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Review on Displacement Sensing Schemes for Blood Pumps

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1. Brief Review on Blood Pump Sensing Scheme

Bearingless motor technology serves as a critical enabler for third-generation artificial hearts to achieve superior blood-pumping performance and long-term reliable operation [1]. Radial displacement sensors are needed for providing reliable real-time feedback of the rotor's radial motion. However, the limited measurement range of the sensors (typically 1–2 mm) will cause the formation of relatively narrow secondary flow paths that inevitably arise from the bifurcation of blood flow within the noncontact-type pump housing. The resultant localized elevated shear stress in the narrow secondary flow paths has been identified as a key contributing factor to the incomplete elimination of hemolysis in clinical studies involving third-generation implantable blood pumps [2]. To aviod the formation of narrow and elongated secondary flow paths, it is imperative either to reposition the displacement sensors or eliminate their use altogether.

1.1. Sensor Arrangement Scheme

This article summarizes the blood pumps with different sensor arrangement schemes, as shown in Table 1. Typical displacement sensor arrangement schemes shows in Fig. 1. Due to the limited measurement range of the sensor probe, these arrangements spatially compete with secondary flow paths for critical space within the device.

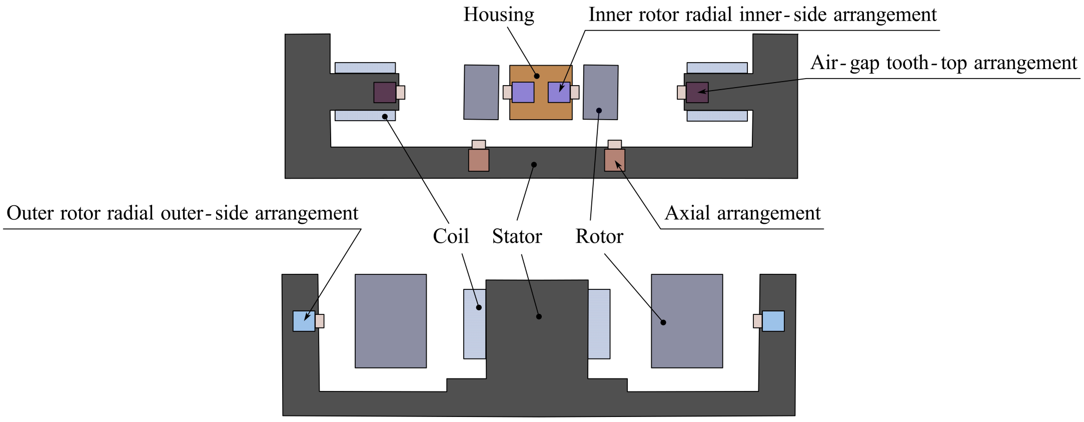

Fig. 1: Comparison of sensor arrangements.

Installing eddy current displacement sensors at the axial ends faces challenges due to spatial constraints and measurement range conflicts. Additionally, axial displacement signals contain extraneous information and strong nonlinearity, making neural network a suitable solution [3].

1.2. Displacement Self-sensing Algorithm

For magnetically levitated artificial heart systems, reconstructing radial rotor displacement using the motor's coils or auxiliary detect coils is preferable to installing displacement sensors. This method relies on EMF variations caused by rotor eccentricity, with mainstream approaches shown in Fig. 2.

1.2.1. Dynamics Based State Reconstruction Algorithm The state reconstruction algorithm reconstructs the rotor state by the accurate model of the fundamental-frequency back-emf concerning the rotor angle and radial displacement, thereby heavily relying on the parameters. While it manages to eliminate the need for high-frequency power electronic converters, the method exhibits a time delay in reconstructed displacement signals, and encounters challenges during the startup phase [9].

1.2.2. High Frequency Injection Algorithm High-frequency excitation enables displacement reconstruction via impedance calculations and applies to both magnetic bearings [10] and bearingless motors [11]. A key challenge is designing filters that suppress noise while minimizing signal delay [12]. Mutual interference between sensing coils and suspension windings is a concern [13], with research focusing on injecting excitation into existing windings and mitigating noise

Table 1: Application of different sensor arrangement.

TT(Tooth-top)	OO(Outer-outside)	II(Inner-inside)	AA(Axial-arrangement)
[4]	[5], CH-VAD [6]	[7]	[3], Corheart [8]

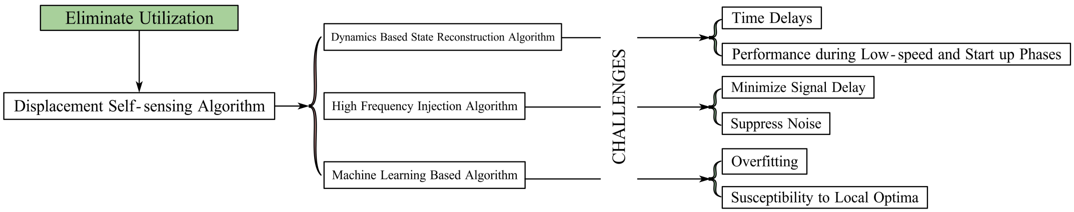

Fig. 2: Overview of the displacement self-sensing techniques.

and harmonics through optimized filtering [14].

1.2.3. Machine Learning Based Algorithm Machine learning algorithms eliminate the need for precise mathematical models and parameters but face challenges like overfitting and local optima. Recent studies have optimized support vector machines using NSGA-II [15], and apply Elman neural networks [16] for rotor displacement prediction.

2. Conclusion

Existing methods lack emphasis on implementation strategies for sensorless control and offer limited solutions for complex conditions, with most research focusing on motors with separated windings rather than combined winding. Theoretically, using a Kalman filter to fuse noisy displacement signals with velocity signals from coils can significantly enhance feedback quality and improve levitation control performance.

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