NUMERICAL INVESTIGATION OF THE 3D FLOW IN THE SUCTION ELBOW AND IMPELLER OF A STORAGE PUMP

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This paper aims to evaluate the hydrodynamic field in the suction elbow and impeller of a storage pump at variable discharge values. The suction elbow has a special geometry that influences the hydrodynamic field at the inlet of the impeller. Three-dimensional numerical simulation is performed in the suction elbow and impeller using "mixing interface" technique in order evaluate the cavitation behavior of the impeller. The numerical results are plotted for three operating points, $0.8Q_n$, the nominal flow rate Q_n and $1.35Q_n$. The conclusions are drawn in the last section.

Keywords: storage pump, mixing interface, suction elbow, variable discharge.

1. Introduction

All areas of relevance to the development and production of centrifugal pumps have undergone fundamental changes during the 50 years. In early 1960s, the main concern was to create fundamentals which allowed the engineer to achieve optimum efficiency, stable characteristic curves and a good suction behavior. Today the development of computers and improvement of CFD-codes tools became available which helps to support experimental experience by a theoretical analysis, Hergt [1].

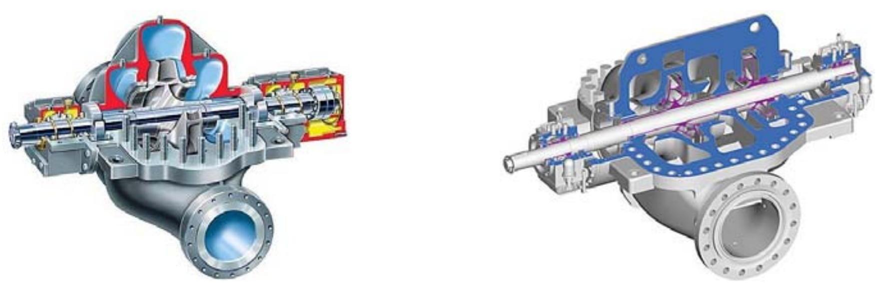

Fig. 1 Storage pump: double suction storage pump with one impeller (left), two storage double suction storage pump with two impellers (right)

In hydraulic systems among hydropower plants there are integrated pumping stations. Pumping stations have the purpose of pumping water from their

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dams into a storage lake. Usually, these pumps can reach high values of flow rate at high efficiency with a tolerate level of cavitation behavior. Nowadays, constructive solutions are presented in Fig. 1. These pumps have constructive differences besides regular pumps in order to insure higher flow rate. Consequently, the complex shape of the suction-elbow generates a non-uniform flow which is ingested by impeller. Several investigations of the flow upstream the impeller have underlined the non-uniform flow generated by the suction elbow and shaft, Sallaberger et al [2].

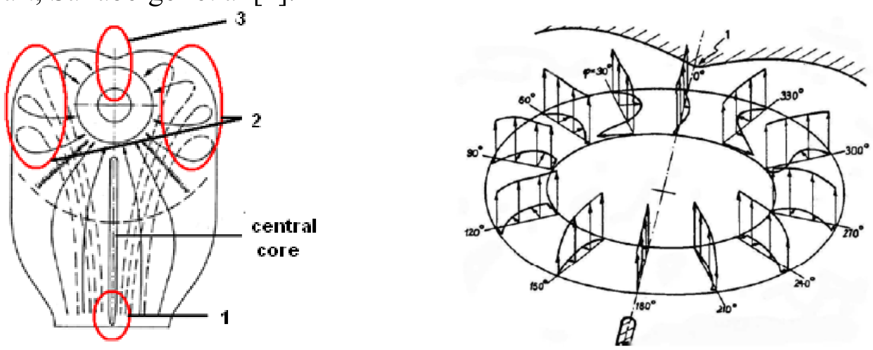

Fig. 2 Flow structure in a suction elbow, van den Braembussche [4]

Ludtke [3] performed a detailed experimental investigation of the flow in radial and tangential suction chambers in order to indentify the flow structure. Three flow separation regions are identified based on these investigations: the first region is located where the pipe diverges, the second one is displaced on the convex side of the inlet bend were the flow turns from radial to axial and the third zone is behind the shaft. The flow structure inside of the suction elbow is depicted in Fig. 2 - left. As a result, the hydrodynamic performances of the pump are deteriorated as well as unsteady phenomena are generated.

This paper aims to evaluate the hydrodynamic performances of a storage pump, Stuparu et al [4]. The three-dimensional computational domains together with numerical methodology are presented in Section 2. Numerical results for three operating points ($0.8Q_n$, Q_n and $1.35Q_n$) are analyzed in Section 3. The non-uniform flow generated by the suction elbow is evaluated. The conclusions are presented in last section.

2. Numerical methodology

2.1 Three-dimensional computation domains and coupling algorithm

Figure 3 - left, presents the storage pump with the suction elbow and the impeller with five blades. The 3D geometries of the suction elbow and impeller were reconstructed based on drawings using Gambit 2.4 [5] (see Fig. 3- right).

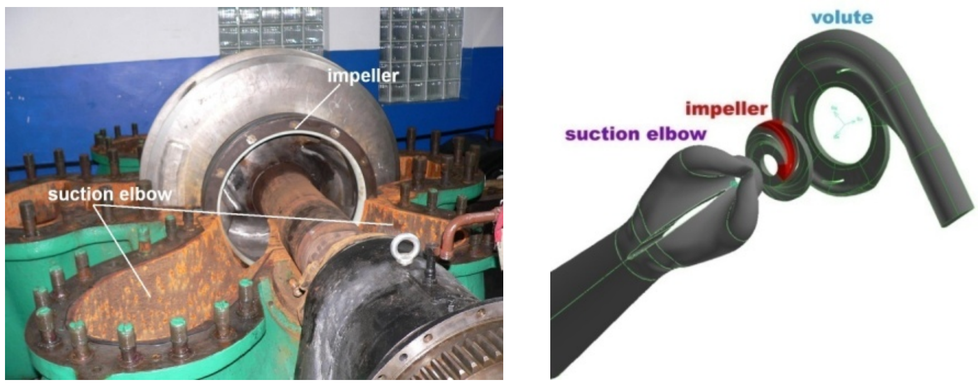

Fig. 3 The hydraulic passage of the investigated storage pump (left), 3D computational domains (right).

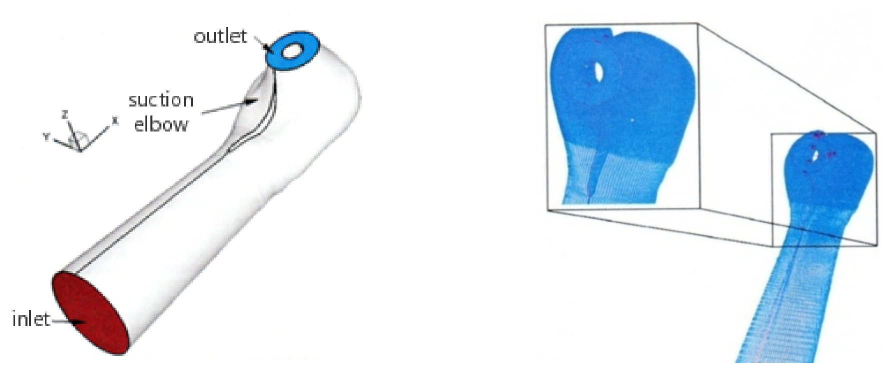

Fig. 4 The suction elbow domain: 3D computational domain (left) and the mesh (right).

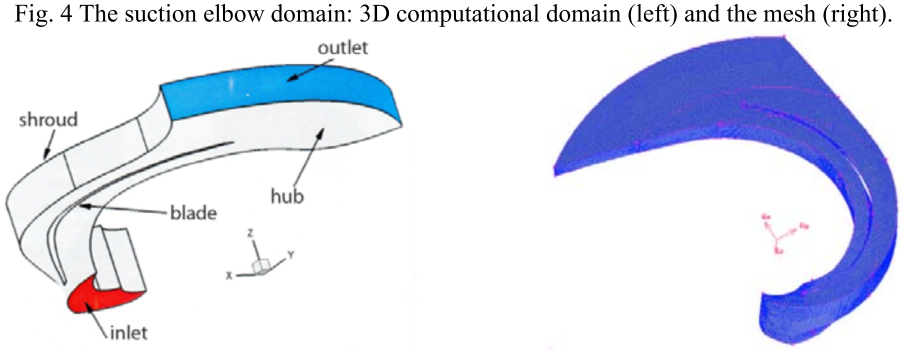

Fig. 5 The interblade impeller channel: 3D computational domain (left) and the mesh (right).

The three-dimensional complex geometry of the suction elbow (Fig. 4 – left) and the mesh with 465635 cells are plotted in Fig. 4 - right. The mesh is refined on the elbow in order to capture the non-uniform distribution of the flow. In this case, one interblade channel of the impeller is considered as computational domain. The three-dimensional interblade chanel domain (Fig. 5 – left) and the mesh with 590268 cells are plotted in Fig. 5 - right.

A simplified numerical simulation method has been achieved, called *mixing interface,* in order to couple the steady absolute flow from suction elbow with the steady relative flow from pump impeller.

The 3D computational domains correspond to suction elbow and one interblade channel of the pump. In order to couple the steady absolute suction elbow flow field with the impeller steady relative flow, a mixing technique is developed and employed on suction elbow-impeller interface.

This mixing algorithm removes the circumferential variation of velocity components, pressure and turbulence quantities using a piecewise polynomial least squares algorithm, Muntean et al [6]. For this particular case the mixing interface algorithm is presented in Fig. 6 - left, and the mixing interface is presented in Fig. 6 - right. The 3D turbulent flow is computed using FLUENT code [7].

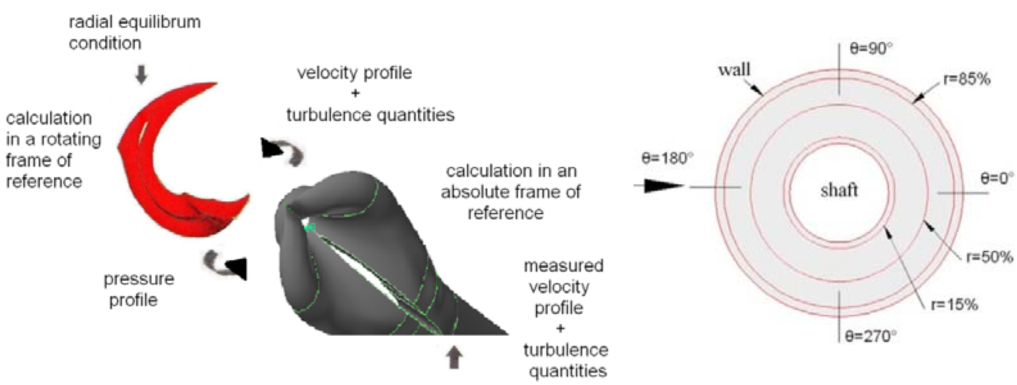

Fig. 6 Mixing interface algorithm for this particular case (left), mixing interface (right).

2.2 Boundary conditions

Velocity field is prescribed on the inflow section for both suction-elbow and impeller domains. The uniform velocity prescribed on the suction-elbow inlet section is computed to satisfy the discharge according to the operating point. The mixed velocity profile on the suction elbow outlet section is imposed on the impeller inlet section. Turbulence quantities are prescribed on the inflow section for both suction elbow and impeller domains. The turbulence intensity of 2% and hydraulic diameter of 0.75 is imposed on the suction elbow inlet section. Pressure distribution is imposed on outlet section of suction elbow. A constant pressure is considered on the outlet section of suction elbow like first guess in order to initialize the iterative process. Constant pressure is imposed on the outlet surface of the impeller. Periodic boundary conditions regarding the pressure, velocity and turbulence parameters are imposed on the periodic boundaries of the impeller. Wall condition is imposed for suction elbow walls, as well for the impeller hub, shroud and blade. Water liquid is selected as a working material.

3. Numerical results

Numerical analysis was performed for three operating points ($0.8Q_n$, Q_n and $1.35Q_n$) with parameters presented in Tab. 1.

Table 1

Parameters of the operating points

Operating point	Flow rate Q (m^3/s)	Pumping head H (m)	Speed n (rpm)
$0.8Q_n$	1.71	274	1000
Q_n	2.14	247	
$1.35Q_n$	2.89	209	

$$H = \frac{p_{out} - p_{in}}{\rho g} \tag{1}$$

Ginga et al. [8] made a detailed investigation of the flow structure on the outlet section of the suction elbow. The hydrodynamic field presents a non-uniform distribution of velocity components and two counter rotating vortices behind the shaft.

Consequently, this non-uniform flow developed by the suction elbow is carried in the impeller. This non-uniform field from impeller inlet induces an improper incidence angle on the leading edge of the blades. As a result, an unsteady loading is generated on the impeller blades.

Numerically, the mixing interface approach performs a circumferential averaging. It is equivalent to the full mixing of the wakes (or any other circumferential non-uniformities). As a result, the numerical analysis on the impeller was performed for an average distribution of the relative flow angle in terms of the radial coordinates from hub to shroud.

The relative flow angle β eq. (2) and the pressure coefficient on the impeller blade eq. (4) are plotted in Fig. 7 and Fig. 8, respectively.

$$\beta = 90 - \arctan\left(\frac{u - c_u}{c_x}\right) \tag{2}$$

where:

$$u = \frac{\omega r}{\sqrt{2gH}} \tag{3}$$

$$c_p = \frac{p - p_{IN}}{\rho \cdot \frac{U_{ref}^2}{2}} \tag{4}$$

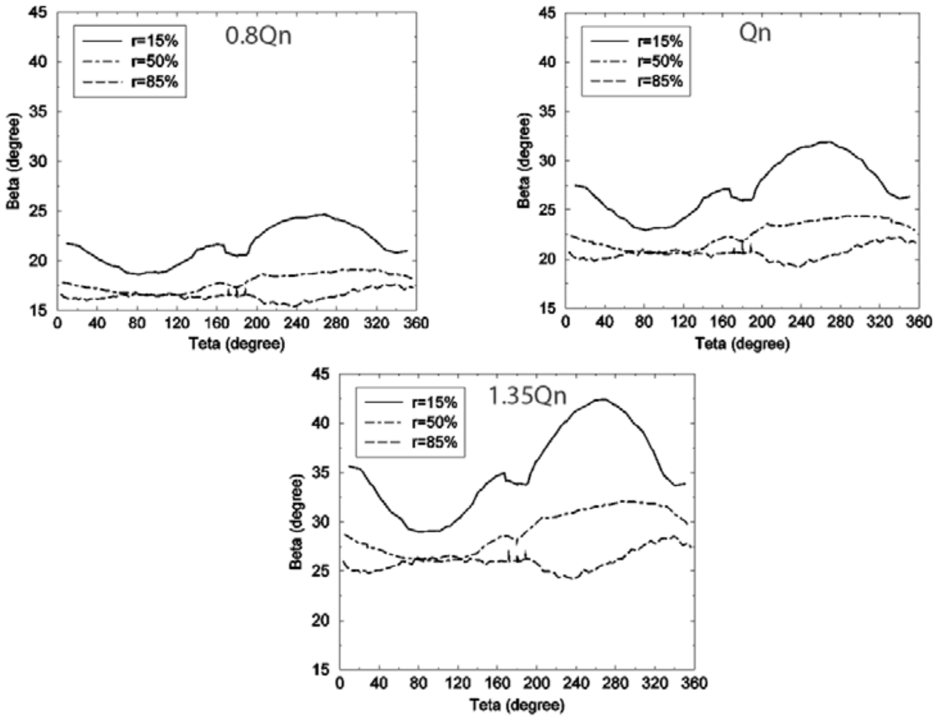

Fig. 7 Distribution of relative flow angle β on outlet section of the suction elbow: $0.8 \cdot Q_n$ – up left, Q_n – up right, $1.35 \cdot Q_n$ – down middle

Fig. 7 reveals that the maximum relative flow angle is obtained at largest flow rate $1.35 \cdot Q_n$ neat to hub. The maximum relative flow angle is 43.1° at θ=270° and the minimum value 28.9° at θ=90°, respectively. Consequently, the most unfavorable condition is obtained where the maximum relative flow angle is located.

As a first guess, the steady relative flow is computed into the impeller using the mixing interface. The pressure distribution coefficient on the impeller blade for three locations (r=15% near to hub – left, r=50% – middle, r=85% near to shroud – right) is plotted in Fig. 8. The sudden drop pressure is obtained on the leading edge even if the mixed velocity field is imposed. That is happened due to the leading edge with sharp geometry. The minimum value of the pressure coefficient reveals the development of the cavitational phenomena near to the leading edge at all investigated operating points.

$$\sigma = -\frac{p_{in} - p_v}{\rho \cdot \frac{U_{ref}^2}{2}} \tag{5}$$

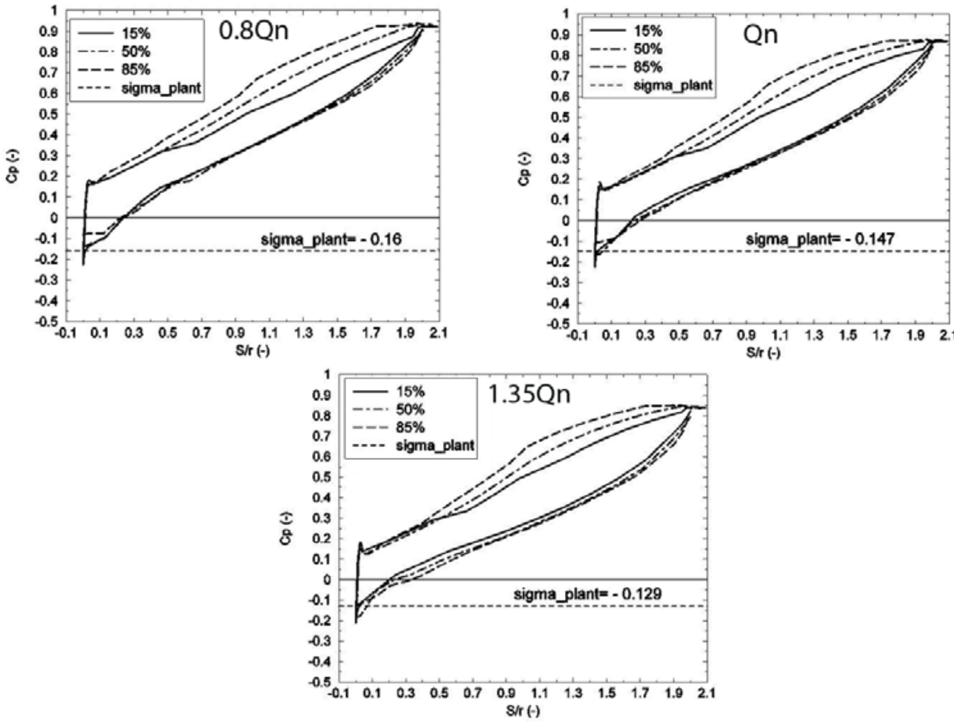

Fig. 8 Distribution of pressure coefficient on the blade: 0.8Qn -up left, Qn -up right, 1.35Qn down middle

4. Conclusions

The paper presents the numerical investigations performed one a suction elbow and impeller of a storage pump. First, three-dimensional geometries of the suction elbow and impeller are reconstructed based on the drawings. Second, three-dimensional turbulent flow using mixing interface technique is considered in order to couple the steady absolute flow from suction elbow with steady relative flow from impeller. The values of the relative flow angle on the outlet section of the suction elbow of the storage pump were investigated for three operating points: $0.8Q_n$, Q_n and $1.35Q_n$. Next, the maximum non-uniformity is indentified at maximum flow rate $1.35Q_n$ near to hub r=15%.

Pressure coefficient distribution on the impeller blade was obtained. Also, the storage pump cavitational coefficient was calculated using the data available in situ. Due to the sharp leading edge of the blade, a sudden drop of pressure is remarked at the inlet section of the impeller even when a mixed velocity is imposed. Consequently, the minimum values of the pressure coefficient reveal the development of the cavitational phenomena near to the leading edge at all investigated operating points. The deep cavitational erosion of the impeller was observed in that region.

Further, full unsteady turbulent flow will be performed into the impeller in order to take into account the non-uniform field generated by the suction elbow as the next step in the investigation of the pump behavior.

Acknowledgments

This work was partially supported by the strategic grant POSDRU 2009 project ID 50783 of the Ministry of Labour, Family and Social Protection, Romania, co-financed by the European Social Fund – Investing in People. Dr. Sebastian Muntean was supported by the Romanian Academy program.

Nomenclature

ρ	Water density [kg/m^3]	c_u	Tangential velocity coefficient [-]
H	Pumping head [m]	c_x	Axial velocity coefficient [-]
Q_n	Nominal flow rate [m^3/s]	g	Gravitational acceleration [m/s^2]
β	Relative flow angle [°]	p_{in}	Inlet pressure [Pa]
r	Radius [m]	p_{out}	Outlet pressure [Pa]
u	Tangential velocity [m/s]	p_v	Vapor pressure [Pa]
		U_{ref}	Reference velocity [m/s]

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