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BACKFLOW INDUCED SWIRL AT THE RADIAL IMPELLER ENTRANCE

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ABSTRACT

This paper presents the results of experimental study of backflow induced swirl component of the flow entering the radial impeller. The appearance of the swirling flow at the radial impeller entrance is a result of the complicated fluid flow conditions, which appears as a consequence of the pump operating out of nominal point which reduces pump efficiency. The goal of this contribution is in estimating the angular position of anemometer and frequency analysis of the swirl in the inlet pipe at radial impeller entrance for different operating regimes.

The results show that backflow induced swirl changes the rotation direction with flowrate change. It is also evident from the results that anemometer fluctuates around same position at the ~90% of nominal flowrates and that major magnitude of the frequency components in recorded signal at low flowrates corresponds to flow fluctuations similar to rotating stall.

Keywords: swirling flow, radial impeller, anemometer

1. INTRODUCTION

The first research on swirling component of the flow at centrifugal pump entrance can be traced back to 1909 when S. Watt reported the presence of prerotation in centrifugal pump suction section. A. J. Stepanoff concluded, that the fluid can flow axially (without swirl) into the rotating impeller at nominal flowrate. When the flowrate is lower than the nominal flowrate, the direction of the swirling flow of the fluid in the inlet pipe is the same as the rotation direction of the impeller. When the flowrate is greater than the nominal flow, the direction of the swirling flow is opposite to the rotation direction of the impeller [1]. C. E. Brennen distinguished between two separated phenomena both of which lead to a swirling flow entering the pump, which was called the backflow induced swirl and/or inlet prerotation. In the first case, the vorticity is diffused into the flow by the action of viscosity and in the second case the flow is accelerated (or deaccelerated) as a result of change of cross-sectional area of the flow [2]. Further analyses show, that the conventional swirling flows in the pump inlet area have the origin of the vorticity in the impeller itself and that the vorticity is transmitted to the inlet area via the backflow mechanism [3, 4, 5]. The extent to which the backflow is being diffused back into inlet pipe remains open since there is important dynamics which comes from blade number, blade incidence angles and impeller rotating speed which directly influences the integral characteristics of rotating machine. In the present study, the general properties of swirling flow and unsteadiness of the backflow are analyzed experimentally. The study is continuation of work presented by the author in 2003 [6], where two different anemometer systems were introduced for measurements. The present contribution deals with angular position of anemometer in unsteady swirling flow field and frequency of swirl in inlet pipe at entrance to impeller.

2. MEASUREMENT SYSTEM

The measurements of backflow dynamics were performed on a radial fan with a tip diameter of D = 0.6 m. The entrance pipe, made of transparent Plexiglas, had a diameter of 0.3 m. The anemometer was placed at a distance of three entrance pipe diameter in an upstream direction in front of the impeller eye (Fig. 1). The tested fan operated at 1600, 1700 and 1800 min^{-1} with a flow rate in the range of 0.1–0.8 m^3/s.

Fig. 2 show basic operating characteristics of analyzed fan.

Measurements of backflow induced swirl were performed using the anemometer with straight blades equipped with RLS RM08 non-contact rotary encoder (1024 pulses per revolution).

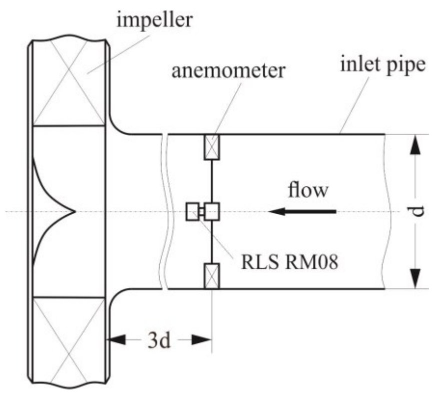


Figure 1. The measurement system.

In this way the rotation angle measurement and measurement of averaged swirling velocity was performed. The Testo 435 multifunction meter was used for the measurements of swirling (tangentional) velocity and static pressure in the pipe. National Instruments 9401 digital I/O module was used for data acquisition. Time interval between consecutive measurements was set to 10 ms. Actual average time delay was 10.33 ms resulting in average sampling frequency of 96.8 Hz. Actual time was recorded at each measurement to compensate for discrepancy in the sampling frequency.

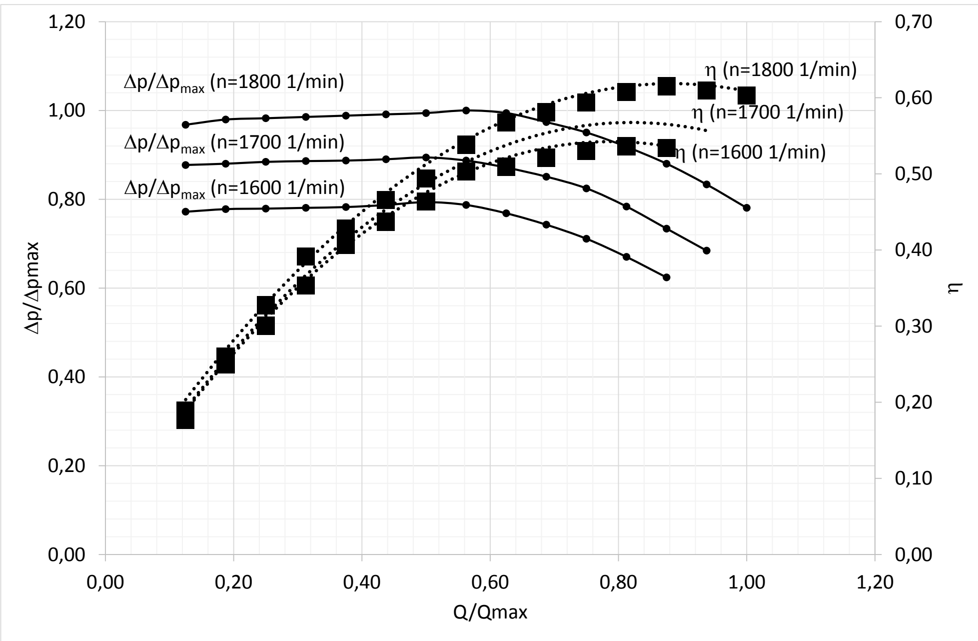
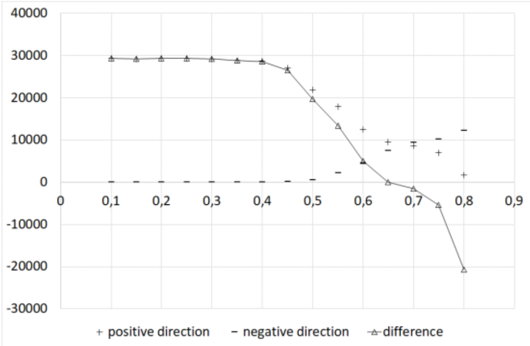


Figure 2. Basic operating characteristics of analysed fan

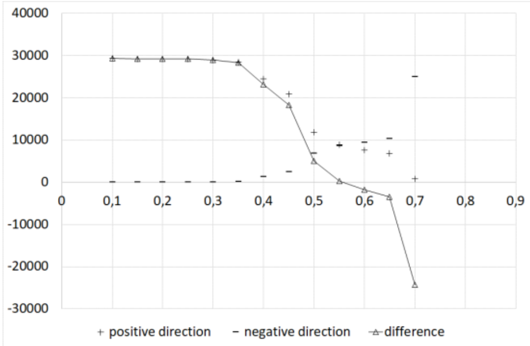
3. MEASUREMENT RESULTS

The measurement results are shown at Figure 3. The diagrams show the number of pulses recorded in positive[1] (+), negative direction (-) and difference at each flowrate (Δ). The measurements were done in time intervals Δt=300 s for different impeller rotating frequencies. The pulses were recorded in flowrate range 0.1 to 0.7 m^3/s for n=1600 min^{-1} and 1700 min^{-1} and in range 0.1-0.8 m^3/s at 1800 min^{-1}.

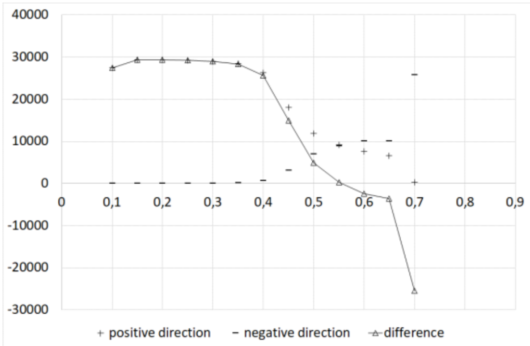
[1] Pulses recorded in positive direction are pulses when anemometer rotates in same direction as rotor.



n=1800 min^{-1}



n=1700 min^{-1}



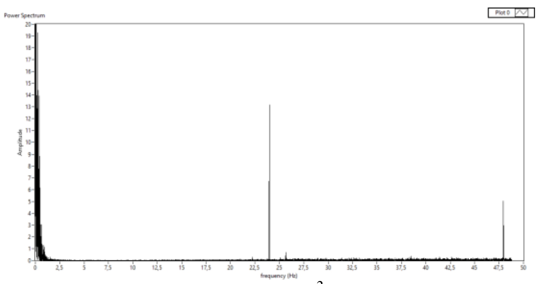
n=1600 min^{-1}

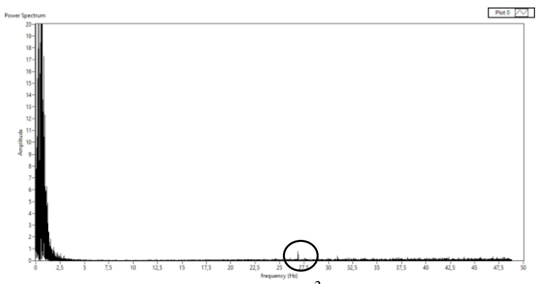
Figure 3. Backflow induced swirl rotation diagrams

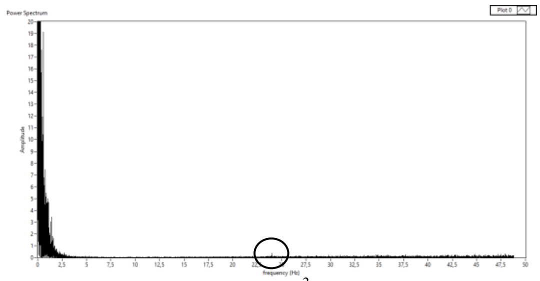
The general course of backflow induced swirl direction confirms the findings of other researchers [1-5]. When the flowrate is lower than the nominal flowrate, the direction of the swirling flow of the fluid in the inlet pipe is the same as the rotation direction of the impeller and opposite when the flowrate is greater than the nominal flow. It is evident from the diagrams at figure 3, that used anemometer does not stand still, but it revolves all the time. In the region at ~90% of nominal flowrates the swirl fluctuates around same position in both directions. In this regime, the sum of positive and negative direction pulses is zero.

3.1. Power spectra

In order to analyze the frequencies of pulsating swirl, power spectra were computed for the signal from encoder. Typical flowrates were chosen at Q=0.2 m^3/s when the anemometer rotates in direction of impeller, Q=0.55 m^3/s when the sum of pulses is zero and Q=0.7 m^3/s when anemometer rotates in direction opposite to impeller rotation direction. The power spectra characteristics are comparable at all impeller rotating frequencies. Figure 4 shows the power spectra for n=1600 min^{-1} at typical flowrates.


Q=0.2 m^3/s


Q=0.55 m^3/s



Q=0.7 m^3/s

Figure 3. Power spectra for n=1600 min^{-1}

The power spectra for the signal from encoder presented at figure 4. show major frequency of 24 Hz at Q=0.2 m^3/s and Q=0.7 m^3/s. At Q=0.55 m^3/s when the sum of encoder pulses is close to zero only the impeller rotation frequency is evident in power spectra. The measured frequency of 24 Hz could be connected to zones of recirculating fluid within flow channels of a pump's impeller which are consequence of reduced flowrates operation and known as rotating stall.

4. CONCLUSION

The behaviour of flow in the inlet pipe at the radial impeller entrance has been investigated experimentally in present study. It is well known that backflow swirl, which is a consequence of the centrifugal pump operation out of the nominal operating point, changes the rotation direction with the flowrate change, but it is not clear when exactly the swirl changes direction. Since the backflow carries a high amount of energy which is produced by the impeller and therefore its existence is decreasing the efficiency of pump, it is important to investigate this phenomenon in depth. The anemometer connected to non-contact rotary encoder has been used to determine the intensity and direction of backflow swirl at different operating regimes of conventional radial fan. At each regime, the pulses from encoder were measured continuously for 300 s and power spectra were computed for the signal. The results show the intense swirling (tangential) component of flow motion in pipe at the position of anemometer for all analyzed regimes. It is evident, that rotation direction change occurs at approximately 90% of nominal flowrate and that anemometer fluctuates around same position in both directions at these flowrate values. According to this, complicated fluctuating and unsteady flow pattern can be concluded in the analyzed section of the pipe. Power spectra show major frequency of backflow at 24 Hz when backflow swirl is present. The measured frequency could be connected to rotating stall. At nearly nominal flowrate when no backflow is present in the inlet pipe, there was magnitude at impeller rotation frequency present in power spectra.

The presented anemometer system can be used as a measuring device for the measurement of swirling flow direction, intensity and frequency analysis of backflow. For further insight into the phenomenon different measurement positions and anemometer diameter should be used.

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