined as follows [5,20]:

$$f_n = \frac{\varpi}{2\pi} = \frac{n}{60}\,[\mathrm{Hz}] \tag{1}$$

where ω is the angular velocity of the impeller [rad/s], n is the rotational velocity of the impeller [rpm].

The blade passing frequency of the impeller is defined as follows [4]:

$$f_{BPF} = N \cdot \frac{\varpi}{2\pi} = N \cdot \frac{n}{60}\,[\mathrm{Hz}] \tag{2}$$

where N is the number of impeller blades.

Huge fan steel casings are frequently large-sized and their most dangerous natural vibrations frequencies reach the level of several Hz. Modern sophisticated method of vibration damping [18,28] would extremely rise cost of the structure. For this reasons casings should be designed in a way to avoid operation in a frequency range resulting from rotational velocity of an impeller.

Literature survey made by authors proved lack of generally available resources which would consider issues of huge power fan casing vibrations, particularly in industrial conditions. However, numerous papers about e.g. influence of the casing on a level of noise emitted during the fan operation can be found [7,16,25,27].

The subject of an analysis presented in the paper was a steel casing of a main centrifugal fan equipped with a nine-blade impeller and used in mine ventilation. It is the largest centrifugal fan operating in Polish mines, marked with the symbol WPK-5.3. Experimental tests and numerical simulations were performed to specify values of frequencies and modes of natural vibrations and decrease the level of casing vibrations during the fan operation in unsteady states. Changes resulting from installation of the new nine-blade impeller instead of the old generation eight-blade impeller [31] were analyzed as well.

2. The analysis of signal in assessment of machine elements vibrations

The analysis of signal recorded is commonly applied in diagnostics of machines and devices operating in various conditions. It covers industrial, civil and military applications [3,12]. Such an approach allows assessment of the machine condition and is frequently applied as a method of detection of machines and rotating devices damages [1,17,20,22]. The analysis of acceleration traces is also applicable in studies of various types of flow machines [2,13,22].

The most frequently applied methods used in assessment of the rotary machine elements condition are those based on the Fourier's analysis. This method allows transition from time to frequency domain and is based on the concept according to which each signal may be presented as the sum of different amplitude and frequency harmonic signals [21].

In the case of "passing through" unsteady states during the rotating machine operation, characteristic frequencies change in time. In this case application of the Fourier Transform, in which integration takes place during the whole period of time, is not sufficient to recognize frequency changes over time. Due to that fact, in the vibrations analysis, it is reasonable to apply so called Short Time Fourier Transform (STFT), which is based on the Fourier's analysis performed within the narrow time frame displaced according to the agreed parameters of length, resolution or overlapping of frames. This method allows to observe relation of frequency and time and recognize transient states of the machine operation. The relation defining the STFT method is presented as follows [21]:

$$S(f,\tau) = \int_{-\infty}^{\infty} x(t)\varpi(t-\tau)\exp(-j2\pi ft)dt \tag{3}$$

where $\varpi(t)$ corresponds to the time frame displaced during data acquisition.

Due to occurrence of unsteady states in presented fan operation, the Short Time Fourier Transform was applied to assess casing vibrations.

Specifying dynamic characteristics of machines and devices is based mainly on specifying modal characteristics of a particular object. Those characteristics are natural vibrations frequencies, their modes and damping ratios. In the case of real objects testing it is easier to determine natural frequencies, while determining natural mode shapes and, particularly, damping ratios is more problematic.

The modal analysis of machine elements is widely applied to specify modal characteristics of a given object. Several types of modal analyses may be distinguished: i.e. theoretical, operational and experimental [4,12,23,29]. The last two methods are applicable in real objects measurements, however, in the operational modal analysis only the system response signal is recorded.

The theoretical modal analysis is frequently the analysis based on numerical methods, which are widely applied in verification of dynamics of various types of constructions