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Modeling and Simulation Baed Analysis of Centrifugal Pump Volute Design Parameters by Finite Element Method

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The performance of pumps are influenced by many factors among which the geometric configuration of the volute. The role of the volute in a centrifugal pump is the transformation of the kinetic energy into pressure with a minimum of losses. The volute is a pump element which is difficult to modify. It must be able to be adapted to impeller with different dimensions. The objective of this work is to investigate by numerical simulation the Von Mises stress distribution and displacements in volutes of different dimension in diameters and width of a centrifugal pump. The study is carried out using finite element method on a three dimensional configuration using ABAQUS code. Only a few attempts of numerical analyses of the mechanical behavior of volute are made. This element plays an important role in the pump adaptation for a given operating conditions by adjusting its dimensions. This activity is conditioned by a good understanding of the design process of the volutes. The obtained results show the modifications of the diameter and the width of the volute have an effect on the values of Von Mises' stresses and on the displacements. The stresses and displacements reach their maximum with increasing diameters and are inversely for the increase in the width. These dimensional modifications can act indirectly on the clearance at the bec and also on the clearance between the volute exit and the impeller. These are functional clearances which allow the determination of the operating characteristics of centrifugal pumps. With these results substantial improvement on the pump design can be made.

Keywords: design, radial volute, centrifugal pump, Finite Element Method (FEM), ABAQUS.

1. Introduction

Centrifugal pumps are used in many industrial applications. However the design process of pumps is a complex activity due to the high number of fundamental geometric parameters of their components to be taken into account. The present study is concerned with the design of volute of centrifugal pump. To deal with problem, designs 'main preoccupation is to have sufficient accurate data in order to construct the geometry of the volute that maximizes the energetic efficiency and minimizes the losses. The main role of the volute is to receive the liquid coming with high velocity from impeller to direct it, then to slow it by reducing the perturbations and thus transforming into pressure an important quantity of its kinetic energy. Due to this fact, the volute is subjected to severe solicitations that can lead to severe damages that make the pump unusable. It is known that the drawing elements which determine the characteristics of the volute are the form of the section, the volute angle, the width of the input section and the diameter of its base circle. The latter conditions the minimum radial clearance existing between the impeller and the volute as well as the effect of the volute outlet. In this aim the analysis of the mechanical response of a volute by modifying its geometry especially the diameter and the width has been addressed. The researches aiming to study the effect of the volute on the performance of centrifugal pumps are summarized in the following: A ERICIN's [1] research aimed to establish an expression that allows the determination of the sections of the volute in order to obtain a static pressure distribution at impeller exit as uniform as possible. The effect of the volute angle had been experimentally studied by R.D BOWERMAN et al. [2]. They investigated given volute with known characteristics in an annular diffuser with three types of volutes. Each volute has a rectangular section and a logarithmic spiral form with different spiral angle. The experimental results of S LAZARKIEWICZ et al [3] showed the advantage of a symmetric volute compared to the dissymmetric one with respect to the meridian plane of impeller. The little difference between a radial volute and a tangential volute exit resides in the advantage of the solutions of double–volute type. This solution allows deleting the radial thrust. A numerical investigation was carried out by F.GU et al [4] concerning the volute–rotor interaction following a radial distortion at the rotor exit. D. Hagelstein [5] suggested an experimental and analytical analysis of a flow in centrifugal compressor in a pump volute. Chan Ho Sin et al [6] carried out a numerical analysis on the effect of a transversal section of a spiral volute on the performance of centrifugal pump. A comparison between the lateral characteristic forces measured and the hydraulic performance of the rotor has been made for spiral volute, a concentric volute and a double volute. Knowing that the maximum efficiency point depends on the chosen dimensions volute was the subject of work of Daniel O Bann's works [7].The present work aims to study numerically the impact of the parameters variation of the volute such as the diameter and the width on the stress distribution in the volute body. The numerical investigation is based on the finite element method using commercial code ABAQUS. This building on the results of the literature found which put into evidence the importance of these parameters and their impact on the operating conditions of the volute and on the modification of predicted rotor operating conditions.

2. Drawing of the volute

The main elements of the drawing that determine the characteristics of the volute are [8]:

- The form of the sections of the volute.
- Angle α of the volute.
- The width at the inlet.
- The diameter D of its base circle.

2.1. *Plot of volute according to the principal of kinetic moment*

There exist many computational methods and drawing of the volute Fig. 1. In this work the method based on the principal of conservation of kinetic moment is used.

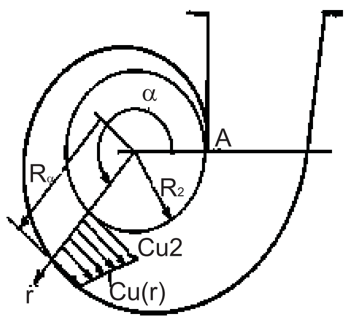

Figure 1 Evolution of the section of the volute

Based on the assumption of irrotational fluid flow in the volute we have:

$$\chi = Cu\, r = Cu_2\, R_2 \tag{1}$$

The section element shown in Fig. 2 is given by:

$$dA = b(r)\, dr \tag{2}$$

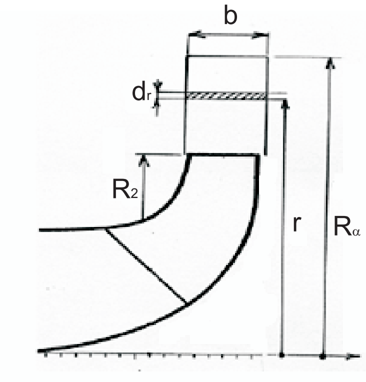

Figure 2 Rectangular section of the volute with angle α

The flow rate is equal to:

$$dq_v = Cu\,dA \tag{3}$$

By integrating along the whole section we have:

$$q_{v\alpha} = \chi \int_{R_2}^{R_\alpha} b(r)\frac{dr}{r} \tag{4}$$

The fraction of total flow rate in pump is equal to:

$$q_{v\alpha} = \frac{\alpha}{360} q_v \tag{5}$$

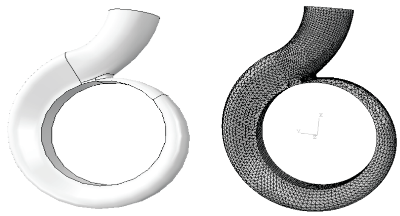

Figure 3 Volute configuration and mesh

3. Investigated configuration and volute meshing Equations

The behavior of a centrifugal pump subjected to mechanical loading has been investigated for the configurations shown in Fig. 3 for different diameters and widths. The computation is made using ABAQUS Code. The meshing of the volute must satisfy the geometrical and physical criteria and must also take into consideration the conditions related to the study. The mesh is structured as tetreadric of type C3D4 is used.

4. Conditions of simulation

In this work a radial volute made of Aluminum is investigated. The mechanical properties of the volute are: Young's modulus E = 70 GPa and Poisson modulus ν = 0,33. At the inlet of the volute a fixed end has been made. An uniform pressure of 300000 Pa has been applied on the entire internal surface of the volute Fig. 4.

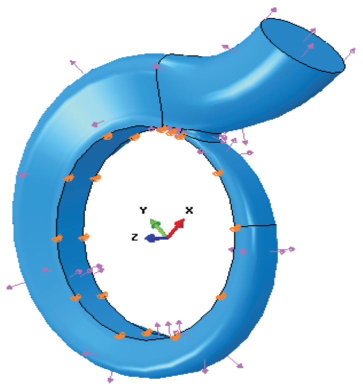

Figure 4 Pressure distribution

5. Results and discussion

In this study the width of the volute and the diameter of its base circle were taken into consideration. These parameters as well as the volute outlet condition, the radial clearance between the rotor and the volute had been put into evidence in order to obtain the contours of von Mises' stress distribution and displacement for different widths b and diameters D of the radial volute. The results are shown in Fig. 5 and Fig. 6.

5.1. *Von Mises distribution*

The distribution of Von Mises stresses are illustrated respectively in Fig. 5 and Fig. 6 for different widths and diameters of the radial volute. One can note, according to the experimental works carried out in the domain of the internal flow in the in the centrifugal pumps, that the geometric variation of the volute (width, diameter and angle) has an effect on the energetic efficiency of the pump mainly on the optimal efficiency point on the inlet and outlet conditions...etc.). It is in this context that the selection of the values of the diameters and widths has been made. From the obtained results it is observed a non–uniform distribution of the stresses due to the complex form of the volute. A stress concentration is observed at the volute inlet precisely at zone near its mouth. This may be considered as a week point of the volute where the stresses can be higher than the allowable stresses predicted by the manufacture. It is noticed that the Von Mises' stresses in the volute increase with increasing of its external diameter. The stresses decrease with increasing width of the volute. It is then required to optimize the choice of these two parameters in order to reduce the stresses as low as possible.

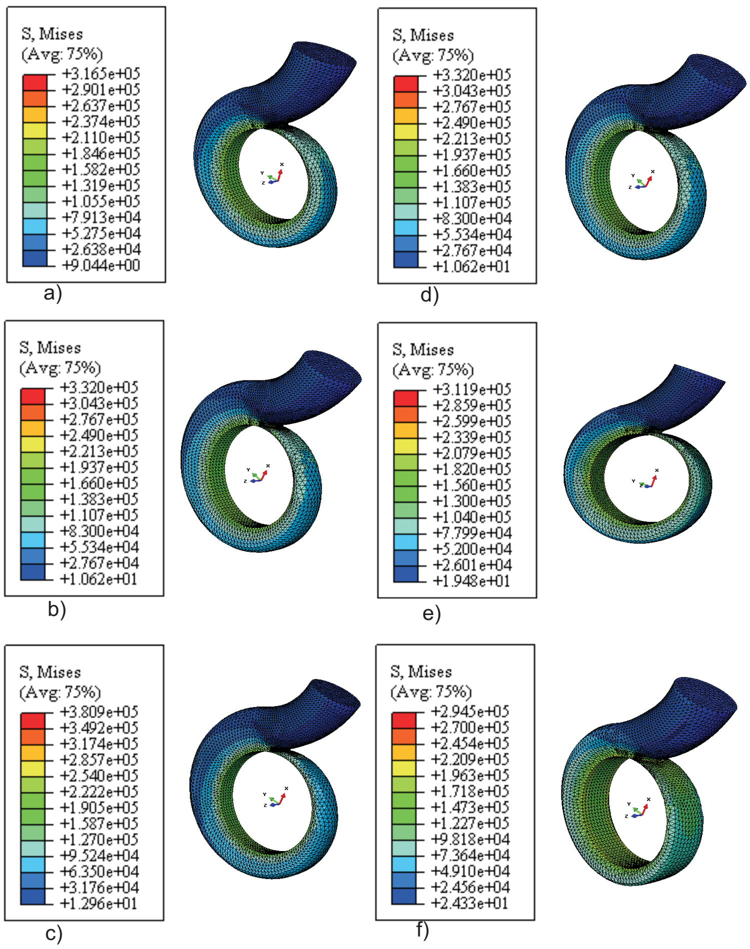

Figure 5 Von Mises' stress distribution (variation of diameter and width): a) diameter$D_1 = 112$ mm; b) diameter $D_2 = 120$ mm; c) diameter$D_3 = 130$ mm; d) width$b_1 = 25$ mm; e) width$b_2 = 30$ mm; f) width$b_3 = 35$ mm

5.2. *Displacement distribution contours*

In the same way, the displacements due to the change of pressure are studied with the variation of the diameter and width of volute. The contours of the displacement distributions for the three diameters show that with the increasing value of the diameter from $D_1 = 112$ mm to $D_3 = 130$ mm, the maximum displacement increases from U $= 9{,}752.10^{-5}$ to $1{,}059.10^{-4}$ and inversely for the case of the variation of the width of the volute as shown in Fig. 5 and 6. The maximum of displacement is observed at the volute exit. This will have a direct repercussion on the clearance at the volute mouth which simultaneously depends on the diameter of the base circle of the volute, on the external diameter of the impeller and on the volute angle. From the simulation results, in the case when the clearance is very small this leads to a noisy operating service due to the impeller volute interference. When the clearance is very high this leads to the drop of efficiency due to the circulation of the fluid between the bec and the impeller. Moreover, any geometrical modification of the volute is rigorously dependant on its adaptation with impeller of different diameters and widths, thus this necessitates a required functional clearance. In practice it advisable to mountain the ratio between the width at the inlet of the volute and the width of the impeller between 1,4 to 1,8. A high clearance tends to favor the increase of internal leaks which affect the efficiency of the pump.

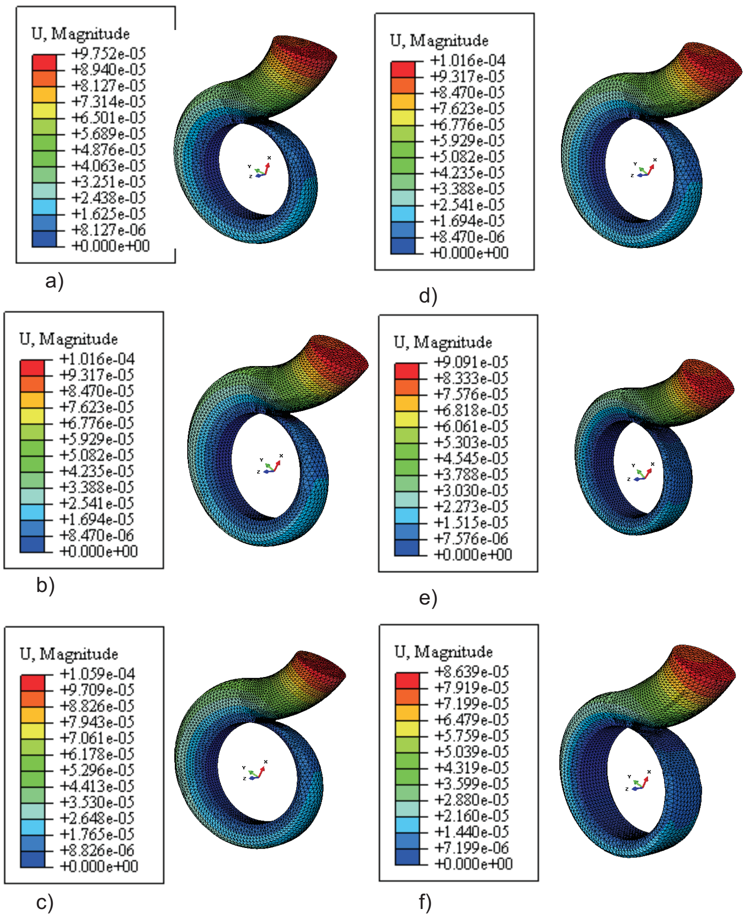

Figure 6 Contours des displacements (variation of diameter and width): a) diameter$D_1 = 112$ mm; b) diameter $D_2 = 120$ mm; c) diameter$D_3 = 130$ mm; d) width$b_1 = 25$ mm; e) width$b_2 = 30$ mm; f) width$b_3 = 35$ mm

6. Conclusion

The pumps are among the most used in industry hydraulic machines. They are threatened failures caused by the wrong choice of the geometric parameters and the adaptation of these pumps operating conditions with respect to design conditions. In this context, this work has been devoted to the study by numerical simulation of the behavior of elasticity in a radial aluminum volute of a centrifugal pump subjected to mechanical loading. The problematic under consideration was the comparative study between the mechanical response of the complicated form of the volute for different values of the base circle diameter and width.From the Von Mises' contour stress analysis it is observed that the highest stresses are in the inlet zone of the volute in the vicinity of the bec. However, the maximum displacements occur at the outlet zone of the volute. It is also noticed that the variation of the diameter and the width of the volute has an effect on the clearance at the bec of the volute. These have a determinant role in order to avoid their impact on the operating conditions of the centrifugal pump mainly on its noise and vibration characteristics.

References

[1] **Ergin, A.**: Étude des volutes spirales des pompes centrifuges, en tenant compte de la répartition des pressions statiques, *La Houille Blanche* 6, 639–660, **2011**.

[2] **Bowerman, R. D.** et al.: Effect of the volute on performance of a centrifugal pump impeller, *Transactions ASME*, 7(9), 4, 1057–1069, **1957**.

[3] **Lazarkiewicz, S.** et al.: Impeller Pumps, *Pergamon Press*, **1965**.

[4] **Fahua, G.**: A numerical investigation on the volute/impeller steady–state interaction due to circumferential distortion, Paper 2001-GT-0328, pp. V001T03A030, **2001**.

[5] **Hagelstein, D.**: Experimental and numerical analysis of the flow in centrifugal compressor volute, *J. Turbo machine*, 122(1), 22–31, **1999**.

[6] **Chang Ho Son** et al.: Spiral casing of a volute centrifugal pump effects of varying the cross–sectional area, *Journal of Mechanical Science and Technology*, 28, 7, 2697–2706, **2014**.

[7] **Baun, D. O.**: Effects of volute design and number of impeller blades on lateral impeller forces and hydraulic performance, *International Journal of Rotating Machinery*, 9(2), 145–152, **2003**.

[8] **Rey R.** et al.: Helicocentrifugal and centrifugal machines, III, **2008**.