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Permanent magnetic-levitation of rotating impeller: a decisive breakthrough in the centrifugal pump

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Magnetic bearings have no mechanical contact between the rotor and stator, and a rotary pump with magnetic bearings therefore has no mechanical wear and thrombosis. The magnetic bearings available, however, contain electromagnets, are complicated to control and have high energy consumption. Therefore, it is difficult to apply an electromagnetic bearing to a rotary pump without disturbing its simplicity, reliability and ability to be implanted. The authors have developed a levitated impeller pump using only permanent magnets. The rotor is supported by permanent radial magnetic forces. The impeller is fixed on one side of the rotor; on the other side the rotor magnets are mounted. Opposite these rotor magents, a driving magnet is fastened to the motor axis. Thereafter, the motor drives the rotor via magnetic coupling. In laboratory tests with saline, where the rotor is still or rotates at under 4000 rpm, the rotor magnets have one point in contact axially with a spacer between the rotor magnets and the driving magnets. The contacting point is located in the center of the rotor. As the rotating speed increases gradually to more than 4000 rpm, the rotor will disaffiliate from the stator axially, and become fully levitated. Since the axial levitation is produced by hydraulic force and the rotor magnets have a giro-effect, the rotor rotates very stably during levitation. As a left ventricular assist device, the pump works in a rotating speed range of 5000–8000 rpm, and the levitation of the impeller is assured by use of the pump. The permanent maglev impeller pump retains the advantages of the rotary pump but overcomes the disadvantages of the leviated pump with electromagnetic-bearing, and has met with most requirements of artificial heart blood pumps, thus promising to have more applications than previously.

Introduction

Rotary pumps have the advantages of a simple structure and small size, need no valves and have no diaphragm, thus having a more extended lifetime than previously. For long term circulatory support or for replacing heart transplantation, however, the rotary pump should solve problems of bearing wear, and thrombosis along the bearing. Some investigators have developed magnetic bearings with electromagnets [1–4], achieving zero friction and no contact between rotor and stator. This results in no mechanical wear, previously limiting long-term use [5–7], and no heat generation in the bearing, which causes the aggregation of platelets and thrombus formation. Although electromagnetic bearings could solve these problems, they result in new problems such as more complicated structure and control, high energy consumption and low reliability. The authors have recognized that it is difficult for devise an electromagnetic bearing for a rotary pump without disturbing its simplicity, reliability and ability to be implanted.

In the past five years, the authors have developed a levitated impeller pump using only permanent magnets. Recent progress has been made. A prototype of a permanent magnetic-leviated impeller pump has been designed, manufactered and tested in the laboratory. The first results have demonstrated the successful levitation of the impeller with permanent magnets, and the pump has met with most technical requirements of blood pumps.

Method

Structure of the device

Figure 1 shows a schematic drawing of the maglev impeller pump. The rotor is borne by permanent radial magnetic bearings. The impeller is fixed on the right

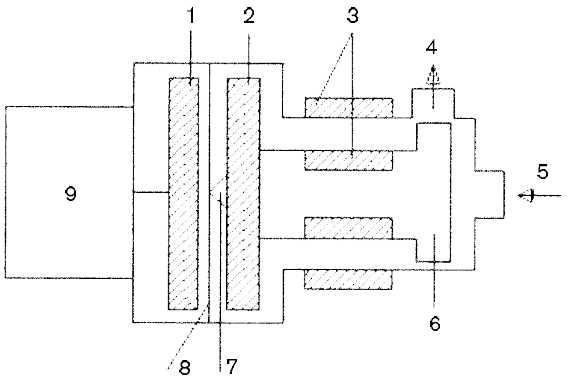

Figure 1. Schematic drawing of permanent/magnetic-leviated impeller pump. 1. driving magnets, 2. driven magnets, 3. radial magnetic bearing, 4. outlet, 5. inlet, 6. impeller, 7. one point contact, 8. spacer, and 9. motor.

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side of the rotor; and on the left side, a driven magnet assemblage is mounted. Opposite this assemblage a driving magnet assemblage is fastened to the motor axis. Therefore, the motor drives the rotor via magnetic coupling. At standstill or where the impellar rotates with a low speed, the driven magnet assemblage has one point in contact axially with a spacer between the driving and driven magnet assemblages. The contacting point is located in the center of the rotor.

The double-effect of magnetic coupling

The magnetic coupling transmits the rotating torque from the motor to the pump. Then, the driving magnets and the driven magnets attract each other. That means that the two magnet assemblages will stay concentric with each other. For this reason, the radial magnetic bearing has been devised only to the right of the rotor: the left of the rotor needs no radial bearing.

The gyro-effect of the driven magnets

The height and the diameter of the driven magnet disc has a ratio of 1 to 10 and thus the disc has a large rotating inertia. If the magnet disc rotates at a high speed, the 'gyro-effect' will result. That is, the disc will stably keep its rotation along its axis. The stable rotation of the driven magnet disc also helps the rotor and the impeller to rotate stably.

Because the magnetic force supporting the rotor can support kilograms of weight and the rotor has a weight of approximately 50 g, the rotor will not contact the stator and the levitation will not be destroyed if the stator moves.

In vitro *tests with saline*

The device was tested in a laboratory with saline. The pump flow rate, pressure head and the rotating speed were measured using a Transonic T110 Flowmeter (Transonie Systems, Ithaca, NY, USA), Hewlett-Packard M1205A Monitor (Hewlett-Packard, Boeblingen, Germany) and a local-made tachometer, respectively. The motor speed was kept constantly at 5000 rpm, 6000 rpm, 7000 rpm and 8000 rpm. Four curves of H ~ Q (pressure head and flow rate relations) were obtained and plotted with a computer.

Results

At standstill or where the motor rotated with a speed under 4000 rpm, the rotor had one point in contact with a spacer between the driving and driven magnets (figure 2, lower). As the rotating speed increased gradually to more then 4000 rpm, the driven magnets moved axially to the right about 0.5 mm and the rotor disaffiliated from the stator axially (figure 2, upper). Then the rotor together with the impeller became fully leviated.

Figure 3 shows the relations between the pressure head and flow rate at 5000 rpm, 6000 rpm, 7000 rpm and 8000 rpm separately.

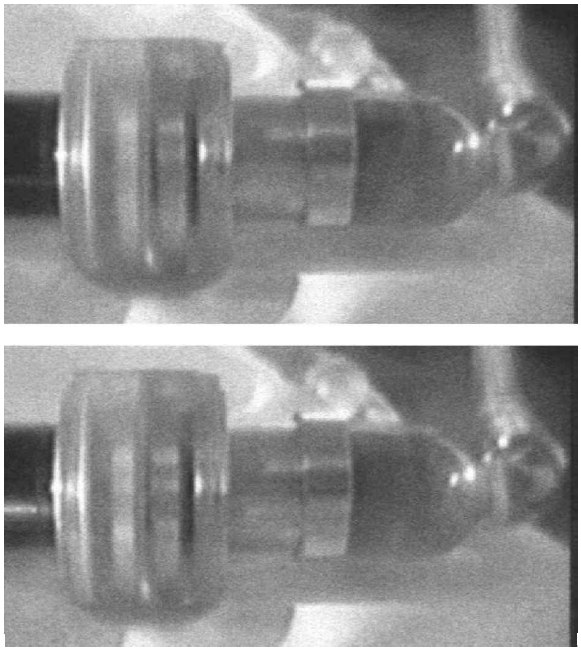

Figure 2 The rotor magnet disc is levitating axially (upper) and in contact with the spacer (lower). The space (black ring) at the right side of the disc in the upper image is 0.5 mm smaller than that in the lower image, because the spacer is located on the left side of the disc.

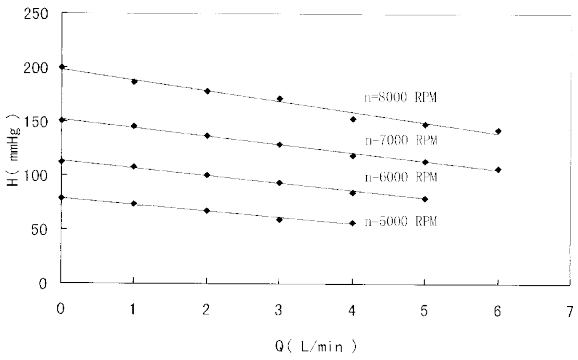

Figure 3 The H ~ Q curves of the permanent magnetic leviating impeller pump indicate that the pump works in a rotating speed range of 5000–8000 rpm, as used as a left ventricular assist device.

As a left ventricular assist device, the pump should deliver a blood flow more than 80 mmHg pressure and 1 l/min flow rate, the rotating speed of the pump must be 5000 rpm, according to figure 3. That means that the levitation of the impeller is assured by practical use of the pump.

Since the 'taking off' of the rotor is generated by a hydraulic force (a reacting force of the flow), which acts on the impeller becauase the impeller propels the flow, and the driven magnet disc has a height/diameter ratio of 1 to 10, and hence has a large rotating inertia, the rotation of the rotor and the impeller is very stable during leviation, as well as during 'landing'.

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Discussion

The authors' work has demonstrated the feasibility of a permanent magnetic-levitated impeller pump. The device has the advantages of the rotary pump, for example, simple structure and control, small size and weight, and no valves or diaphragm; and also retains the advantages of electromagnetic bearings, such as the absence of contact between rotor and stator, mechanical wear and thrombosis, etc. The device has lower energy consumption and higher reliability than electromagnetic bearings.

In conclusion, this permanent magnetic-levitated impeller pump has met with most requirements of blood pumps, thus promising to have more applications than previous designs.

Acknowledgements

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