EXPERIMENTAL INVESTIGATION OF THE NON-UNIFORM INFLOW GENERATED BY THE SYMMETRICAL SUCTION ELBOW OF A LARGE PUMP

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This paper aims to experimentally investigate the non-uniform velocity field on the suction elbow outlet of the large pumps. The suction elbow has a three-dimensional symmetrical shape that induces non-uniform hydrodynamic field at the impeller inlet. The velocity field is measured using LDV system in order to be quantified the non-uniformities generated at the impeller inlet. A large variation of the circumferential velocity component induces a significant modification of the absolute angle flow in front of the impeller over each full rotation. Therefore, strong unwanted effects are generated in the impeller. The conclusions are drawn in the last section.

Keywords: large pump, symmetrical suction elbow, non-uniform inflow, LDV measurements.

1. Introduction

Nowadays, pumping systems account for nearly 20% of the world's electrical energy demand and range from 25-50% of the energy usage in certain industrial plant operations [1]. The large pumping units are widely used in industry to store energy, to provide cooling, to ensure propulsion and to transfer fluids. The large pumping unit includes the electrical motor and the hydraulic pump with various impeller types and different impeller arrangements. Normally, these pumps can reach high values of flow rate at high efficiency with a tolerate level of cavitation behavior if its selection criteria with respect to suction behaviour and optimum efficiency meet various system requirements [2]. Clearly, the large pumping units consume a significant amount of the total electrical energy. Therefore, even smaller improvements of energetic and cavitational performances of the large pumps are significant to minimize the overall costs.

Constructively, the solutions for large pumps are different than regular one [3]. A suction elbow with complex three-dimensional geometry is installed upstream to the impeller or the first impeller of the multistage pumps. As a result, the non-uniform flow is generated by the suction elbow then ingested by the

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impeller [4]. This suction elbow generates circumferential component in velocity distribution at the impeller inlet due to the suction chamber and the flow around the shaft [5]. As a result, the flow with pre-rotation is generated over roughly one half of the impeller inlet section and counter-rotation in the second half [6]. The uneven velocity distribution at the impeller inlet leads to the following: (i) the flow angle varies over the circumference and the radius, [7, 8]; (ii) loss in efficiency, [9]; (iii) noise and vibrations are excited, [10 - 12]; (iv) radial forces are generated, [13]; (v) cavitation damage on the impeller blades, [14, 15].

The paper aims to experimentally investigate the non-uniformity generated by a symmetrical suction elbow. The experimental test rig is described in Section 2. The setup for LDV measurements together with experimental details are presented in Section 3. The non-uniform inflow generated by the suction elbow is quantified through the absolute flow angle in Section 4. The conclusions are drawn in last section.

2. Experimental test rig

The test rig was developed at Politehnica University of Timisoara, Fig. 1. It consists of two tanks of 1 m^3 each, a set of pipes and vanes, which form a closed hydraulic circuit, and a PCN 80-200 pump actuated by a 37kW asynchronous motor. The inlet and outlet pipes diameters are 0.11m and 0.08m, respectively. Pump parameters are presented in Table 1 while the energetic and cavitational curves are plotted in [16].

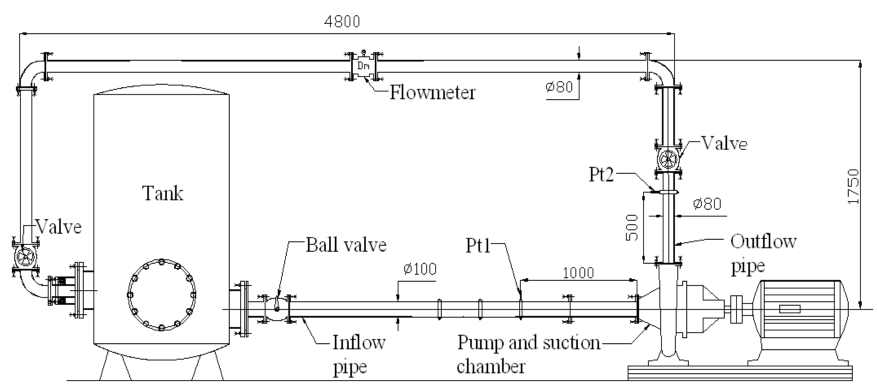

Fig. 1. The schematic view of the test rig. Actual dimensions in mm

The test rig is equipped with a real time acquisition data system. To acquire pressure at the inlet and outlet sections of the pump the rig is equipped with two pressure transducers: a vacuum gauge, located on the inlet pipe denoted *Pt1* as well as a manometer placed on the outlet pipe labeled *Pt2*, in Fig. 1. An electromagnetic flow meter is installed on the rig`s top pipe in order to measure the discharge. Its range is 0÷45 l/sec with an accuracy reported to be ±0.4%. Real time data acquisition system ensures proper sensor biasing and serial PC communication.

Table 1

Hydraulic pump parameters

Parameter	Value
Nominal puming head H_n [m]	44
Nominal discharge Q_n [m^3/s]	0.0335
Power at nominal discharge P_n [kW]	20
Maximum efficiency [%]	72

3. LDV measurements setup

The inlet suction through which passes a pump shaft surrounded by a protective sleeve at least one radial rib is mounted on the sleeve surface away from the elbow inlet, [17]. In our case, two ribs are included like in Fig. 3. The rib R1 is located where the two partial flows around the hub meet. If this rib is omitted, cavitation characteristics and work transfer (head coefficient and efficiency) are seriously affected. A periodic pre-rotation can also be induced which would result in unsteady operating. The rib R2 is not absolutely necessary with symmetrical inlets but desirable for reasons of mechanical design in order to limit casing deformation under the internal pressure, [6].

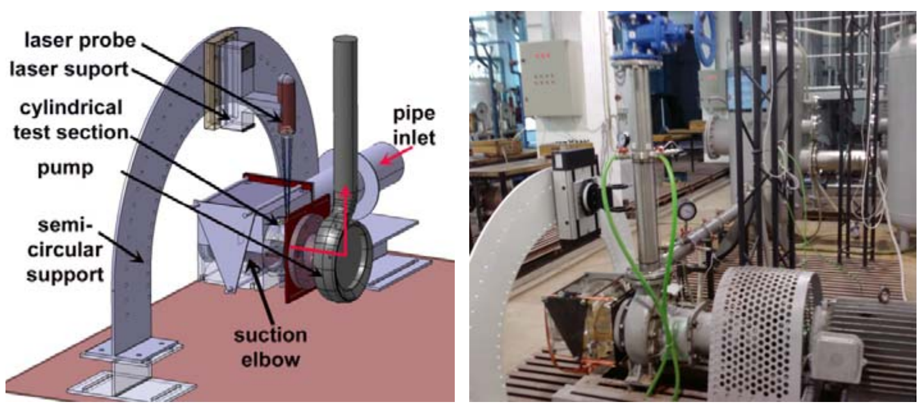

Fig. 2. LDV system installed on test rig: schematic view (left) and photo (right).

As it is previously mentioned, the flow with pre-rotation is generated in the symmetric inlet suction over roughly one half of the impeller inlet section and counter-rotation in the second half. The symmetry plane includes the rib R2 located at -90° and the rib R1 positioned at +90° like in Fig. 3. Therefore, the measurements are performed over upper half plane of the inlet section. The extensive three-dimensional numerical investigations performed by Ginga [18] support the experimental procedure presented in this paper.

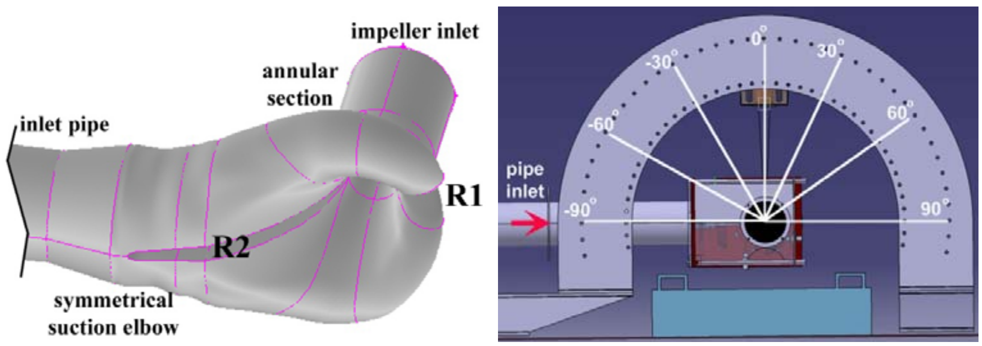

Fig. 3. The axonometric view of the symmetrical suction elbow (left) and all seven radial survey axes established for LDV measurements (right).

An annular section is displaced between the elbow outlet and the pump inlet. This section has an annular shape with the inner diameter of 40.2 mm and the outer diameter of 103 mm, respectively. The optical window was installed on this cylindrical test section. LDV measurements are performed along to the radial survey axis in 62 points with step of 0.5 mm. The annular test section is rotated around its axis in order to be measured on several radial survey axes. The experimental measurements were done on seven radial survey axes from -90° to 90° like in Fig 3. The laser probe curved link on the semi-circular support in order to be radial aligned with optical window on each survey axis position. Several alignments and checks were performed for the optical system on each radial survey axis position in order to be ensured uncertainties less than 2.5%. Each alignment procedure includes the following: the laser beams alignment, the cylindrical test section rotation around its axis and the optical window, respectively.

The experimental investigation was performed with a Laser Doppler Velocimetry (LDV) system able to simultaneously measure two velocity components (axial and tangential components). LDV system measures the velocity of the seeds (silver coated particles with 10 μm diameter) inserted in the water. The measurements were performed with minimum 1000 samples/second (1 kHz sampling frequency). The LDV system consists in an argon-ion source with 300 mW power and an optical fiber who guide the beams to the flow. The main characteristics of the LDV system are as follow: focal length of the probe 400 mm; beam diameter 2.2 mm; beam spacing 39.2 mm. For the probe positioning on radial survey axis, 1D traversing system is used with 0.01 mm accuracy. It was established that for each point is necessary to measure 50000 particles in 20 seconds in order to be ensured uncertainties less than 2.5%.

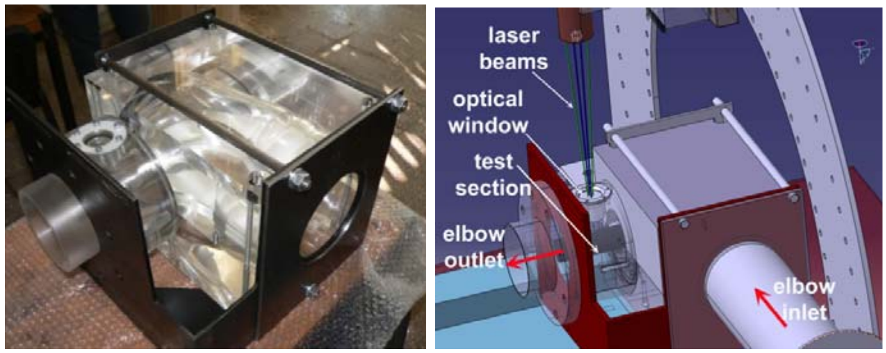

Fig. 4. The suction elbow manufactured on plexiglass in order to visualize the flow (left) and LDV system installed to measure two velocity components (axial and tangential) (right).

4. Experimental data analysis

LDV measurements are performed on seven radial survey axes (see Fig. 3) at nominal discharge Q_n=33.5 l/s and speed n=2500 rpm. The average absolute velocity profiles (axial and circumferential velocity components) versus radial coordinate were measured on all radial survey axes. The average absolute velocity profile measured on the radial survey axis located at 0° is plotted in Fig. 5. Also, the root mean square quantity for each measured value is added as a bar.

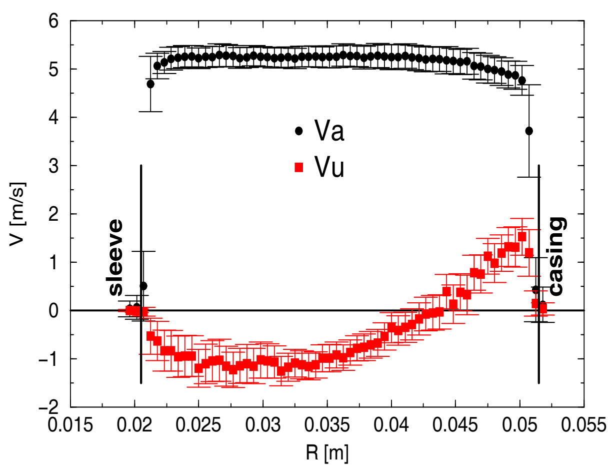

Fig. 5. The axial V_a (black) and circumferential V_u (red) velocity components measured on the radial survey axis located at 0° at the operating point: Q_n=33.5 l/s and n=2500 rpm.

The average absolute velocity profiles (axial and circumferential components) for all survey axes are presented in Fig. 6 at nominal discharge Q_n=33.5 l/s and speed n=2500 rpm. One can observe a quasi-uniform absolute axial velocity component while the circumferential one is not negligible as it was assumed at the design stage. The absolute circumferential velocity component is modifying from -2.5 m/s to +1.5 m/s over one half of the section elbow outlet surface.

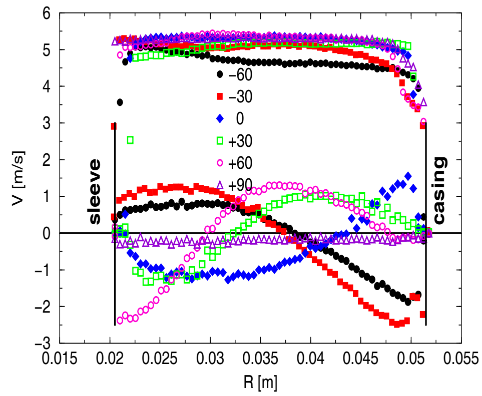

Fig. 6. The velocity components measured on all radial survey axes located at nominal discharge Q_n=33.5 l/s and n=2500 rpm.

The absolute flow angle α is defined according to the following equation:

$$\alpha = arctan\left(\frac{V_u}{V_a}\right) \quad [\circ] \tag{1}$$

The absolute flow angle on all survey axes is plotted in Fig. 7 while the map over annular outlet section is presented in Fig. 8.

The most significant variation of the absolute flow angle on the outlet surface of the suction elbow is generated near the boundaries (in vicinity of the sleeve and casing, respectively). This non-uniform flow generated by the suction elbow is ingested by the impeller leading to the unwanted effects already mentioned in first section.

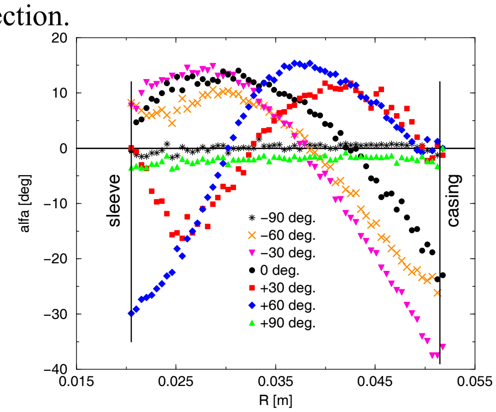

Fig. 7. The absolute flow angle (α) computed based on LDV measurements.

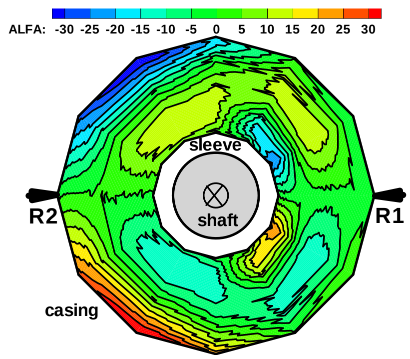

Fig. 8. The absolute flow angle (α) map reconstructed on the annular outlet section of the suction elbow based on LDV measurements.

5. Conclusions

The paper presents experimental investigation of the non-uniform velocity field on the suction elbow outlet of a large pump. Usually, the large pumps are equipped with a suction elbow with complex three-dimensional geometry upstream to the impeller. In our case, the suction elbow has a three-dimensional symmetrical shape inducing a non-uniform hydrodynamic field. The absolute velocity field is measured using LDV system on several radial survey axes at the suction elbow outlet. As a result, the average absolute velocity field (axial and circumferential components) is obtained. A quasi-uniform absolute axial velocity is measured while the circumferential one is not negligible as it was assumed at the design stage. The absolute circumferential velocity is modifying from -2.5 m/s to +1.5 m/s over one half of the section elbow outlet surface. As a result, a large variation of the absolute angle flow in front of the impeller is revealed. Therefore, strong unwanted effects are induced on the large pump impeller.

Acknowledgements

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