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Design and Analysis on Hydraulic Model of The Ultra -low Specific-speed Centrifugal Pump

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Abstract:

The Super-low specific-speed centrifugal pump has been used widely in most industrial fields of petroleum, chemical industry, aviation, pharmaceutical industry, metallurgy, etc. With the development of the petrochemical industry and the space technology, the lower ultra high speed centrifugal pump is gradually developed, its speed is much higher and the flow rate is much lower than the low-specific speed centrifugal pump [1,2]. Based on the foundation of the former researcher, I have designed and developed GSB20-380 hydraulic model of the ultra-low specific-speed centrifugal pump. In order to rich the achievements on the ultra-low specific-speed centrifugal pump in theory, CFD(Computational Fluid Dynamics)numerical simulation and performance tests were adopted to study the model of the centrifugal pumps, to analysis the hydraulic properties of the ultra-low specific-speed centrifugal pump.

Keywords: centrifugal pump; high-speed impeller; ultra-low specific-speed; hydraulic model; numerical simulation

1 Introduction

According to the model conversion or speed coefficient method of traditional centrifugal pump, specific speed is lower than 30, we should not design centrifugal pump, the main reason is that reflux and flow separation in the impeller will appear under the small flow rate condition, especially in the high speed

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centrifugal pump is easy to happen,so the pump will appear unstable and low efficiency phenomenon in small flow rate condition.Basing on low specific speed centrifugal pump design and studies,using long and short blades impeller structure of centrifugal pump, Shouqi Yuan, Zuchao Zhu and others can obtain the ideal performance index[3, 4].In this paper, we design a new hydraulic model of centrifugal pump with ultra-low specific-speed,and make numerical simulation with CFD.

2 Design of centrifugal pump impeller

Performance of ultra-low specific-speed centrifugal pump in table1:

$Q/(m^3/h)$	H/m	$n/(r/\min)$	η	n_s	$NPSH_a/m$	C_{kp}
20	380	8300	$\eta \geq 45\%$	26	4.0	1230

The design of the impeller mainly include: the number of blade z, vane setting angle of import, vane setting angle of export, width of blade import, width of blade export,, hydraulic diagram of impeller in figure 1 and figure 2.

Blade number selection of impeller have certain effect for high speed centrifugal pump head, efficiency and cavitation.Selection principle is to minimize blade Crowding-out and surface friction, on the other hand to ensure that the liquid flow in the blade passages is in steady flow and the blade have a full effect for the fluid.C Pfeffer Ryder NAR put forward calculation formula for the ultra-low specific-speed centrifugal pump[4].

$$z = \frac{D_2 + D_1}{D_2 - D_1}\sin(\frac{\beta_2 + \beta_1}{2})$$

We should take the small value for the impeller blade number。In this way,the blade to the liquid flow out of entrance will be reduced, compound impeller entrance pressure drop can be reduced, thereby improving the impeller cavitation performance.

Impeller inlet diameter can be determined by using of inducer and impeller pull-out matching form. Because this design does not use the inducer, the inlet diameter of impeller is the same as inducer of diameter[5].This paper we use the lift coefficient φ experience formula to determine the diameter of impeller.

$$D_2 = \frac{60}{\pi n}\sqrt{\frac{gH}{\varphi}}$$

we should use large inlet liquid flow angle, decrease inlet vane crowding, increase the blade inlet flow area, that reduces the blade inlet flow of absolute and relative velocities,when design ultra low specific speed high speed centrifugal pump impeller. Using positive angle design, it prevents the blade stall to produce flow diffusion in the design flow.We take 17° to inlet vane setting angle of the in this design.

Because impeller of the pump is easy to generate wake flow and stall, we can select the large outlet vane setting angle to increase the lift coefficient for making the flow steady. So we take 39° to outlet vane setting angle in this design.

Inlet width of blade b_1 influence the performance of impeller inlet flow.When b_1 increases, the fluid pressure between the impeller and the hub increase, and the pressure between the tip and the front inlet of the impeller also increase.so return flow of inlet enhance at small flow rate condition, return loss increase, while the second flow of the impeller passage aggravate, so that the tail flow - jet structure strength and produce flow stall,and the head and efficiency decrease in small flow condition. This phenomenon is reflected in the positive slope ascending segment of the centrifugal pump performance curve.Therefore, b_1 should take the small value from flow rate stability considerations.

Considering the high speed centrifugal pump cavitation performance and b_1 on the flow passage of impeller flow diffusion extent, using the following formula:

$$b_1 = \frac{D_t - d_{h2}^2}{4D_1\alpha}$$

α is the acceleration coefficient, values range from 0.5 to 0.8.this design mainly considers the energy performance, take into account both cavitation performance and efficiency,the α is 0.65 in this paper.

Now Enlarging flow design method is used extensively for the design of the ultra-low specific-speed centrifugal pump , we can use the following formula:

$$b_2 = 2.413(n_s/100)^{0.977}\sqrt{2gH}/n$$

Above the design of impeller parameters are shown in table 2:

model	D_1/mm	D_2/mm	$\beta_1/(\circ)$	$\beta_2/(\circ)$	b_1/mm	b_2/mm	z
GSB20-380	59.7	180	17	39	17.5	7	5

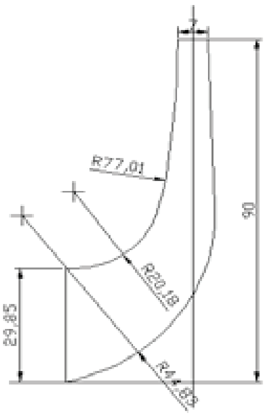

Fig.1 Axial plane projection drawing

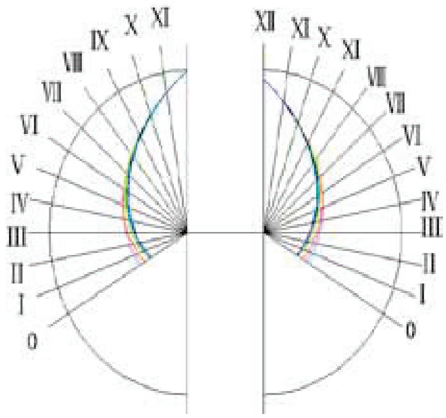

Fig.2 Plane shear drawing of blade

3. Design of centrifugal pump Volute

The main function of the volute is that collect the high speed fluid flow from the impeller,reduce the speed,and take the kinetic energy into pressure energy.We should try to avoid the secondary backflow and reduce hydraulic loss of the volute, because that the fluid in the volute is in a turbulent state,the import velocity of impeller is ununiform distribution,and take secondary backflow easily.

The main design parameters of volute include the base diameter, volute width, vane setting angle of the volute tongue, area of throat. The base diameter is 188mm,the volute width is 13mm, area of throat is 132mm and the section area of volute is in table 3 through design and calculation.

A_8	A_7	A_6	A_5	A_4	A_3	A_2	A_1
131.95	114.985	98.020	81.055	64.090	47.125	30.160	13.195

4.Solid modeling of ultra-low specific-speed centrifugal pump

Based on the hydraulic model design,we take the 2D model into 3D model from the software PRO /E, and complete the design of 3D solid model.The figure3 and figure4 show the five blades impeller solid model and solid model of centrifugal pump.

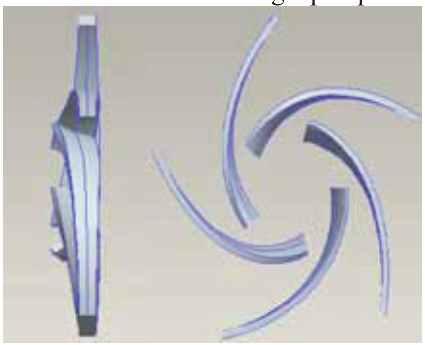

Fig.3 Blade solid modelling

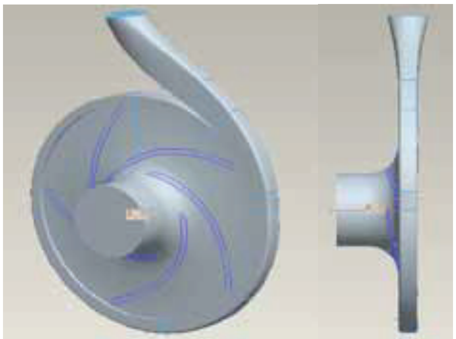

Fig.4 centrifugal pump solid modeling

5. The numerical simulation and its results and analysis of ultra-low specific-speed centrifugal pump

5.1Control equation and Turbulence model

The Pro/E solid model import the pre-processing software ICEM of ANSYS,the model get mesh in the sofeware,so the gird model import the FLUENT software.The numerical simulation adopt three-dimensional incompressible unsteady Reynolds equation and the standard turbulent model, calculation method adopt the time marching method,discrete scheme adopt centered difference scheme. In order to improve the rate of convergence,we adopt the local time step and multigrid techniques.In the difference scheme, the pressure adopt second order centered difference scheme,the speed,the tubulence energy and Turbulent viscosity coefficient adopt second order upwind difference scheme.The velocity distribution is the solid wall function of number law near wall region.We adopt the SIMPLEC algorithm and realize the pressure and velocity coupling solution. In the iterative calculation,we adopt low relaxation iteration.

5.2 Boundary condition

The inlet boundary of calculation area,speed is uniform and continuous boundary conditions.In the computational domain boundaries of exports, average pressure of export is assumed. The solid wall boundary condition is thermal insulation,and the impeller is rotating boundary.We adopt wall function near the wall region,blade surface, front cover, back cover and other solid wall are no slip coefficient.

5.3 Analysis of calculation results

We get the pressure field and the velocity field of ultra-low specific-speed centrifugal pump by CFD calculation.There are 98957girds and 21357 nodes in the mesh file from ICEM software.Calculating quantity and head in 1.5Q, 1.2Q, 1.0Q, 0.7Q, 0.5Q five different operating conditions, experimental results are shown in table 4:

$Q/(m^3/h)$	p_{out}/p_a	p_{in}/p_a	$Q_m/(m^3/s)$	$M_z/(N\cdot m)$	n	$\eta/\%$	H/m
10	3797948.5	28539.674	2.7579	39.441026	474	29.63	384.63
14	3790844.5	14546.705	3.8723	42.421941	454	38.75	385.34
20	3806869.0	4616.1377	5.5438	48.863881	403	48.49	387.98
24	3858396.3	4168.4448	6.6302	53.317483	435	53.87	393.29
30	3761433.0	5785.9272	8.3017	59.820371	340	57.88	378.64

From the data in Table 4, at the design point,the head and the effiency of pump can meet the qualification.The head of high-speed centrifugal pump can meet the qualification in0.5Q and 0.7Q.The $H-Q$ curve do not exist positive slope ascending segment in the small flow rate condition,so the hydraulic model of pump can meet the qualification.

6. Conclusion and Prospect

(1)In this paper,we design and develop hydraulic model of GSB20-380 type centrifugal pump with ultra-low specific-speed.By using the CFD numerical simulation,the hydraulic model is very well, the head and efficiency are higher than the similar product performance index.

(2)Because of ultra-low specific-speed centrifugal pump with high speed,the speed of the centrifugal impeller inlet flow is very high ,cavitation performance of centrifugal pump impeller will get bad. In this paper, we analyzed the model of energy performance, we should have a study on the cavitation characteristics,too.

Acknowledgements

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