MECHANICAL CONTROL OF CIRCULATORY ASSIST DEVICES

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ABSTRACT

Mechanical circulatory assist devices are grouped in two major classes depending on the manner in which they supply the pumping action: pulsatile or non-pulsatile. Electrohydraulic ventricular assist devices (EVADs) are inherently pulsatile. There is a tendency, in the design of such devices, to create an alternating flow by incorporating the alternation into the control system. This can create a reliability problem as it often requires that a mechanical component be made to reverse direction repetitively. One method to resolve this problem employs a rotary control valve constructed in a manner such that a pulsatile flow is created in spite of a constant angular speed. The rotary valve is driven by the same electric motor used to drive the axial flow pump that propels the working fluid.

INTRODUCTION

Artificial heart research has been ongoing for the last forty years.[1] Devices have been used as interim support for patients awaiting transplant for some time. However, these devices have left patients tethered to large control systems, greatly restricting patient mobility. As well, the number of donor hearts available at any one time is very small in comparison to the number of patients requiring heart replacement.[2] To address these problems, research has recently focussed on the development of a totally implantable, long term artificial heart as a substitute for heart transplantation. In the design of these devices, attention must be paid to the quality of life that will be afforded to the patient. A high level of reliability is particularly important, as any failure of an artificial heart, no matter how brief, seriously affects the life of the patient. Designs must be simple and elegant, to be sufficiently reliable.[3]

Devices that create pulsatile flow are generally more complicated, and possess an inherent reliability problem. Any mechanical device that undergoes cyclic loading, reversing, or other repetitive motion generally has a limited lifetime. It is the challenge of pulsatile device designers to minimize this effect.

BACKGROUND

The mechanical parts of the EVAD 3.0[4] are depicted in Figure 1. The ventricle (LV, this device is built to assist the left ventricle of the natural heart) consists of a chamber with a flexible membrane separating blood from hydraulic fluid. The blood side is fitted with two one-way valves such that one is an intake valve while the other is an eject valve. Pumping of the blood can be achieved by alternately filling and emptying the hydraulic fluid side. This is done with the use of an axial flow pump. The pump is spun in one direction to fill the LV and is then reversed during the other half of the cycle. A volume displacement chamber (VDC) fitted with a flexible membrane is used to hold the hydraulic fluid emptied from the LV. Devices such as these require an electronic control system to function. Each electronic component is highly reliable alone, but as the number of components rises, the reliability of the overall system decreases. It was determined that much of the control system could be simplified with a mechanical control valve.

In a healthy heart, blood fills the atria passively during diastole. The natural heart is composed primarily of muscle that occupies the most volume in its relaxed state. As a consequence, the natural heart provides a small level of suction, as much as 5 mm Hg[5], simply because it is made up of a highly elastic material. This suction should be present in any device intended to assist the natural heart.
METHODS

Figure 2 shows a simplified depiction of a three dimensional rotary valve. In the figure, hydraulic fluid flows from the VDC and is directed by the valve rotor into a chamber through a wedge-shaped window labelled Lower. The fluid is then drawn from the lower chamber to the upper chamber through the centre of the valve rotor along the axis of rotation. The fluid then travels through another window, labelled Upper, and is directed by the valve rotor toward the LV. As the valve rotor continues to rotate, the fluid is still drawn in the same direction through the centre of the rotor but will switch direction to flow from the LV to the VDC. The axial pump draws the fluid through the centre of the valve rotor, continuously in the same direction. This arrangement eliminates the reliability problems inherent in a conventional switching valve, because the rotor never stops.

The challenge of propelling the rotor in this valve depends on geometry and the method used to transfer torque. As a design approximation it can be assumed that fluid flow rate is roughly proportional to the angular speed of the axial flow pump. To make stroke volume roughly constant, the speed of the valve rotor must then be proportional to the speed of the motor. In other words, the entire device could be propelled with the same electric motor, which would never need to reverse or drastically change speed. The specific method of transferring torque to the rotary valve employed a hydrodynamic transmission. No additional parts were necessary. A prototype of this device was built as a proof of concept. Preliminary tests were conducted to qualitatively evaluate the function of the valve and promising results[6] were obtained.

DISCUSSION AND CONCLUSIONS

A control system employing a valve of this sort has an important reliability advantage. Any additional electronic control system required would have the sole purpose of fine tuning the operation of the artificial heart. A failure of the electronic control system would not be critical. So long as the electric motor continues to function, the artificial heart continues to pump blood.

The prototype was intended as a proof of concept to demonstrate potential as a component of a heart assist device. With added development, it is entirely feasible that a device could be designed to deliver a relatively constant stroke volume regardless of heart rate at reliability levels appropriate to long term implantation.

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REFERENCES


