

Parametric Modeling of Single-stage Double-suction Centrifugal Pump Impeller

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Abstract. Aiming at the parametric modelling design of the single-stage double-suction centrifugal impeller, C# was used for secondary development with software SolidWorks. Based on the created parametric driving model, the impeller with different design parameters can be obtained quickly. The boolean operation was performed on the parameterized impeller structure model to obtain the water body model. And the fluid numerical simulation of hydraulic performance of the impeller can be obtained through ANSYS, which saves a great work of the impeller design and improve work efficiency.

1. Introduction

A single-stage double-suction centrifugal pump is a typical centrifugal pump with an impeller, two suction inlets and one discharge outlet, and adopts a mid-open structure. Due to its advantages of simple structure, easy maintenance, high reliability, high flow rate, high efficiency, and small cavitation loss, single-stage double-suction centrifugal pumps have a wide range of applications in various fields of production and life [1].

The impeller is the core component of the single-stage double-suction centrifugal pump and it determines the hydraulic performance of the pump. Therefore, the design of the impeller is the most important task of the pump design. At present, modeling software has been widely used in the process of impeller design, and the model is simulated by computer to get the impeller products that meet the requirements of the design. However, because of the complex geometry of impeller, the 3D modeling process is rather cumbersome. The manual modeling method is time-consuming and laborious. In the process of designing an impeller, the parameters of the impeller need to be modified many times for the optimized simulation results, which causes the designers a lot of work and affect the design efficiency [2-3]. The impeller is a typical serialized product. The same type of impeller has a similar structure and different sizes. The modeling process and the modeling method are basically the same. Therefore, the parametric modeling method can be adopted. Based on the created parametric driving impeller model, with the input modeling parameters, the preset process automatically completes the modeling of the impeller, improving design efficiency and shortening the design cycle.

In order to realize the parametric modeling of the single-stage double-suction centrifugal pump impeller, C# language was used to carry out the secondary development of SolidWorks software, and

created the pump impeller parametric modeling procedure. The created model was imported into ANSYS to carry out the hydraulic simulation to verify the effectiveness of the developed program.

2. Centrifugal pump impeller modeling method

Considering the general applicability of the program and the difficulty of development, SolidWorks software was selected as the supporting platform. Based on the manual modeling process, a parametric modeling process for a single-stage double-suction centrifugal pump impeller for a closed impeller was designed as follows:

(1) According to the three-dimensional coordinates of the intersection point of the wood pattern cutting line and the axial plane intercept line, the "XYZ point curve" function is used to obtain the wood pattern cut lines of all the blades. Use the "Slope" function to get the working surface and the back of the blade, respectively.

(2) Use the "extended surface" function to extend the working face and back face of the blade toward the direction of the impeller outlet and the direction of the rear cover plate by a certain distance.

(3) Using the "Slope" feature to obtain the four sides of the blade, using the "Surface Suture" function to stitch all the surfaces of the blade into one entity. The "cut-out" function is used to remove the blade solids to ensure that the blades do not extend beyond the impeller, so that the blades do not interfere with the front and rear cover plates after cutting.

(4) Use the "array" function to get all the blades.

(5) Draw the sketches of the front and rear cover plates, and use the "rotary boss/substrate" function to obtain the front and rear cover plates.

(6) Use the "mirror" function to get a complete impeller model.

3. Parametric modeling program procedure

3.1. Selection and processing of parameters

Using program-driven method, it is necessary to provide the required parameters for each step according to the already determined parametric modeling process. Some parameters can be obtained through the operation of other parameters. Therefore, a set of modeling parameters that require designers to input must be determined. The model parameters of the blade and the cover are relatively independent, so they are explained separately.

The parameters of the blade modeling section are the number of blade woodcut lines and corresponding angles, the number of axial plane intercept lines and the axial coordinates, the radial coordinates of the intersection point of the woodcut line and the axial line or the boundary line, and the blade boundary line parameters shown in Figure 1. This paper only analyzes the blades with a single arc boundary line and double arc boundary line. For the blades with other types of boundary lines, similar processing can be performed with reference to this method.

With the function "through the XYZ point curve" to draw the cut line of the wood pattern, and after the wood pattern cut line undergoes laid out, extended, and stitched, the blade model was obtained by the array function. The three-dimensional rectangular coordinate system was established with the rotation axis of the impeller as the Z axis and the mirror surface as the XY plane. The XY coordinate of the intersection point of the wood pattern cutting line and the axial plane intercept line or the boundary line can be obtained by multiplying the radial coordinate of the intersection point and the sine and the cosine of the section angle of the wood pattern cutting line corresponding to the point. The Z coordinate of the intersection point of the wood mold cutting line and the axial surface section line is the same as the axial coordinate of the axial surface section line corresponding to this point. The Z coordinate of the intersection point between the wood mold cut line and the boundary line is more complex and related to the type of the boundary line. It needs to be calculated according to the

geometric relationship. In this paper, the single-arc boundary line blade is taken as an example to illustrate wooden cutting line and the boundary point Z coordinate calculation process. The double-arc boundary line blade and other types of boundary line blade can be similarly calculated with reference to this process.

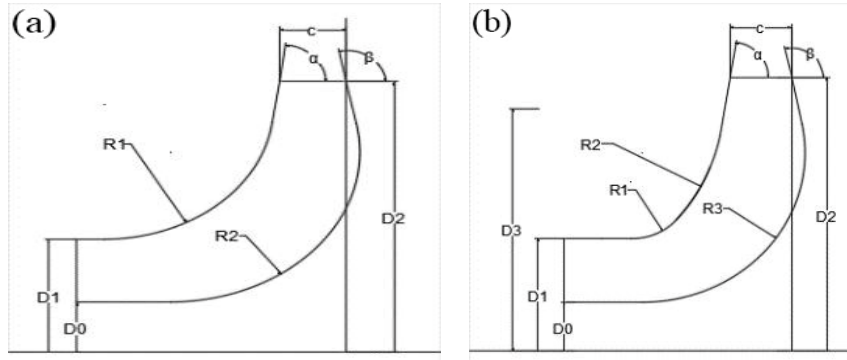


Figure 1. Parameters of blade boundary line **a)** Single Arc. **b)** Double arc.

For the intersection point on the boundary of the single arc front cover, the following formula can be obtained according to the geometric relationship:

$$I = R_1 \times \tan \frac{\alpha}{2} \times \sin \alpha \tag{1}$$

$$H = \frac{D_2 - D_1}{\tan \alpha} + R_1 \times \tan \frac{\alpha}{2} \tag{2}$$

When the $\alpha \neq 90^\circ$,

$$Z = (H + c - \sqrt{R_1^2 - (R_1 + D_1 - \rho)^2}) \tag{3}$$

, ($D_1 < \rho \leq I + D_1$)

$$Z = \frac{D_2 - \rho}{\tan \alpha} + c \tag{4}$$

, ($I + D_1 < \rho < D_2$)

When the $\alpha = 90^\circ$,

$$Z = R_1 + c - \sqrt{R_1^2 - (R_0 + D_1 - \rho)^2} \tag{5}$$

, ($D_1 < \rho \leq I + D_1$)

$$Z = c \tag{6}$$

, ($I + D_1 < \rho < D_2$)

For the intersection point on the borderline of the single arc rear cover, the following formula can be obtained according to the geometric relation:

$$I = R_2 \times \tan \frac{\beta}{2} \times \sin \beta \tag{7}$$

$$H = \frac{D_2 - D_0}{\tan \beta} + R_2 \times \tan \frac{\beta}{2} \tag{8}$$

When the $\beta \neq 90^\circ$,

$$Z = H - \sqrt{R_2^2 - (R_2 + D_0 - \rho)^2} \tag{9}$$

, ($D_0 < \rho \leq I + D_0$)

$$Z = \frac{D_2 - \rho}{\tan \beta}, \quad (I + D_0 < \rho) \quad (10)$$

When the $\beta = 90^\circ$,

$$Z = R_2 - \sqrt{R_2^2 - (R_2 + D_0 - \rho)^2}, \quad (D_0 < \rho \leq I + D_0) \quad (11)$$

$$Z = 0, \quad (I + D_0 < \rho) \quad (12)$$

After obtaining all the three-dimensional coordinates of the intersection point of the wood mold and the axial line or the boundary line, the blade part modeling can be completed according to the determined parametric modeling process.

The cover plate model is obtained by the function of "rotary convex platform/matrix". Therefore, the key to the modeling of the cover plate is to determine the coordinate of each parameter point needed in the sketching command. Taking into account the actual drawing of the project, reduce the designer's calculation of the parameters as much as possible, the modeling parameters selected in this paper can be obtained directly from the engineering drawings. This article only takes one structural type cover plate as an example, and other types of cover plate parameter selection can refer to this process. All the parameters required in the modeling of the cover plate are shown in Figure 2. According to the geometric relationship between each parameter point, the equations between the coordinates of each parameter point and the modeling parameters can be established, and the coordinates of each parameter point can be obtained through calculation. In this way, using the drawing function of SolidWorks to insert straight lines, arcs and chamfers, completing the sketching of the front and rear cover plates, and finally using the "rotary convex platform/matrix" function to obtain the front and rear cover solid models.

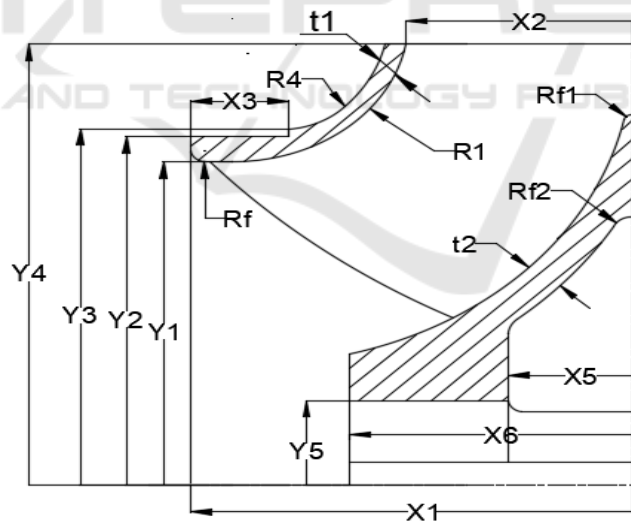


Figure 2. Parameters for the cover.

3.2. Program design

The main API functions are as follows:

Insertion Point: ModelDoc2.InsertCurveFilePoint

Surface Loft: ModelDoc2.InsertLoftRefSurface2

Surface extension: ModelDoc2.InsertExtendSurface

Surface Suture: FeatureManager.InsertSewRefSurface

Cut: ModelDoc2.InsertCutSurface
 Array: FeatureManager.FeatureCircularPattern4
 Sketch: SketchManager.CreateLine, SketchManager.CreateArc
 Rotary Boss / Base: FeatureManager.FeatureRevolve2
 Mirror: FeatureManager.InsertMirrorFeature

The impeller modeling is divided into two parts, blade modeling and cover plate modeling. Each part is divided into two major steps, modeling parameter coordinate calculation and three-dimensional modeling. In this way, the designer inputs the modeling parameters through the user interaction interface, the program automatically completes the parameter calculation, and calls the SolidWorks API function to perform the modeling operation in a predetermined sequence to complete the modeling of the impeller.

4. Examples and discussion

A typical single-stage double-suction centrifugal pump impeller was used as an example to verify the correctness of the impeller model established by this SolidWorks secondary development program, and the numerical simulation of its hydraulic performance was performed using ANSYS software.

4.1. The establishment of an impeller model

The single-stage double-suction centrifugal pump impeller is selected as an example. The type of the boundary line is a single arc boundary line. By entering the following parameters of the blade: the number of wood mold cutting lines and the corresponding angle, the number of axial plane intercept lines and the axial coordinate, the radial coordinates of the wooden cutting line between the axial plane or border line, and blade number, the blades can be generated. Enter the modeling parameters of the cover plate, click the function button to complete the cut off, front cover modeling, rear cover plate modeling and impeller mirror functions, the generated impeller model is shown in Figure 3.

4.2. Meshing and numerical calculation

The structure of the double-suction mid-open pump is complex and there are rotating and stationary areas. The design parameters are: revolving speed 990 r/min, flow rate $3200\text{m}^3/\text{h}$, head of delivery 22m, efficiency 88%, water density $997\text{kg}/\text{m}^3$. First, the parameterized impeller model is used to perform Boolean operation to obtain the impeller water model. Then, the impeller water model and its associated shell water calculation model are imported into ICEM in the Parasolid format for boundary and entity definition, and then the grid division function is used to generate the mesh, and imported for the numerical simulation of internal flow. The walls adopt triangular meshes, and the unstructured tetrahedral meshes are used in the solid part to facilitate the convergence of calculations and obtain more accurate simulation values. The water flows in the pump as incompressible flow, and there is no heat exchange between the water flow and the outside [4-5]. Therefore, the numerical model does not include the energy equation model. Speed condition is selected as the inlet boundary, and outflow condition is selected as the outlet boundary. The adopted mesh model is shown in Figure 4.

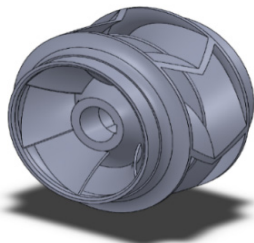


Figure 3. Impeller model.

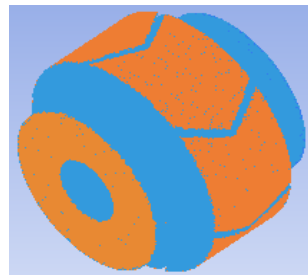


Figure 4. Impeller water grid diagram.

4.3. Simulation results and analysis

The simulation results of the design condition is shown in Figure 5 and Figure 6. Figure 5 shows the total pressure distribution of the impeller. The total pressure is the sum of the static pressure and the dynamic pressure, representing the energy of a unit volume fluid. It can be seen that as the impeller rotates at high speed, the fluid energy gradually increases along the impeller flow path under centrifugal force. From a physical point of view, the maximum flow velocity in the impeller's internal flow field should be located at the impeller outlet, and the minimum flow velocity at the impeller inlet. As shown in Figure 6, the flow of fluid entering the impeller is relatively uniform, the flow of fluid in the pressure chamber is relatively smooth, and the speed gradient change is small, which is consistent with the theoretical analysis results [6]. The working medium is thrown from the impeller to the pressure chamber outlet, the flow velocity gradually decreases along the flow direction and reaches a minimum value near the outlet of the pressure chamber, and there is no obvious sudden change. This is consistent with the design principle of the pressure chamber. From the overall flow field distribution, it can be seen that the overall flow trend simulated by the commercial software ANSYS is consistent with the design theory of the impeller and the pressure chamber. And the simulation results show that the pump's analysis efficiency is 89.1%, which has exceeded the design efficiency of 88%, proving that the performance of the calculation model meets the design requirements.

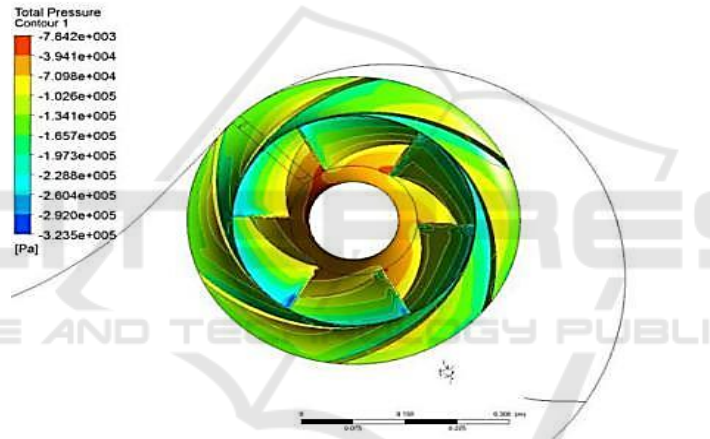


Figure 5. Impeller total pressure distribution.

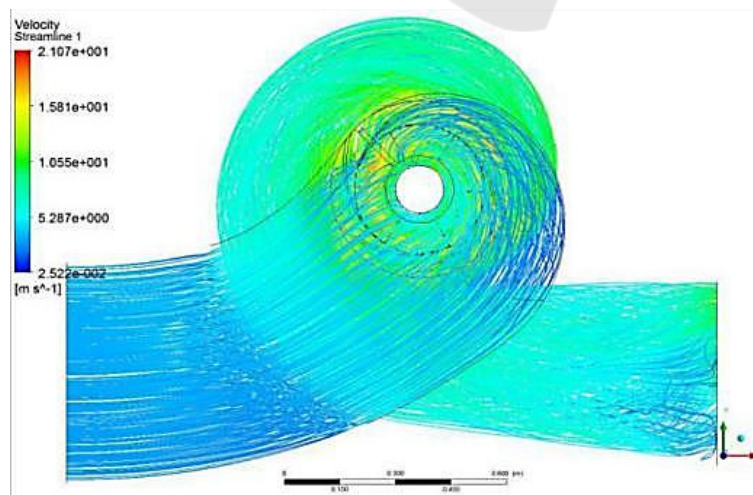


Figure 6. Overall flow field distribution.

5. Conclusions

- 1) Establishing a single-stage double-suction centrifugal pump parametric modeling system using SolidWorks secondary development is feasible;
- 2) The impeller model generated by this method is the same as the model obtained by manual modeling. It can generate impeller models with multiple blade types, and more types of impellers can be added as needed to meet the actual design needs.
- 3) The impeller model generated using this method can meet the requirements of the model for the hydraulic analysis of the impeller.

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