The 15th International Symposium on Magnetic Bearings, August 3-6, 2016, Mojiko Hotel, Kitakyushu, Japan

ISMB15

An Axial flow blood pump with magnetic fluid mixed support

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Abstract

In this paper, the axial flow blood pump with magnetic-fluid support is presented. With the goal that the implanted blood pump should have the advantages of small volume, light weight and low power consumption, we studied the blood pump structure with permanent radial magnetic bearings and axial fluid-film bearing, designed and calculated the relationship between impeller and blood flow, finally gave the analysis of power calculation. The axial flow blood pump with magnetic fluid mixed support is presented. The motor rotor is supported by 2 radial PM bearings. The assembly of the motor stator and the PM bearing stators is supported (or clamped in place) inside of the 4-blade diffuser. The motor wirings will go through the diffuser vanes. In this paper, two radial bearings are used in the Halbach structure design of the full permanent magnet, and the electromagnetic field simulation is carried out by using the finite element method. The results show that the permanent magnetic bearing of the structure increases the bearing capacity, and reduces the power consumption. In this paper, the total power loss of the blood pump is not more than 10W, and the weight is about 225 grams. The results show that the blood pump with magnetic fluid mixed support can achieve the purpose of reducing power loss and reducing the volume.

Keywords : Axial flow blood pump, Magnetic fluid mixed support, Small volume, Light weight, Llow power loss

1. Introduction

Heart failure is led by the change of myocardial structure and function caused by the Initial myocardial injury, such as myocardial infarction,cardiomyopathy, hemodynamic overload,inflammation and so on, finally it will cause the inefficiency of pumping blood or filling function. Heart failure has become a global health burden,China Heart Failure Prevention Strategy Summit Forum led by Heart failure Specialized Committee of theChinese Medical Doctor Association was held in Beijing in July 4, 2015. Experts from Fuwai Hospital, Chinese Academy of Medical Sciences made a detailed introduction about the present situation and research progress of heart failure in China at the meeting. According to statistics, China has the largest number of patients with heart failure in the world, and the incidence of heart failure in China is rapidly increasing at present. So far the number is about 3.5%.According to the survey of 50 hospital patients in China, there are about 20 million heart failure patients due to the proportion of patients with heart failure.With the development of the aging population, the incidence of heart failure is increasing exponentially [1-5]. When all kinds of heart disease develops to the advanced stage, the only way to save patients is to transplant the heart. But most of them must face the death of heart failure due to the serious shortage of donor heart.

Artificial heart pump, also known as blood pump, is a device to help the heart pump blood.The installation of auxiliary circulating blood pump can prolong the life of patients andthe time waiting for the donor. The function of auxiliary circulating pump is to compensate or replace cardiac function,decline the former load of heart, so it canpromote the recovery of heart function and it plays the best role in the recovery of cardiac function.For the heart which cannot fully restore its function. Artificial heart pump can replace it and exert its physiological pump blood function [6-10]. The pump which uses the magnetic levitation or other suspension technology is known as the third generation of artificial heart pump. More and more evidence shows that the third generation blood pump has better performance than previous two generation's products. The third generation blood pump can achieve the purpose of eliminating thrombus formation by eliminating the mechanical bearing.HeartMate and VAD HeartWare pump are representative of this technology [27-40]. Due to the suspended impeller, there is no friction and extrusion, the hemolysis is reduced obviously, and the mechanical wear and tear are lost, and the energy efficiency ratio is increased.

Reducing the volume of the artificial heart pump and reducing the power consumption are the key problems needed to be solved. This paper is aimed at reducing the volume and reducing the power consumption.

2. Axial flow blood pump integrated structure with magnetic-fluid support and fluid-film bearing

Typical axial-flow blood pumps have motor windings wrapped outside of impeller casing. Presented in Fig.1 is an Axial-Flow Blood Pump（AFBP） configuration with the motor built inside the casing for minimizing radial space and facilitating PM radial bearing implementation.

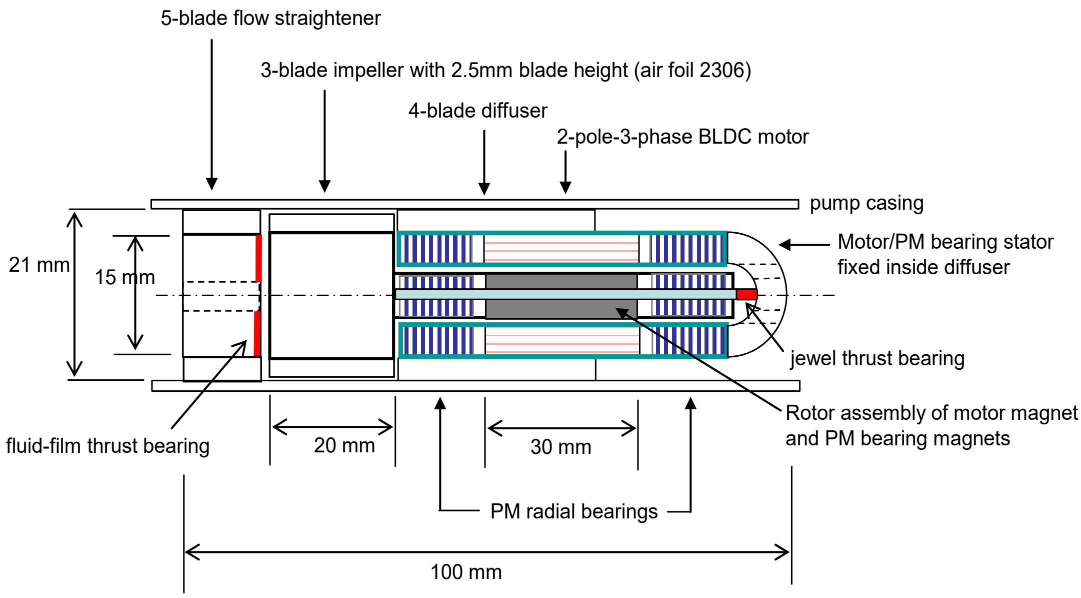

Fig. 1 - an AFP Layout

The impeller of Fig. 1 has 3 airfoil blades with 2.5mm height and 20mm in axial length. To its left is a 5-blade straightener with a taper-land fluid-film thrust bearing facing the impeller. Fig. 2 shows a configuration of the thrust bearing.

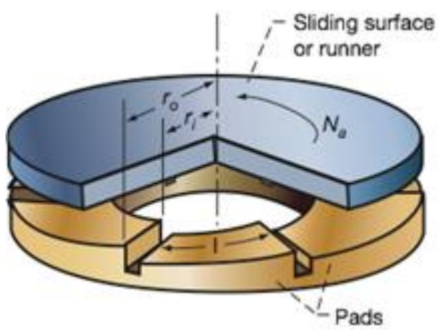

Fig. 2 - Taper-land fluid-film thrust bearing

The right hand side of the impeller is attached to the rotor of a BLDC motor. The motor rotor is supported by 2 radial PM bearings. The assembly of the motor stator and the PM bearing stators is supported (or clamped in place) inside of the 4-blade diffuser. The motor wirings will go through the diffuser vanes.

The motor rotor is an assembly of a 2-pole magnet and two sub-assemblies of PM bearing magnet rings. The right end of the rotor is supported by a jewel bearing. The latter may consist of a rotating piece of ruby against a stationary flat piece of zirconia. The rotor PM bearings are shifted slightly to the right in axial direction with respect to their stators. This provides a bias thrust force toward the jewel bearing when the pump is at rest. When the pump runs at its rated flow and speed, the blood flow reaction thrust will overcome the bias force and the rotor will work on the fluid-film thrust bearing with small load.

3. Radial permanent magnet bearing

Magnetic-fluid magnetic structure with five degrees of freedom: Using the full permanent magnetic bearing as radial bearing, axial design can eliminate axial magnetic bearing by using fluid-film bearing and there is no any another component, theaxial magnetic coupling force caused by radial permanent magnet bearings must be studied and the inner force of impeller rotor is also needed to be accurately calculated. After all these we can design a suitable axial fluid-film bearing.

The topology of the radial permanent magnet bearing is shown in Fig. 3.

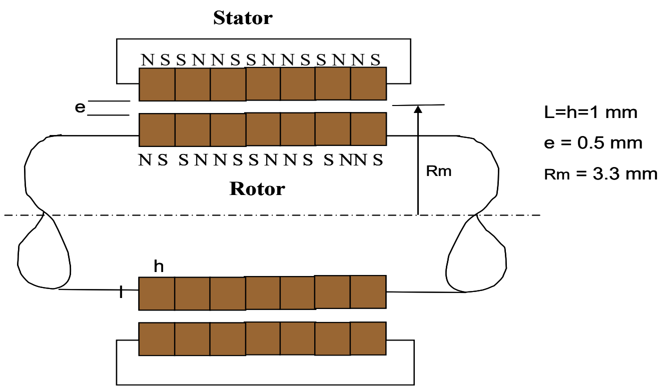

Fig. 3 PM bearing with 7 magnet-ring pairs

Two such bearings are required to support the artificial heart pump rotor. They are installed in the front and back guide vanes.Each of themis composed of 7 pairs of ring magnets. Each of the magnetic ringconsists of a small magnetic ring mounted on the rotor and a large magnetic ring mounted on the stator. A Halbach structure magnetizes axial direction of magnet; the adjacent magnetic polarities. The outer diameter of the total size of the design of artificial heart pumpis 25mm and the length is 100mm.If it is a solid titanium alloy bar, then the weight is about 225g. The actual weight of the pump may be close to this value. Our goal is to make the weight of the pump less than 300 grams.

Finite element analysis of electromagnetic fieldof the permanent magnetic radial bearings is shown in Fig. 4.The diagram shows that the magnetic force lines are centralized in the gap, so it can provideeffective support and reduce the magnetic loss of the magnetic circuit so as to improve the efficiency.

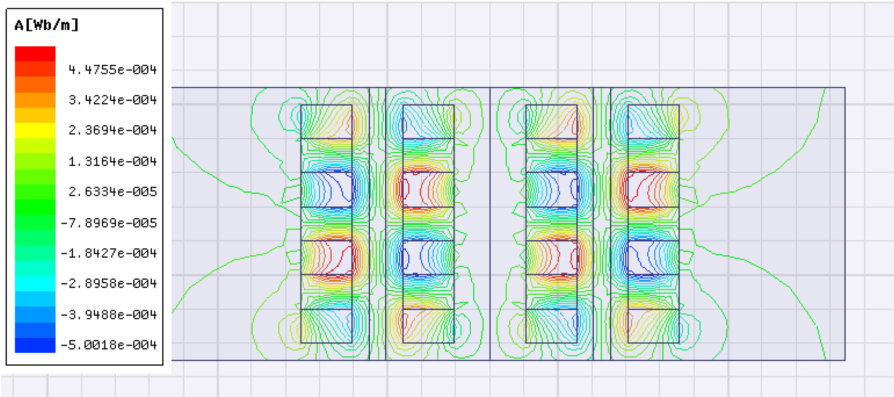

Fig. 4 Magnetic field of permanent magnetic radial bearing

4. Study and design the flow and power of the axial flow blood pump with magnetic-fluid support

The blood flow paths in the pump are presented in Fig. 5.

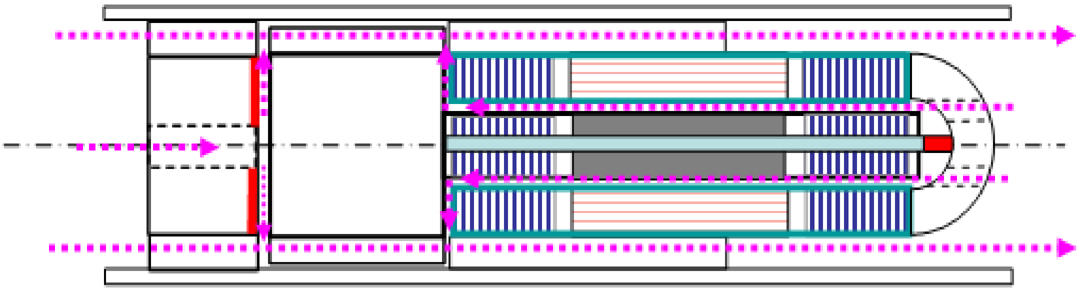

Fig. 5 - Blood flow paths

In additional to the main blood flow through the straightener, impeller and diffuser, there is a small amount of flow through the fluid-film thrust bearing. There is also a backward flow through the annual gap between the motor rotor and stator to keep the space flushed. The gap is about 0.5mm to 1.0mm. This gap determines the sizes of the PM bearings required. All the rotor critical speeds should be designed above the pump maximum speed to avoid damaging rotor vibrations.

In sizing the impeller, assumed are the axial impeller length, the blade inlet angle (β_1) and outlet angle (β_2). These parameters define the mean line of each blade as shown by the unwrapped or developed view in Fig. 6.

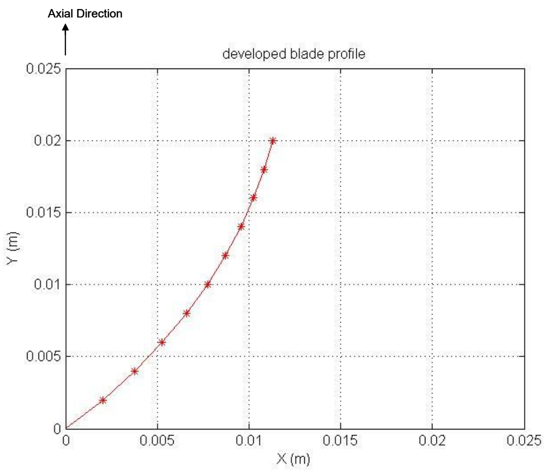

Fig. 6 - Impeller blade mean line

Note that the blade outlet absolute flow angle (α_2) can be determined by the flow rate and the outlet blade angle (β_2). The angle α_2 defines the diffuser's inlet profile.

Using the airfoil 2306 (see Fig. 7) for the blades, and assuming 20mm for the impeller OD and 15mm for its hub diameter, the pump head and power were calculated versus flow rate at 3 different speeds. The results are presented in Fig. 8 and Fig. 9.

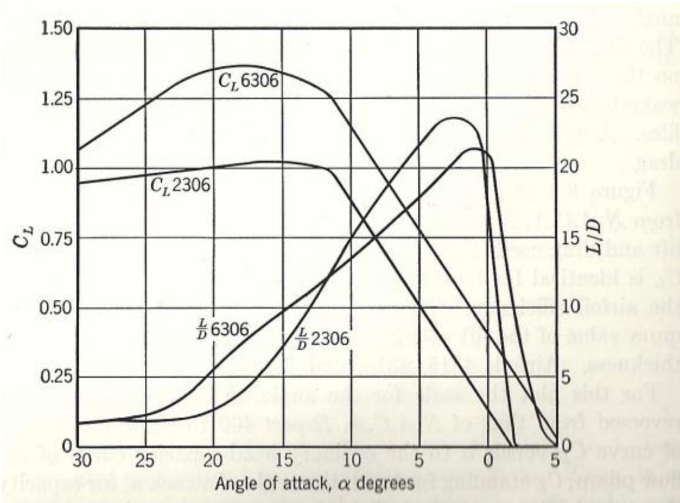

Fig. 7 - Airfoil 2306 data

Fig. 8 suggests that the pump operating point (4 LPM at 100 mm-Hg) is at a speed of about 7000 rpm. Fig. 9 shows that the maximum power required to operate this pump is approximately 2 watts.

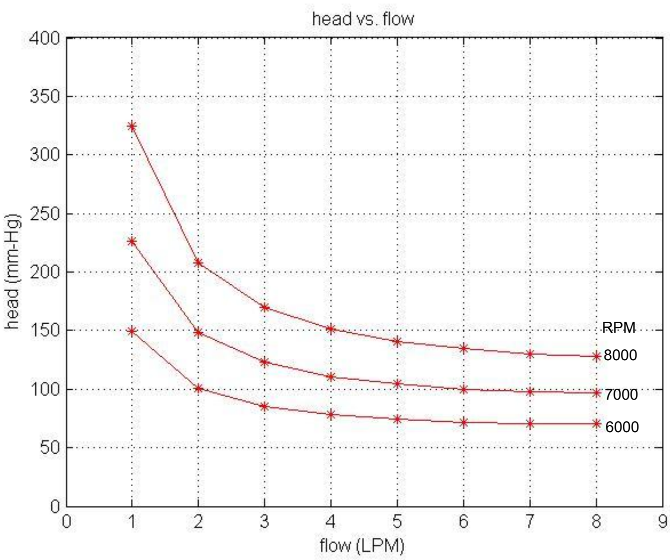

Fig. 8 - Pump head vs. flow rate

An estimate of the drag power loss of the rotor at 8000 rpm was about 4 watts including the fluid-film thrust bearing power loss. Therefore, the total power needed to run the impeller is 6 watts (=2 watts +4 watts). A sizing analysis of the BLDC motor indicated that the motor may deliver approximately 6 watts at a current density of 10 A/mm^2. The associated motor copper loss was about 2 watts. In other words, the required maximum input power to the pump is 8 watts including 2 watts to produce useful impeller work, 4 watts of rotor drag loss and 2 watts of copper loss.

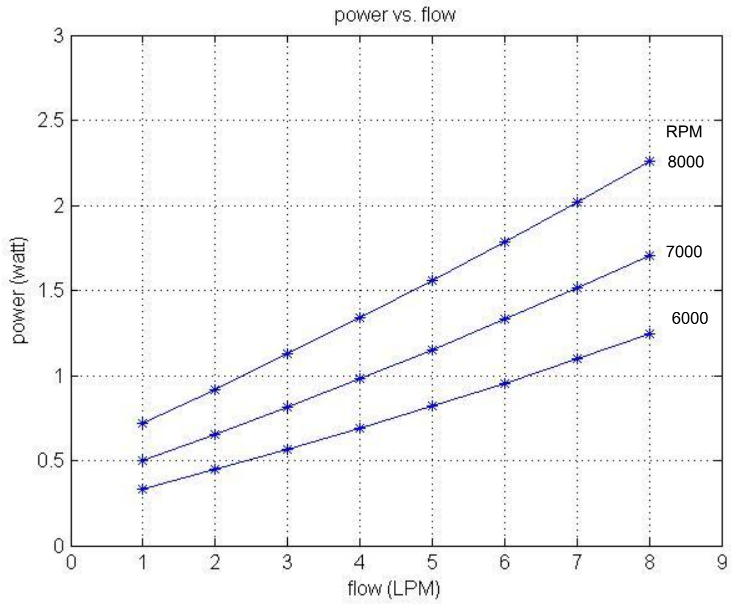

Fig. 9 - Required power vs. flow rate

5. The results and discussion

The total dimensions of the pump in Fig. 1 are about 25mm in outside diameter and 100mm in length. If it was a solid rod made of Titanium, it would weigh about 225 grams. The actual weight of the pump may be close to this value. Our goal is to make the pump weight to be less than 200 grams. It is possible to make the pump length shorter than 100mm, if the motor gap is chosen to be 0.5mm (instead of 1.0mm), because shorter PM bearing with smaller radial gap can achieve the same amount of bearing radial stiffness required. The specific size in table 1.

Table 1 The parameters of the blood pump.

outside diameter	length	weigh	rotating speed	Motor power	Total r power
25mm	100mm	225 grams	8000 rpm	$2 - 4w$	$< 10w$

The layout of Fig. 1 is a plausible scheme for the axial-flow blood pump. It has the advantages:

1. Small outside diameter, and
2. Easy implementation of PM radial bearings.

Acknowledgements

Supported by: National Natural Science Foundation of China (51075236) and "The Fundamental Research Funds of Shandong University" 2014YQ010

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