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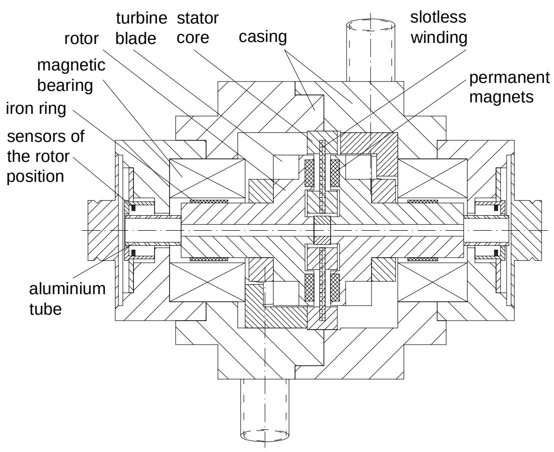
MAGNETIC BEARING IN BLOOD PUMP SYSTEMS

Abstract: Since the eighties years of the last century, scientists of the Department of Electrical Machines, TUB with cooperation of Brno University Medical Faculty tried to developed a mechanical device to temporarily supplant heart action. During these years the first artificial heart (made from polyurethane) was implanted inside a goat and consequently inside a calf body. Blood pump development continued and devices became smaller, lighter and more acceptable. A number of plastic pumps of long life time were also developed. During nineties new political administration cut financial sources and imposed more restrictive rules to the medical devices standards, also leading to higher development costs. The extensive research program was in Medical Faculty reduced and consequently also in our department only to the electromechanical part of the artificial heart.
In cooperation with the Victor Kaplan Department of Fluid Engineering we have continued in the field of mechatronic drive destined for centrifugal and whirling blood pump. Some of these mechatronic systems were manufactured and tested in laboratory conditions and published in the previous papers.
The paper presented deals with the test experiences of the magnetic active bearings used in the mechatronic system of the total artificial heart and presents some new proposal and discussion in the different types of the magnetic passive bearings, which could be in some cases more suitable than magnetic active ones.

1. Active and passive bearings

Bearing system used in blood pump is shown in the Fig.1, and described in details see e.g. [4] is one in which electromagnets are working on the electromagnetic principle. This system, to be able stabile operation, must use electrical feedback control for electromagnet's current. Active magnetic bearing according to this figure is heteropolar and consist of stator which has in our case 8 poles and rotor is made of ferromagnetic sheet material to reduce eddy currents. Control system has sensor to read rotor position, regulator and amplifier which by feedback control magnet's current as well as force of attraction. Active magnetic bearings require complicated control hardware, such as digital signal processor amplifiers, digital-to-analog converters and vice versa and software. Active magnetic bearings are more complicated, have higher energy consumption and need electronic control so they are heavier and theirs cost is also higher.



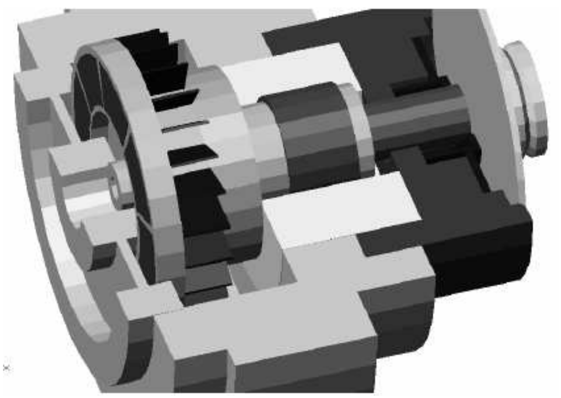


Fig 1. Drawing of blood pump

Magnetic bearing when compare with the conventional bearing have also some other disadvantages: smaller ultimate bearing capacity and dynamic stiffness. The system can be so complicated that in some cases it is more useful to think in some system about application magnetic passive bearings.

Principles of the magnetic passive bearings are based on the principle of the repulsion of magnet the same polarity and attraction of the magnets of the opposite polarity. Disadvantage of these systems is their instability. Radial bearing is axial instable and axial bearing radial instable. Instability can be removed by the help of the mechanical bearing point or using suitable system structure. Magnetic passive bearing using permanent magnet can be simple, reliable and cheap. Using professional programmes for magnetic field analysis it is possible to solve magnetic bearings effectively see e.g. [3]. Some proposals are described in the following articles.

Proposal according to the Fig. 2 is a mechatronic blood pump system, in which for radial bearing is used set of permanent magnet thoroids with axial magnetic flux. The permanent magnets are alternately fixed on the stator and rotor parts of the pump. To improve magnetic radial stiffness of the bearing, the magnets can be multipole. To provide stabile operation according to the Ernshaw criteria, the axial stiffness is provided mechanically by system using ceramic balls used on both sides of the pump's rotor. Motor used in the mechatronic system is disc type synchronous slot-less motor, where two parts of the permanent magnets rotor drive two turbine of the blood pump rotating with the same speed for left and write ventricles of the artificial heart.

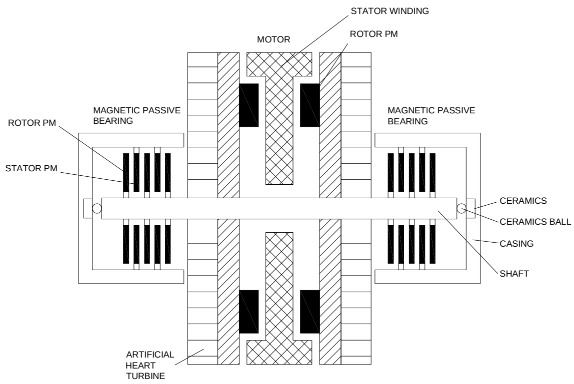


Fig 2. Drawing of 1st variant of the system

The same bearing system is used in the system illustrated in the Fig 3, but synchronous permanent magnet slot-less motor is now changed to double winding(the winding used in Fig. 2 is divided to two discs so the air gap of each part is now half of that used before). Mechanical power produced by this system is increasing nearly proportionally to the air gap reduction.

Another general assembly drawing of the drive for blood pump is shown in the Fig. 4. Radial bearing system in this case comprise two passive radial bearings on each ends of the shaft and two radial bearings in the middle part of the shaft, one of which is simultaneously part of the permanent magnet synchronous motor. Axial bearing is mechanical one similar as is used in the systems above. Air-gap of the magnet's thoroids must be set carefully to ensure stability of the system. In this construction is recommended to apply magnetic bearing with mechanical safety end stop. In the alternative construction the ball mechanical axial bearings can be replaced by axial active magnetic ones.

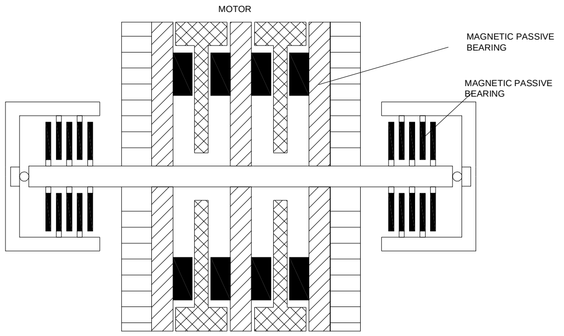


Fig 3. Drawing of 2nd variant of the system

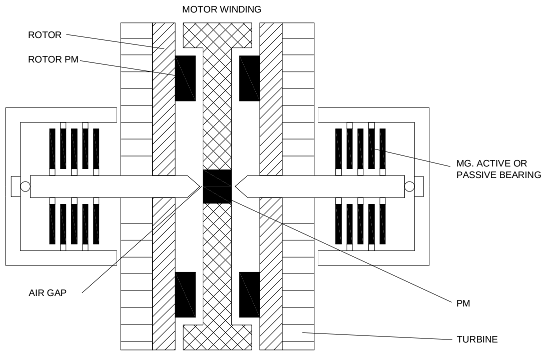


Fig 4. Drawing of 3rd. variant of the system

When we need separately control left and right ventricle of the artificial heart it is necessary in this case divided shaft of the blood pump to two parts with turbine for each of them. Stator of disc motor in this case is divided to two stator and control units must be two for each stator separately. Any of the bearing systems can be used for double motor construction.

During our research work we have also realized the blood pump in which were used only mechanical bearing and the electric motor was slot-less so the axial and radial load on the rotor was produced only by hydraulic forces. Using gel material for mechanical bearings, the system can be made very simple and reliable.

2. Conclusion

The centrifugal pump presented is double turbine because the natural heart has two pumps, each with two chambers. With each heart beat, the two atria contract together, followed by the large ventricles. An artificial heart maintains the heart's blood circulation and oxygenation for about 100 000 times a days, this is the reason for magnetic bearing to be applied. It must also pump faster or slower depending on the activity of the patient. Raw materials for artificial heart must be biocompatible and must have suitable structural properties. TAH is usually made of plastic, metal and ceramic.

There are several critical issues when designing TAH. All materials must be biocompatible, fluid dynamics of the blood flow must be understood not blood clots are created. The electric motor must have proper dimensions and efficiency not to overheat. The total volume and surface area of the entire device should be kept as small as possible.

Some general conditions are well known and must be followed during manufacturing and testing. After assembly of artificial heart is completed, each part must be tested using special equipment that simulates pressure in the body. All components are tested to ensure proper function of all circuitry. The components of the artificial heart are manufactured for laboratory use. For clinical use, to meet medical regulations, every component (including adhesives) used in the process should be controlled and specified so that tracking problems is possible. Within the next decade, a number of new batteries come on the market. Patients carry a battery pack so the system for charging the batteries should be specified.

Ten years ago we have abandoned system using pumping action. Nowadays we are using pumps that circulate blood continuously, rather than using a pumping action, since these pumps are smaller and more efficient. As to the drive control, the medical fellow workers must predetermine if follow curve of the heart pressure or keep pressure constant during systole and diastole. In clinical application will be decided if artificial heart is a permanent replacement type of the form of a left ventricle assist device or a total artificial heart, depending on the patient's physical condition. Last decision is made by the medicine doctor, who decided if patient meet the conditions for getting the artificial heart and which type.

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