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種別(和文)	論文要旨
Type(English)	Summary

（博士課程）

Doctoral Program

論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）

Thesis Summary（approx.800 English Words ）

The title of this thesis is "Extracorporeal Centrifugal Blood Pump Employing a Bearingless Slice Motor with a PM-free Rotor" and comprises six chapters.

Chapter 1, "Introduction," presents the imperative role of extracorporeal Ventricular Assist Devices (VADs) in addressing heart failure, offering diverse treatment options ranging from short to long-term applications. Based on the application scenarios, the requirements of the blood pump in VAD, various generations of blood pumps, and their respective strengths and limitations were introduced. Notably, the widely used commercial blood pumps available, such as CentriMag with bearingless slice motor (BELSM) technology, still face challenges such as high disposable costs attributed to embedded Permanent Magnets (PMs) in the impeller/rotor. Hence, the adoption of a BELSM with a PM-free rotor emerges as a viable solution to meet all requirements effectively. Several BELSMs with a PM-free rotor have been proposed in the previous research, however, they cannot meet the requirements of sufficient rotational torque and passive stiffness, angle-independent magnetic levitation, small power consumption, simple structure, and hollow design inside of the BELSM simultaneously. Therefore, a centrifugal blood pump (CBP) utilizing a novel BELSM with a PM-free rotor and a radial displacement measurement method employing Eddy-Current Displacement (ECD) sensors below the rotor are proposed to satisfy all the requirements.

Chapter 2, "Principle and design," explains the principle and design of the proposed BELSM to fulfill the above-mentioned requirements. A 12/8 homopolar BELSM with a PM-free rotor is proposed, whose structure is similar to the conventional switched reluctance motor. Two PM rings and two iron rings are positioned at the ends of the stator teeth, forming a triple-layer homopolar biased flux. The working principle of passive stabilization in the axial and tilt directions, radial suspension force generation, and torque generation were explained. Built upon the proposed structure, the BELSM offers the advantages of simple structure, cost-effectiveness flux bias generation, enhanced passive stiffness, PM demagnetization prevention, and angle-independent magnetic suspension. Leveraging previous research, target values for passive stiffness and rotational torque were set, with subsequent finite element method simulations confirming their attainment. The achieved passive stiffness far exceeds the set targets, the average rotational torque meets requirements, and the angle-independent magnetic levitation is validated.

Chapter 3, "Prototype fabrication," details the fabrication of a CBP prototype, comprising the proposed BELSM, a disposable pump head, electrical systems, and controller systems. The BELSM was machined and assembled based on the numerical simulation model. The disposable pump head, constructed from polyetherimide, integrated a waterproof impeller/rotor with an initial priming volume of 20 mL. The twelve linear amplifiers were connected to twelve combined windings for electrical power transfer. ECD sensors were placed inside the rotor to measure radial displacement. Hall Element (HE) was positioned between two stator teeth, and the signal process system was designed to measure both rotational speed and rotor angle precisely. Besides, the suspension and rotational feedback control systems were established by employing PID and PI controllers, respectively.

Chapter 4, "Performance evaluation," outlines the performance evaluation of the CBP within a mock circulatory loop filled with 40wt% glycerol water, showing its suspension, rotation, and pump capabilities. The stable suspension at 0 rpm with a displacement amplitude below 15 μm and a closed-loop suspension system bandwidth of 61 Hz were achieved. The rotation accuracy was maintained below 100 μm to avoid any physical contact between the rotor and pump housing. Subsequently,

the CBP provided a maximum pressure of 214.5 mmHg and a flow rate of 4.59 L/min, falling slightly short of the goal. The limitation was attributed to the lower current loop bandwidth, affecting the accurate tracking of suspension and rotation currents in line with the command current.

Chapter 5, "Radial displacement measurement using ECD sensor below the rotor," introduces a novel approach for measuring radial displacement by installing the ECD sensors beneath the rotor. Compared to the conventional placement of locating it on the rotor's side, this placement can avoid increasing the rotor's height and simplify the secondary flow within the pump head to improve CBP performance. However, ECD sensors at that location make obtaining highly accurate radial displacement challenging due to interference from multiple-DOF displacement and nonlinear effects on the ECD sensor output. To solve this problem, a seven-ECD sensor arrangement and sensor calibration method based on the neural network method are proposed. The proposed method exhibits a good linearity, with maximum errors of 13.6 μm and 17.1 μm in the X- and Y-directions, respectively. A measured bandwidth of 200 Hz was also achieved. Furthermore, successful radial displacement feedback control was implemented during magnetic suspension startup and rotation, resulting in an RMSE within 16 μm. Furthermore, the impact of dataset size and the number of ECD sensors on measurement accuracy was explored.

Chapter 6, "Conclusion," summarizes the results of each chapter and lists possible future plans.

Words (English).

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