A novel permanent magnetic bearing and its anti-wear effect in impeller total artificial heart*

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Abstract A novel permanent magnetic bearing has been developed, which consists of two magnetic rings with different dimensions in the same direction of axial magnetization, located concentrically. Because of the effect of magnetic field, the magnetic rings keep a distance axially from each other. If the distance between the two rings changes, a rehabilitation force is produced to return to the original position. When this distance decreases, a repelling force will be generated; its component in axial direction can be used as a magnetic spring and its radial component can function as a bearing. With this novel permanent magnetic bearing, an impeller total artificial heart (TAH) is designed, manufactured and tested. The rotation is driven radially. On the left and right sides of the rotor magnets, two small magnetic rings are fixed onto the rotor, coupling with two big magnetic rings on both sides of the motor coil, to form the magnetic bearings. Hereby the bearings are used for wear reduction rather than rotor levitation. That means the magnetic bearings counteract the attractive force between the motor coil iron and rotor magnets so as to reduce the friction between the motor stator and rotor. At the left and right ends of the rotor, two impellers with the same width but different diameters are mounted. Thus the device has only one moving part—rotor; both the left pump and the right pump eject the blood synchronically; the volume equilibrium of both pumps can be achieved automatically without need of control. The device weighing 250 g has a length of 60 mm and a diameter of 40 mm at its largest point, and can produce a blood flow up to 150 mm Hg and 6 L/min from left pump, 50 mm Hg and 6 L/min from right pump, at rotating speed of 4000 r/min of the motor. The consumed power is under 10 W.

Keywords: **permanent maglev, magnetic bearing, impeller blood pump, friction-reduction.**

In recent years, a novel permanent magnetic bearing has been developed[1~4]. Recently, this novelty has been applied to the author's total artificial heart (TAH) for wear reduction, that is, to reduce the friction between the motor stator and the rotor. Our former work demonstrated the blood compatibility of the impeller TAH[5~7], but its durability remains to be investigated. Like other investigators who worked on rotary pumps[8,9], the authors tried to use magnetic suspended motor for the impeller TAH[10,11], regrettably met with some new problems such as complicated construction and control, considerable energy consumption and poor reliability, etc. If the friction of the rotation could be remarkably reduced via magnetic bearing, the impeller TAH would reduce the wear and thereby have a long-term performance. This paper presents the concept and construction of this novel bearing, its application in impeller TAH (i.e. biventricular assist impeller pumps), and the hydrodynamic testing of the device.

1 Novel permanent magnetic bearing

Fig. 1 illustrates the concept and the construction of a novel permanent magnetic bearing. Small magnetic ring 3 and big magnetic ring 5 are located concentrically, nonferrous disc 2 and 4 together with axis 1 enable small magnetic ring 3 to move axially. Two magnetic rings have the same height and thickness, but with different diameter. They are magnetized axially and have the same magnetic direction (Fig. 1, left). Between two magnetic rings, there are three magnetic fields: A, B and C (Fig. 1, right). In areas A and C, there is rejective magnetic force, and in area B there is attractive magnetic force. Two rings keep each other with a due distance under the effect of the magnetic field, to achieve a balance of push and pull forces. If the distance between two rings changes, a rehabilitation force will be produced to return to the original position. For example, when this distance decreases, the rejective and attractive forces between two rings will both increase, because the magnetic force is reversely proportional to the second power of the distance between two magnetic bodies.

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The repelling force increases much more quickly than the drawing force, a resultant force of rejection will play a leading role in the magnetic field. It is the same the other way around. The axial component of this rejecting force can be used as a magnetic spring and its radial component can function as a bearing.

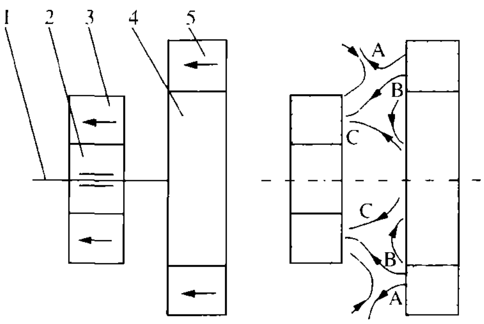

Fig. 1. The construction of the novel permanent magnetic bearing (left) and the magnetic field (right). 1, axis; 2, nonferrous disc; 3, small ring; 4, nonferrous disc; 5, big ring; A and C, repelling area; B, attracting area.

2 Impeller TAH

The newly designed impeller TAH is shown in Fig. 2. The rotor consists of motor magnets 3, right impeller 1 and left impeller 6, and small rings of magnetic bearing 2 and 5. The motor coil 4 and big rings of magnetic bearings 2, and 5 together with pump housings form the stator. It is obvious that there is only one moving part, namely, the rotor, in the system. The magnetic bearings counteract the attractive force between motor coil iron core 4 and rotor magnets 3 so as to reduce the normal pressure and thus to reduce the friction between rotor and stator. That means, the magnetic bearing is used for bearing wear reduction rather than for rotor-suspension.

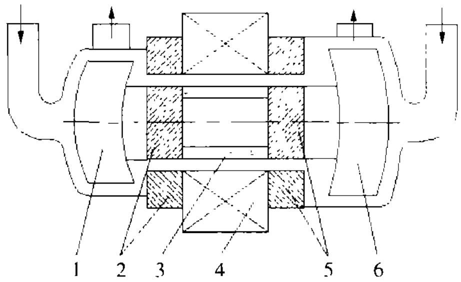

Fig. 2. Schematic drawing of the TAH. 1, left impeller; 2, left magnetic bearing; 3, rotor magnets; 4, stator coil; 5, right magnetic bearing; 6, right impeller.

The right impeller 1 has the same height but smaller diameter than the left impeller 6, because the right pump delivers the blood to pulmonary artery with the same flow rate but lower pressure head than the blood from the left pump to aorta.

If the rotating speed of the motor keeps constant, both pumps produce a steady flow. If a square wave form voltage is introduced to the motor coil, the rotating speed will change periodically, and both pumps produce a pulsatile flow. The right and left pump eject the blood synchronistically. This is a unique TAH at the present in the world, which is driven by a single motor, two pumps deliver the blood flow simultaneously.

The volume equilibrium of two pumps will be achieved by self-modulation property of the centrifugal pump. That is, the flow rate will change according to the pressure difference between the outlet and the inlet of the pump.

3 Hydrodynamic testing

The device was tested in a circulatory model with saline (Fig. 3). The flow rate of both pumps was measured by Transonic T110 flow meter. Hewlett-Packard M1205A monitor measured the pressure in inlet and outlet of both pumps separately. The motor voltage and current were displayed digitally by a locally made DC power supply.

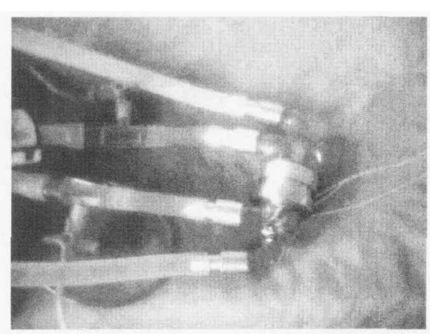

Fig. 3. The TAH tested with saline in a simulated circulatory model.

The motor worked at five different speeds from 3000 to 4000 r/min. At each speed the relation between pressure head (H) and flow rate (Q) of right and left pumps was computerized and diagrammed (Fig. 4). The left pump can produce a flow up to 150 mm Hg and 6 L/min, the right pump can produce a flow up to 50 mm Hg and 6 L/min, at rotating speed of 4000 r/min. It evidenced that impeller TAH can meet with the physiological requirements for both biventricular assist and heart replacement.

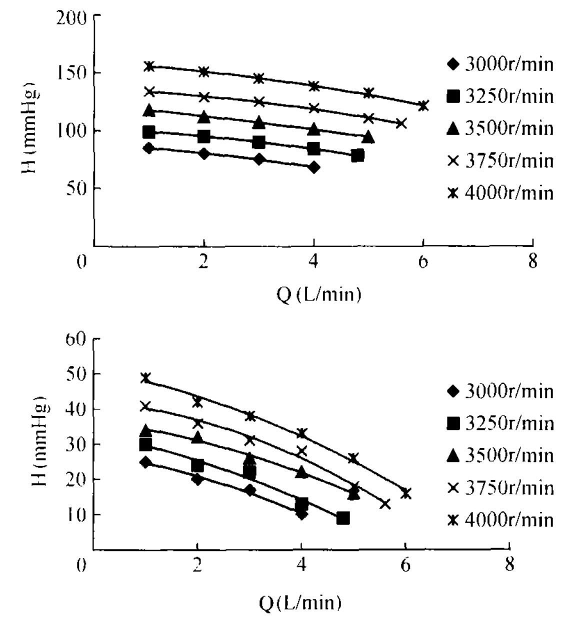

Fig. 4. The H−Q curves of the left pump (upper) and the right pump (lower).

The consumed power is mostly under 10 W. For instance, the device consumes 8.5 W electric power when it rotates at 3500 r/min, the left pump head is 100 mm Hg and the right pump head 25 mm Hg, both pump flow rate is 4 L/min.

The device weighing 250 g has a length 60 mm and a diameter 40 mm at its largest point.

4 Discussion

This paper presents an impeller total heart, which has many improvements compared with its previous design: 1. The brush DC motor is replaced by a motor coil-rotor magnets assemblage; 2. Two magnetic bearings are used to reduce the friction of the rotation; 3. The pump and the motor are compacted in one unit. With these improvements, the authors intend further to develop an implantable, blood compatible, pulsatile and durable rotary total artificial heart (TAH). The endurance test of the device is now underway.

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