Cavitation Swirl in the Inlet Pipe of the Radial Pump

Andrej PREDIN, Ignacijo BILUŠ
University of Maribor, Faculty of Mechanical engineering
Smetanova 17, 2000 Maribor
SLOVENIA

Abstract: Numerical and experimental analyse of the cavitation swirl in the inlet pipe of a radial pump is given in the contribution. The real radial pump impeller geometry was used for numerical simulation performed with CFX. Frozen rotor interface model, which requires the least amount of computational effort, was used, since the stationary pipe mesh is topological different than rotating impeller channel mesh.
The measurement testing system was built for numerical results validation. The system was developed as a closed loop with possibility of inlet pressure variation. Modified housing of tested radial pump and inlet pipe are transparent which allows visualisation of cavitation swirl and measurement of pressure pulsations at three different pipe locations. Cavitation swirl length, diameter and rotating frequency were measured at different operating conditions (impeller rotating speed, inlet pressure, operating flow-rate …).

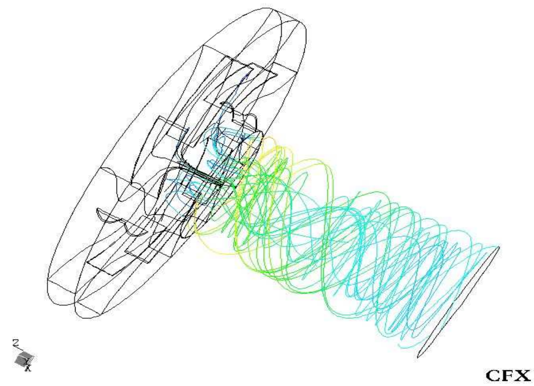
Key words: fluid flow modelling, water flow modelling, experimental test, cavitation, flow swirl, cavitational swirl, numerical modelling

1 Introduction

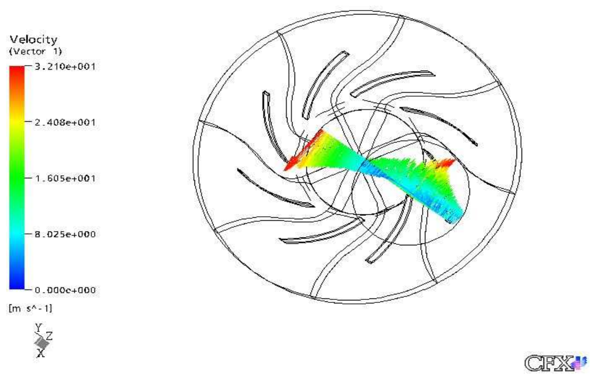
Cavitation occurs when flow pressure drops below the saturated vapour pressure of the liquid, consequently resulting in the formation of gas filled or gas and vapour filled bubbles. When pump operates with small capacities near to zero capacity, the bubbles swirl flow is formed in the entrance pipe. The swirl is composed from individual gas/vapour bubbles formed into the swirl that propagates from impeller entrance eye into the intake pipe in opposite direction as it is flow direction.

2 Numerical swirl model results

During pump normal operating the swirl in the entrance pipe exist. When pump operates with larger capacities, the flow swirl rotates in direction opposite to direction of impeller rotation. This phenomenon is known as prerotation flow [1]. When pump operating capacity is decreased the prerotation flow change its direction into the impeller rotation direction (Figure 1). If intake pressure decreased below the saturated vapour pressure of the liquid, the cavitation swirl appears. The mechanism of this phenomenon is explained by forming small water hammer effects that creates the individual gas/vapour bubbles at the swirl centre [2].



a)



b)

Fig. 1: Streamlines (a) and vector plot (b) of flow swirl at the fan entrance eye

From streamlines plot (Figure 1.a) the swirl path is evident. Direction of swirl rotation is evident from vector plot of swirl flow at the impeller entrance eye (Figure 1.b). The existence of this swirl flow is observed by measurements of the prerotation flow in the entrance pipe of the radial turbomachines [3].

3 Numerical Cavitation swirl model results

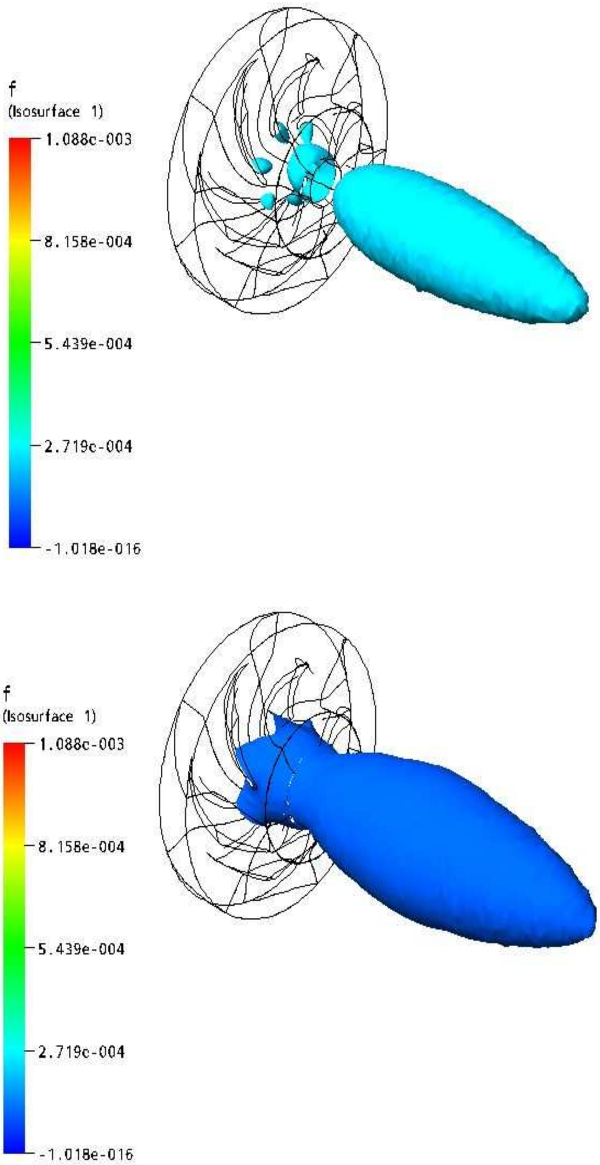


Fig. 3: Cavitation swirl vapour fraction (isosurface plot)

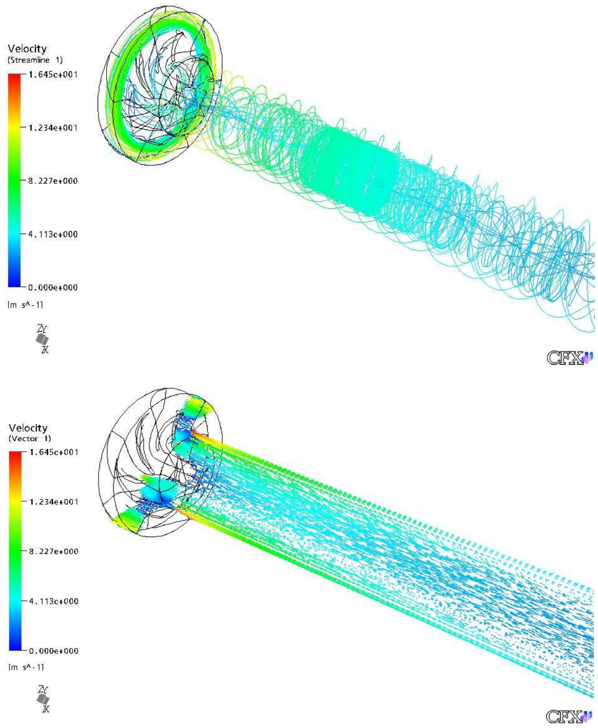


Fig. 4: Cavitation swirl flow pattern - streamlines and vector plot.

4 Cavitation swirl pressure measurements

The pressure pulsations are measured at the entrance pipe of the radial pump as shown in figure 3. The measurement testing system is manufactured according to ISO 2548 recommendations for cavitation tests performed using pump NPSH variation. The system is developed as closed loop in which the radial pump (Fig. 3, position 1) is put. The suction pipe system (Fig 3, pos. 3) goes from the reservoir (pos. 2) to pump the pressurized water flow to the pressure pipe system (pos. 4), which returns the water to the reservoir. The gas pressure above the water level in the reservoir can be changed using the vacuum pump (pos. 5) and so the pump suction head can be varied. Since the measuring system is geared for pump characteristic measurements during different operating regimes, an electric heater is put into the reservoir (pos. 6). The transparent suction pipe, which allows cavitation swirl observation, is placed at the pump entrance. The operating capacity can be changed by the valve (pos. 8) and measured by the orifice plate (pos. 9) manufactured according standard DIN 1952 [2].

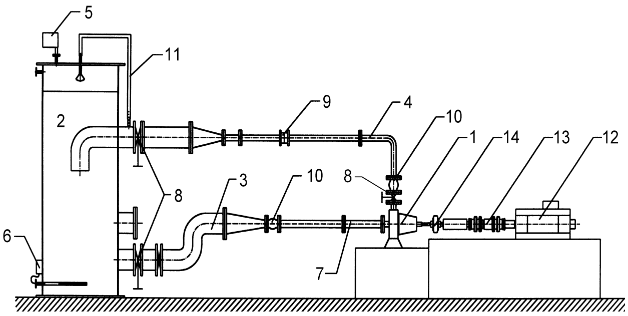


Fig. 5: Measuring system drawing

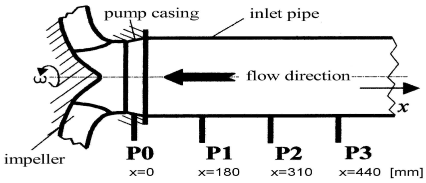


Fig. 6: Measuring places at the pump entrance

A rubber compensator (pos. 10) dampens vibrations, which are caused as a consequence of the un-centric and un-balanced driving system. The compensator is put into the pressure pipe system directly after the pump. The special pipe system (pos. 11) for water degassing is created. The driving motor (pos. 12) drives the pump over elastic gear (pos. 14). The operating torque is measured using the measuring torque shaft (pos. 13)

5 Measuring results

The results of the frequency analyses after fast Fourier transform at a pump operating speed of n= 1650 rpm and at a pressure over the water level in the reservoir of prez = 0,6 bar as shown in figure 7.

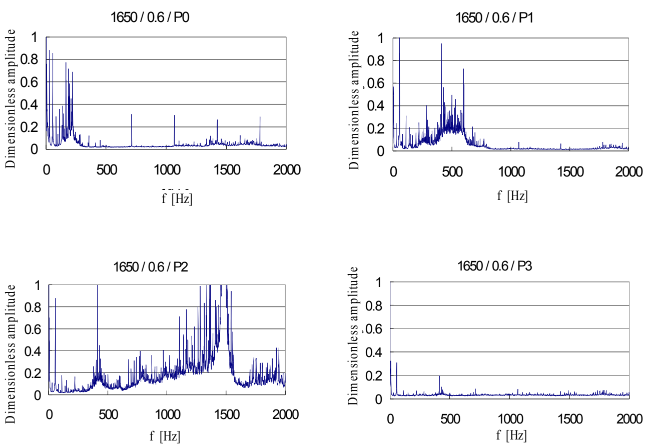


Fig. 7: The results of the FFT analyses of the pressure pulsations

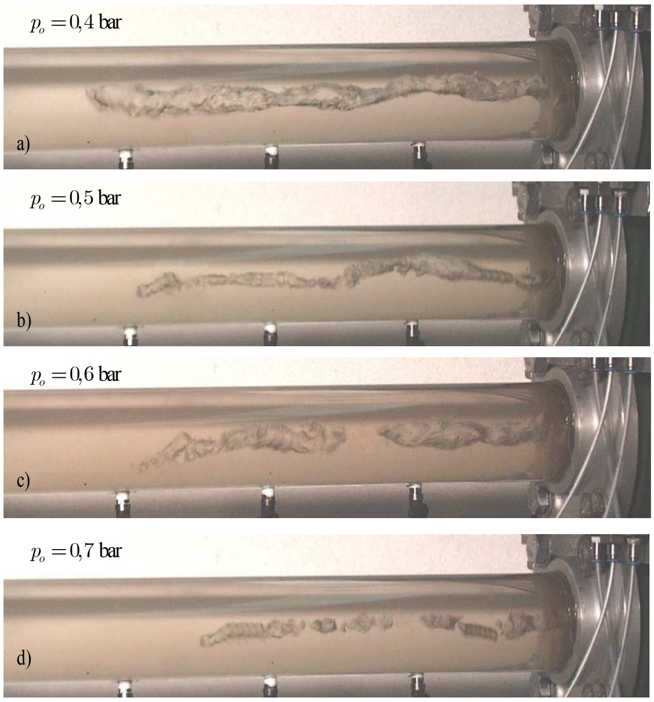


Fig. 8: Cavitation swirl tearing and reducing its diameter with pressure in the reservoir

At the measuring position P0, the frequency of the cavitation swirl and its first higher harmonic, and second higher harmonic of the blade passage frequency are dominant. The swirl frequency is between 2 and 10 Hz, which coincide with Grist's considerations.

At the positions P1 and P2 the first higher harmonic of the impeller speed frequency, second higher harmonic of the blade passage frequency are dominant. In the recording higher frequencies with smaller amplitudes are also evident. These frequencies are probably because of the swirl tearing.

At the position P3 the first higher harmonic of impeller speed frequency and second harmonic of the blade passage frequency are present.

From the given pressure amplitudes recorded, the pressure amplitude increase at increased impeller speed is evident. When the pressure over the water level in the reservoir decreased the pulsations amplitude decrease is evident. The larger measured pressure pulsations were taken at position P2 which is also in agreement with the photos in figures 8 b and d, where the swirl tearing between positions P1 and P2 are evident. From 8 c and 8 d we can conclude, that the swirl diameter is smaller when pressure over the water in the reservoir increased.

6 Conclusions

Cavitation swirl is a consequence of a pump operating with small, under-optimal capacities at different pressures above the water level of the reservoir.

It is a result of complicated flow conditions in the impeller channels and in the impeller eye.

Cavitation starts in the impeller channels as a result of the entrance flow angle change.

The cavitation swirl transition from the area of impeller channels up to the entrance pipe is connected with recirculation flow and with decreased active flow area in the intake pipe.

The cavitations swirl appears at different impeller speeds (also at smaller as it is its design speed).

Because of secondary flows, appearing at the impeller channels, caused by small, below-optimal operating capacities, during pump operating in the unstable cavitation regime, the cavitation swirl can cause erosion damage to the impeller material at the pressure side of the impeller blades.

The cavitation swirl does not change its length during impeller speed change or pressure above the water level change. This means that the swirl length is a function of the pump impeller eye geometry.

The swirl length is based on the geometry of the pump entrance area and could propagate up to 8-entrance diameters length in the upstream direction.

Pressure above the water level in the reservoir defines the volume flow rate of the gas phase and the cavitation swirl diameter.

Higher pressures above the water surface in the reservoir decrease the swirl diameter and tear it at more places.

From the measured results, a “critical” place, where the periodic swirl tearing appears is evident

The pulsation amplitudes directly depend on this phenomenon at the frequency area at about 1500 Hz.

The frequency of the cavitation swirl is in a range between 4 and 10 Hz and is changed by the prerotation speed.

References

[1] Predin A., Biluš I. Prerotation Flow at the Entrance to a Radial Impeller, *Journal of Mechanical Engineering*, Vol. 46, No. 5, 2000, pp. 276–290.

[2] Predin A., Biluš I. The Driving Mechanisms of the Cavitation Swirl in the Entrance Pipe of a Radial Pump, *Journal of Mechanical Engineering*, Vol. 47, No. 6, 2001, pp. 234–247.

[3] Predin A., Biluš I. Prerotation flow measurement, *Flow Measurement and Instrumentation*, Vol. 14, 2003, pp. 243-247.

[4] Knap, R. T., Daily, J. W. *Cavitation*, McGraw-Hill Company, New York, 1970.

[5] Wallis, G. B. *One – dimensional Two – phase Flow*, McGraw-Hill Company, New York, 1969.

[6] Brennen, C. E. *Cavitation and Bubble Dynamics*, Oxford University Press, London, 1995.

[7] Grist, E. *Cavitation and the Centrifugal Pump*, Taylor & Francis, London, 1999.

[8] Singhal, A. K., Athavale, M. M., Mathematical Basis and Validation of the Full Cavitation Model, *Journal of Fluids Engineering*, Vol. 124, 2002, pp. 617-624.