Study on Fluid Characteristics of Centrifugal Maglev Blood Pump

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Abstract

Optimal designing the magnetic bearing structure of the Centrifugal Maglev Blood Pump, then using the speed coefficient method to design a six-blade impeller and pump chamber, and using fluent software to simulate the pressure field, velocity field and flow field of the centrifugal maglev blood pump.

Keywords: Blood pump; Maglev; Centrifugal; Flow field

1 Introduction

Maglev blood pump with its unique advantages of contactless bearing can make impeller no friction, no lubrication, which can effectively reduce the incidence of thrombosis and hemolytic [1]. So far, the bearing characteristics of centrifugal maglev blood pump are so litter in the condition of hemodynamic at home and abroad. The structure of the impeller and pump affect the supporting characteristics directly .so it's very important to simulate the pressure field, velocity field and flow field of the centrifugal Maglev heart pump.

2 Structure of Centrifugal Maglev Blood Pump

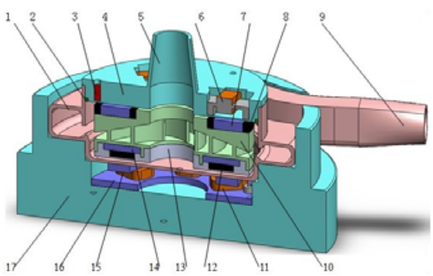

Figure.1 Structure of Centrifugal Maglev Blood Pump

1. Pump chamber 2.seal washer 3.hall sensor 4.pump cover 5.blood inlet 6.stator coil 7.impeller rotor yoke 8.permanent magnet ring 9.blood outlet 10.impeller 11.Stator coil 12.roter permanent magnet 13. Aluminum cap 14.roter yoke 15.stator 16.stator yoke 17.motor slot

Figure.1 shows the structure of centrifugal maglev blood pump. Use hybrid magnetic bearing to support impeller rotor. The bias magnetic field is generated by permanent magnets, greatly reducing the power consumption [2]. The three degree of freedom will be controlled by three solenoid coils; the centripetal effect is

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generated by the permanent magnet ring and the special structure of the magnet, combined with the role of fluid to control the radial direction of the two degrees of freedom.

3 Design of the magnetic bearing structure

The centrifugal maglev heart pump designed in this paper is used the way of electromagnetic permanent magnet mixed supporting. The three electromagnet and three hall sensor in the supporting parts is 60 angle and alternate distribution. The three hall sensors are used to detect the position variation of the impeller, which regulates the size of the current, make the impeller rotor stable suspension, the bearing structure distribution is shown in Figure.2:

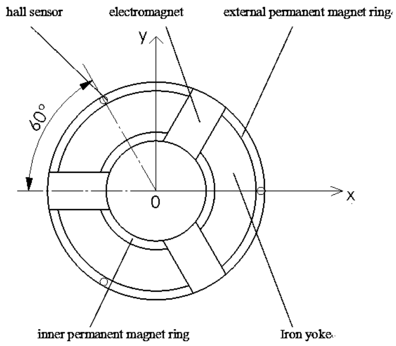

Figure.2 the bearing structure distribution

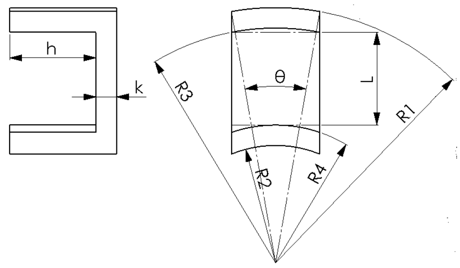

Figure.3 Electromagnet structure

The electromagnet structure is shown in Figure.3. When the impeller is in the blood of interference, it will produce a certain offset in the radial direction, Each electromagnet has an inner arc-shaped teeth and the outer arc-shaped one, Their radius and width are the same as the inner permanent magnet ring and the external permanent magnet ring of the rotor respectively, Because of this special structure, the three electromagnets forces generated can make the impeller tend to a central location.

Analysis the single magnetic bearing unit, Using magnetic equivalent circuit method to deduce the magnetic field of each electromagnet [3] [4].The equivalent magnetic circuit is shown in Figure.4:

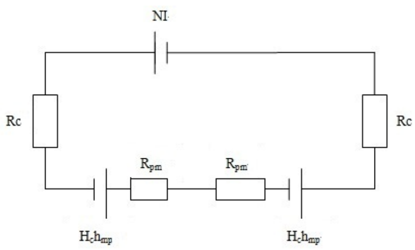

Figure.4 Equivalent magnetic circuit

Shown in Figure.4, NI is ampere turns of the electromagnet, R_c is reluctance of each pole gap, R_{pm} is reluctance of the permanent magnet ring， H_c is coercivity of the permanent magnet ring， h_{mp} is thickness of the permanent magnet ring.

$$R_c = \frac{x_0}{\mu_0 A} \tag{1}$$

$$R_{pm} = \frac{h_{mp}}{\mu_{pm} A} = \frac{h_{mp}}{\mu_r \mu_0 A} \tag{2}$$

x_0 is magnetic gap, μ_0 is vacuum permeability, A is effective pole area, μ_r is the relative permeability of permanent magnet rings. By the equivalent magnetic circuit diagram we can calculate the flux of the entire magnetic circuit：

$$\phi = \frac{NI + 2H_c h_{mp}}{2R_c + 2R_{pm}} \tag{3}$$

Substitute equation (1) and equation (2) into equation (3), we can get equation (4):

$$\phi = \frac{\mu_0\mu_r H_c + \dfrac{\mu_0\mu_r NI}{2h_{mp}}}{1 + \mu_r \dfrac{x_0}{h_{mp}}} A \tag{4}$$

the magnetic field of each electromagnet is as follows:

$$B = \frac{\phi}{A} = \frac{\mu_0\mu_r H_c + \dfrac{\mu_0\mu_r NI}{2h_{mp}}}{1 + \mu_r \dfrac{x_0}{h_{mp}}} \tag{5}$$

$$B_r = \mu_0\mu_r H_c \tag{6}$$

Substitute equation (6) into equation (5),we can get the magnetic field of each electromagnet:

$$B = \frac{B_r + \dfrac{\mu_0\mu_r NI}{2h_{mp}}}{1 + \mu_r \dfrac{x_0}{h_{mp}}} \tag{7}$$

The electromagnetic force generated by each electromagnet is as follows:

$$F = \frac{B^2 A}{2\mu_0} \tag{8}$$

4 Impeller and Pump chamber structure

Using speed coefficient method to design the impeller structure, choose the right design coefficient and flow coefficient according to the theory, starting from the perspective of improving the blood damage of the heart pump, optimizating and improving the impeller structure continuously. The impeller structure geometry is shown in Figure.5:

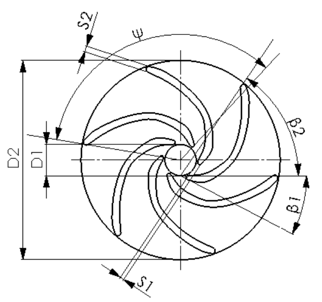

Figure.5 Impeller structure geometry

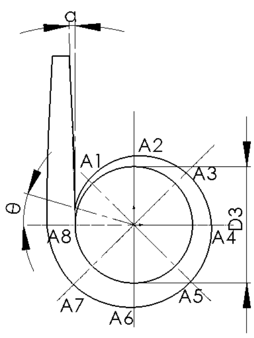

Figure.6 Geometry cavity of the pump chamber

The flow of the liquid that lies in spiral volute chamber is very even, velocity is quite gentle and not easy to create flow separation, that kinetic energy can be converted into the pressure has high energy efficiency, and is suitable for performance requirements to heart pump. In the design of the pump chamber, it is generally thought that the liquid flows from impeller uniformly and makes constant movement in the pump chamber. Geometry cavity of the pump chamber is shown in Figure.6

Refer to the relevant physical books combined with size requirements of human intravenous, the total blood flow is generally 4 ~6L/min,Arterial blood pressure difference must be met 110~120 mmHg, Considering comprehensively, Take the speed of centrifugal pump impeller as 2000r/min, the flow is 5L/min, the head is 110mmHg, the impeller structure parameters is shown in Table.1:

Inlet diameter D_1	8mm	Corners ψ	125°
Inlet diameter D_2	50mm	Inlet installation angle β_1	30°
Inlet width b_1	7mm	Outlet installation angle β_2	35°
Outlet width b_2	2mm	Leaf thickness s_1	1mm
Number of leaves z	6	Tip thickness s_2	1.5mm

Table.1 The impeller structure parameters

The pump chamber structure parameters are shown in Table.2:

Base diameter D_3	55 mm
Inlet width b_3	4 mm
Tongue angle α_3	6°
Pump tongue installation angle θ	16°
Inhalation caliber	6 mm
Spit caliber	10 mm

Table.2 The pump chamber structure parameters

5 FLUENT simulation

5.1 Boundary conditions set

Blood density is 1.055x10^3kg/m^3, viscosity is 4x10^{-3}kg/ (m·s), Assuming blood is incompressible Newtonian fluid [5], Select the standard k-ε turbulence model and standard wall function method and SIMPLE pressure velocity coupling algorithm, the pressure difference between inlet and outlet is 110mmHg, rotational speed of the impeller is 2000r/min, the flow is 5L/min， using the inlet pressure boundary and outlet pressure boundary [6].

5.2 Pressure and velocity field

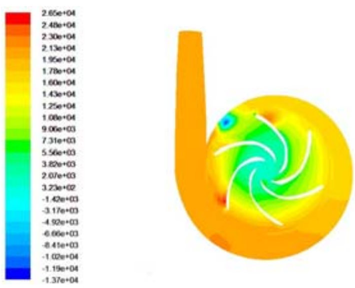

Figure.7 Pressure distribution

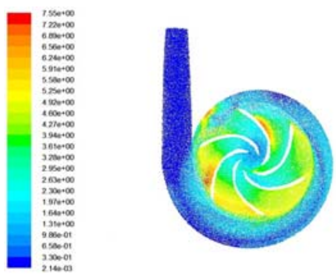

Figure.8 Velocity field distribution

The pressure distribution of the maglev blood pump is shown in Figure.7.The distribution of blood fluid pressure is uniform and then from the inlet of the impeller passage to the outlet of impeller passage, and again from impeller passage to the volute passage, finally from the volute passage to outlet passage, blood pressure increasing gradually along the direction of the blood flow, the blood pressure is the biggest nearby the outlet.

The velocity field distribution of the maglev blood pump is shown in Figure.8.Blood in the impeller inlet flow at low velocity and uniform, without flow separation occurs, the velocity of blood into the impeller flow passage gradually increased along the radial direction of the impeller diameter, to achieve the highest velocity nearby the outer diameter. The velocity of blood decrease gradually until it flows into the outlet of volute passage.

5.3 The relationship between the pressure difference of import and export , export flow and speed

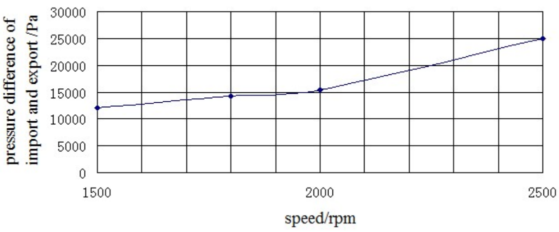

Figure.9 The relationship between the pressure difference of import and export and speed

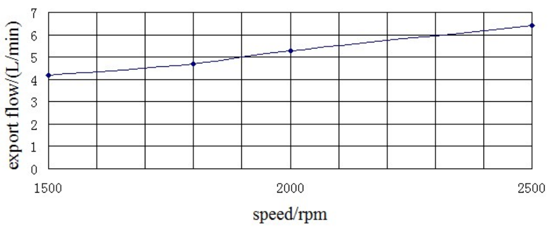

Figure.10 The relationship between export flow and speed

From the Figure.9 and Figure.10, the pressure difference of import and export and export flow gradually increase with the increase of impeller speed, consider comprehensively, when the impeller speed is in range of 1800rpm to 2000rpm, the heart pump can demand for human.

6 Conclusion

The impeller can effectively transformate mechanical energy to kinetic energy of the blood, and the volute can collect the high speed fluid of the impeller and transformate its kinetic energy to dynamic pressure energy. This paper just does the theoretical simulation; experimental study will be done in the future.

7 Acknowledgment

This work was supported in part by a grant from Youth Chenguang Project of Science and Technology of Wuhan City of China (No.201150431088), the Fundamental Research Funds for the Central Universities (No.2011-IV-120), the Fundamental Research Funds for the Central Universities (No.2011-IV-121).

References

[1] Liushuqin,Bianzhongguo,Lihongwei,Guanyong, Magnetic Bearing of the artificial heart pump [J], scientific and technological achievements of China,2009,10(4).

[2] Professor David L. Trumper Mr. Michael K. Liebman. Magnetically Suspended Artificial Heart Pump Impeller [J].2009.

[3] Wataru Hijikata,Taichi Mamiya,Tadahiko Shinshi, SetsuoTakatani. Cost-Effective Magnetic Bearing System using a Single-Use Magnet-Less Rotor for an Extracorporeal Centrifugal Blood Pump[J].The Twelfth International Symposiumon Magnetic Bearings (ISMB 12),2010, 654-659.

[4] Yohji Okada, Naoto Yamashiro, Kunihiro Ohmori,Toru Masuzawa,Mixed Flow Artificial Heart Pump With Axial Self-Bearing Motor[J], IEEE/ASMETRANSACTIONSONMECHATRONICS,2008,658-664.

[5] Zhubaolin, Centrifugal pump internal flow field of three-dimensional numerical simulation [D], Zhejiang University of Technology.2008.

[6] Renzhian, Numerical simulation of centrifugal pump flow [D], China University of Petroleum.2008.