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Feasibility analysis and design of a novel ventricular assist miniscule nutation pump

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Abstract

For the questions that the rotating continuously artificial heart pump would damage blood cells and cause hemolysis running at high rotating speed, this paper proposes a novel ventricular assist miniscule nutation pump based on nutation principle. The novel nutation pump aims to reduce the speed of the rotating parts under the premise of necessary flow rate and without the increasing of the pump volume. The equations for the pump flow discharge are obtained based on the mathematical modeling of pump flow discharge. The three-dimensional modeling of the novel ventricular assist miniscule nutation pump is further established. And the kinematic equations of the nutation disk are deduced, which provides the basis of the simulation. The flow field model of the pump is established and the meshing grids are divided in the software. Finally, the curve of volumetric flow rate, velocity vector diagram, pressure nephogram and shear stress nephogram in the internal pump are further obtained based on the simulation in the related software.

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Keywords: Artificial heart pump; Nutation pump; Nutation swing; Dynamic simulation.

1. Introduction

1.1 Application background

Heart is the original driving force of human blood system. Heart failure will disorder or disable the function of pumping blood, leading to the result that the blood flow is not enough to maintain normal metabolism of human body. Heart failure is not only known as one of the most serious illness causing death in the 21st century, but also the most challenging diseases [1]. It has shown that the global incidence of heart failure had continued to increase year by year. According to the survey, there have been 5 million heart failure patients in the United States with the growth of 10% every year [2].

Due to the amount of the heart donors is too small, and no effective immunosuppressive drugs are used for resolving the human tissue immune rejection after heart transplantation, it has become a trend that transplanting the heart with the artificial heart pump rather than the human body heart. Artificial heart pump is a device which promotes blood circulation by mechanical movement in order to completely or partly replaces human heart to pump blood.

1.2 Research background

With the characteristics of non-friction, small volume, high efficiency, long life, and so on [3], magnetic levitation heart pump becomes the new direction of artificial heart pump research [4].

However, almost all of the artificial heart pumps have hemolysis problems, which are mainly caused by high-speed rotating blade flapping blood. The volume is smaller and the efficiency of heart pump is higher, the working speed is higher. But the increased working speed of the pump blades causes more serious damage to blood cells. As the optimized design of blade surface has little effect on weakening the damage to blood cells, the magnetic suspension becomes new hotspots of research. However, if there is no change on the pump body, the high-speed problem of blades still exists.

For the aim to reduce the velocity of the rotating parts under the premise of necessary flow and no increasing volume, this paper proposes a novel miniscule nutation pump for the heart-assist. And a lot of work has been done, including the research on working principle, structure design, mathematical

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modeling of flow calculation and workflow field simulation.

2. The novel ventricular assist miniscule nutation pump

2.1 Basic principle

New miniscule nutation pump is based on the improvement of nutation motion shown in Fig. 1. For the nutation motion, the axis of a nutation disk has an angle with the space axis Z, and the disk rotates around the space axis with self rotating. Where in Fig. 1, when the intersection of the disk axis and the Z axis just lies on the center of the disk, the rotating speed of the disk is 0 and the disk is only doing nutation swing motion with its edge swing up and down. Then, the blood fluid separated by a baffle plate will form a circular directional flow motion and makes the pump sucking and discharging fluid.

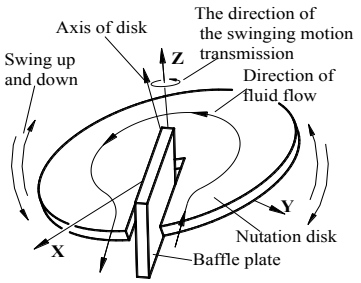

Fig. 1 The orientation of fluid flow

2.2 Structure design

The new miniscule nutation pump, shown in Fig. 2 (a), consists of pump body and drive motor. The pump body is composed of a upper cover, a sleeve, a nutation disk, a pump body shell, a lower cover, a flat clapboard, a cullis and lock screws as shown in Fig. 2 (b).

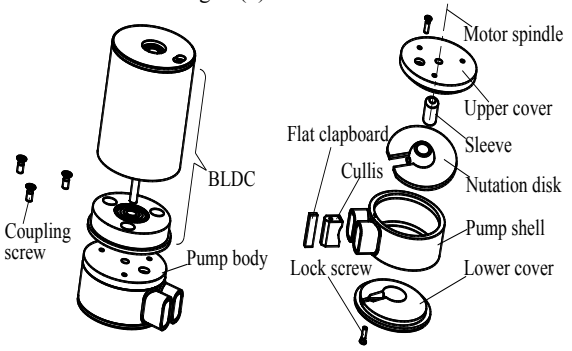

Fig. 2 (a) The component of pump; (b) Pump body assembly diagram

Where in Fig. 3, the motor shaft is fixed to the sleeve with incline axis (the tilt angle is nutation angle), and there is a through-hole in the spherical pair of the nutation disk. During the working time, the motor drives the sleeve rotation and the sleeve drives the nutation disk doing swing motion.

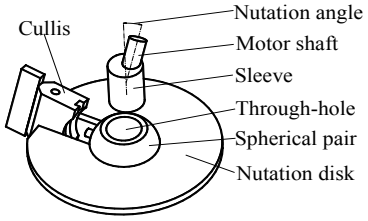

Fig. 3 Drive of sleeve

2.3 Working process

The internal vessel of pump is surrounded by a part of sphere and two inside cone. The nutation disk in tilt state within the vessel has contacting lines with the upper and under covers.

By taking the vessel which is under the nutation disk for an example as shown in Fig. 4, the under vessel is divided into two areas by the contacting line. The area connected to inlet is called inlet area and the area connected to outlet is called outlet area. When the motor shaft rotates counterclockwise, the nutation disk makes a cycle swing in counterclockwise. The contacting line also rotates counterclockwise, and the rotating speed of the contacting line is equal to the speed of the motor shaft. At this moment, the continuous increase area of the inlet area generates negative pressure, leading the fluid flow into the inlet area. Then the outlet area continuously diminishes and leads the fluid outflow from the outlet. When the under contacting line coincides with the position of cullis, the inlet area reaches the maximum value, and the outlet area reaches the minimum value. As shown in Fig. 4 (b), when the contacting line passes by the cullis, the outlet area changes from the minimum to maximum, and the change of inlet area is opposite. Then the above processes form a repeated working cycle.

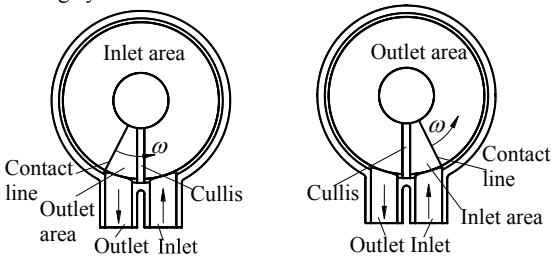

Fig. 4 (a) Contacting line not bypasses cullis; (b) Contacting line bypasses cullis

The working principle of above vessel is the same as under vessel. The motor drives the nutation disk making a counterclockwise swing, and drives the blood on either side of the nutation disk doing counterclockwise circular motion, forcing the fluid flow from the entrance (on the right) to the export (on the left).