Study of Passive and Active Magnetic Levitation Bearings for Implementation in Pediatric Left Ventricle Assistant Device

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Background

In 2019 alone, an estimated 3.12 million newborns were diagnosed with congenital heart defects across the world [1]. While a heart transplant is the most optimal treatment for end-stage congenital heart diseases (CHD), children waiting for heart transplantation have the highest mortality rate among all solid organs due to the scarcity of a compatible heart [2].

With the advancement of technology, mechanical Ventricular Assistant Devices now have the capability to move on from their bridge-to-transplant role and become a promising long-term solution for managing CHD in adults [3]. To account for the differences of constraints in size, flow rate, and hemocompatibility of pediatric patients, our team proposed an intra-ventricular Left Ventricle Assistant Device (LVAD) consisting of a contactless, magnetic-levitated impeller.

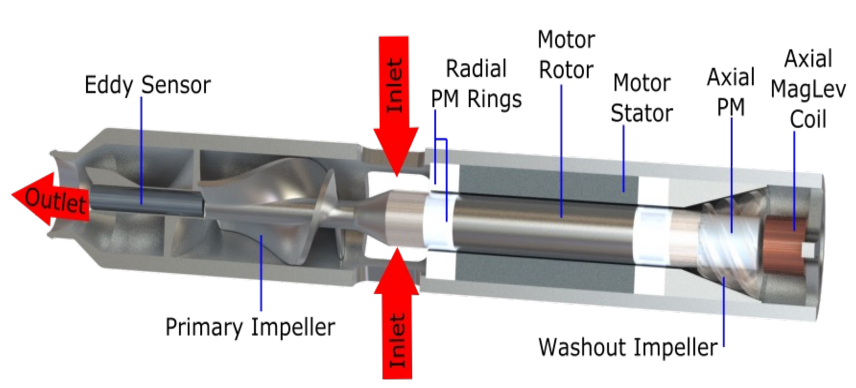

Figure 1: Cross section of the LVAD

The Magnetic Levitation (Maglev) system is made up of a Passive Maglev Bearing component and an Active Maglev Bearing component. The Passive Bearing sub-system consists of permanent magnetic (PM) rings both on the impeller shaft and on the motor casing. As the impeller shaft is attracted to any side of the motor stator casing, these PM rings will produce a stabilizing force that returns the rotor to the center position.

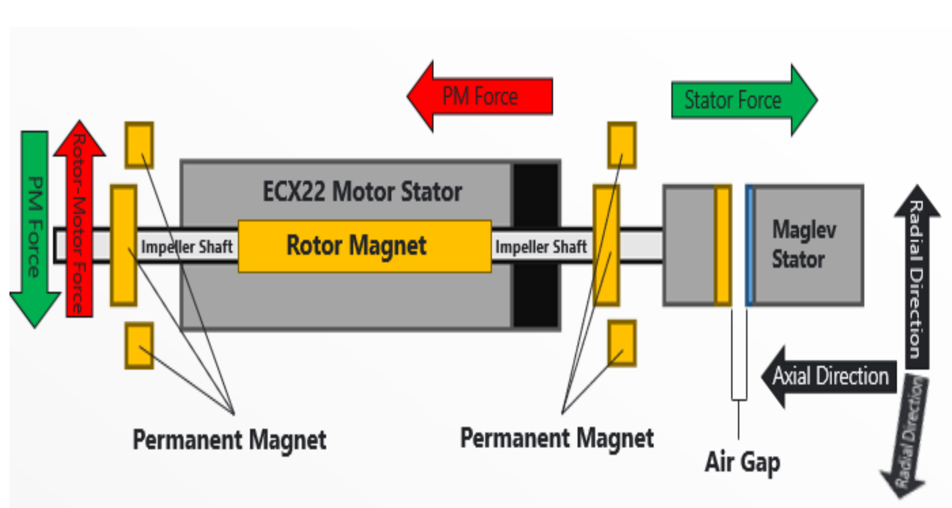

Figure 2: Force representation of the Maglev system

However, the PM rings from the passive bearing component will also produce a destabilizing axial force in the left direction. This is when the second subsystem, Active Maglev Bearing, comes into play. This system includes a permanent magnet attached to the right end of the impeller's shaft to constantly supply a rightward axial force. By controlling the current running through the coil, we can change the net force acting on the rotor in the axial direction. On the opposing end of the rotor is a current sensor, which will sense the gap between the sensor and the rotor. We can use this information to decide how much current to supply to the maglev coil to control the rotor's position in real-time.

Methodology

The Maglev passive force test rig is made up of a force transducer connected to a 3D-printed chamber that firmly holds the motor stator and PM rings in place. This chamber is then mounted to a 3-axis linear translation stage. By keeping the rotor fixed in place while varying the position of the chamber in X, Y, and Z directions, we were able to record the force exerted on the rotor at precise axial and radial displacements.

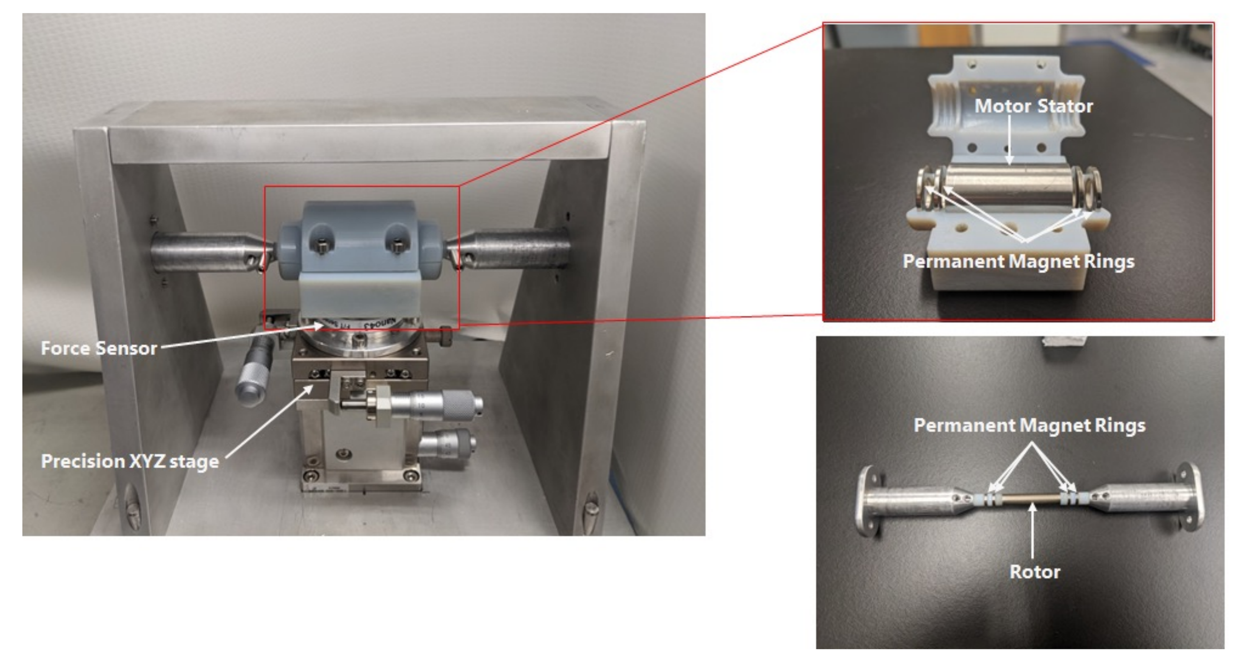

Figure 3: Passive magnetic levitation test rig

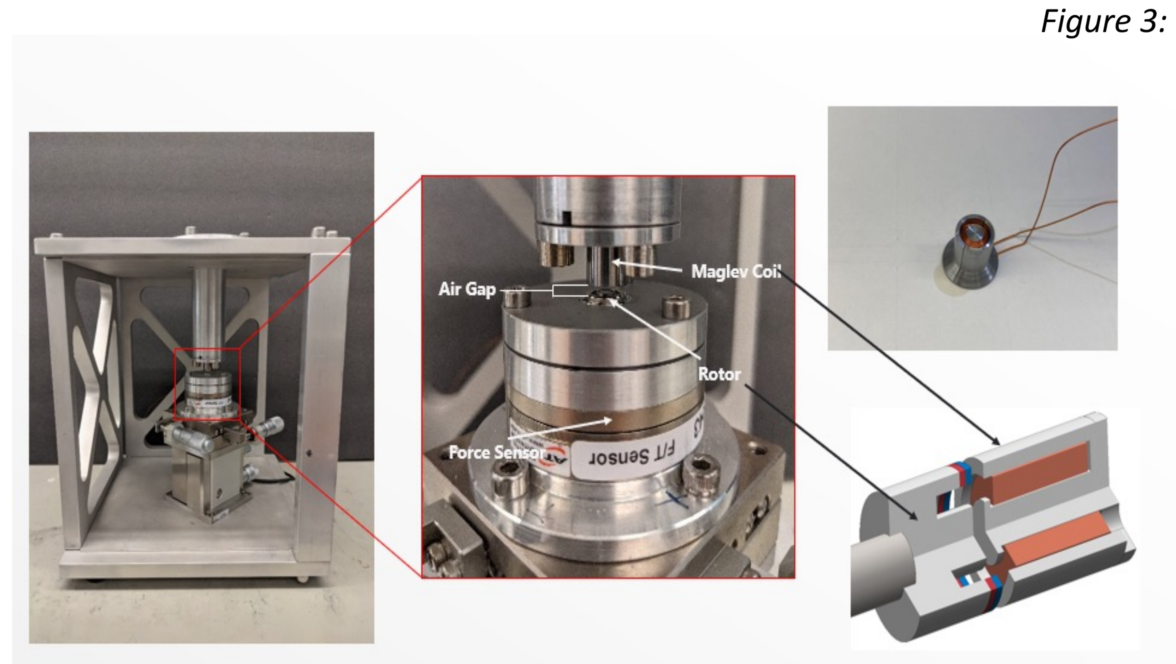

Figure 4: Active magnetic levitation test rig

The Maglev active force test is set up with the rotor's terminal PM ring connecting to a force transducer that is mounted on a 3-axis linear translation stage. The PM ring is separated from a copper magnetic coil 150-turns by an adjustable distance. By varying the current running through the magnetic coil, the induced magnetic force could be obtained to verify the stability of the system.

Results

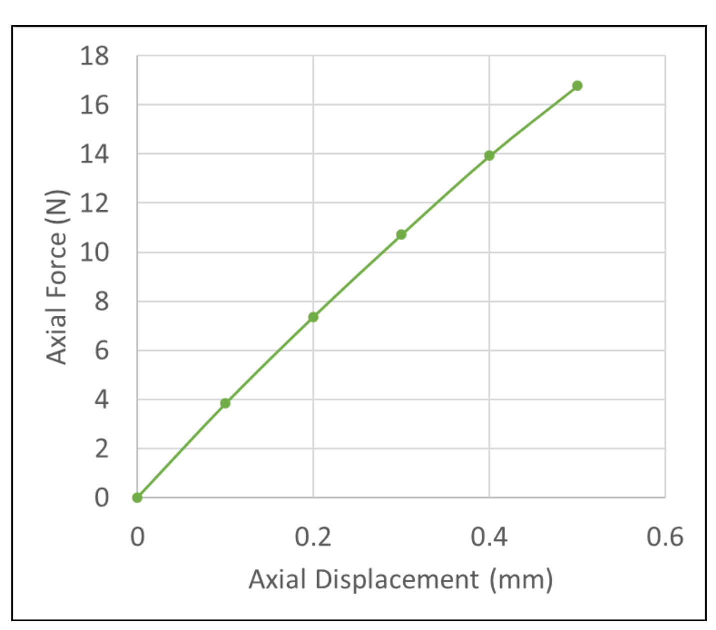

Figure 5: Axial force per axial displacement

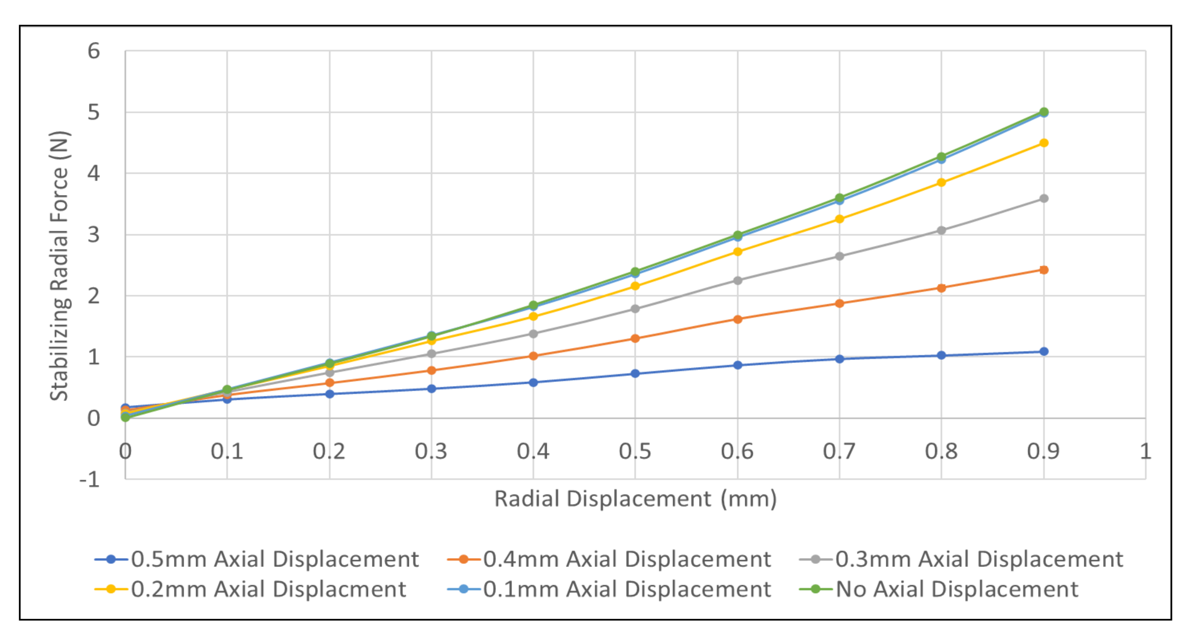

Figure 6: Radial force per radial displacement for different axial displacement

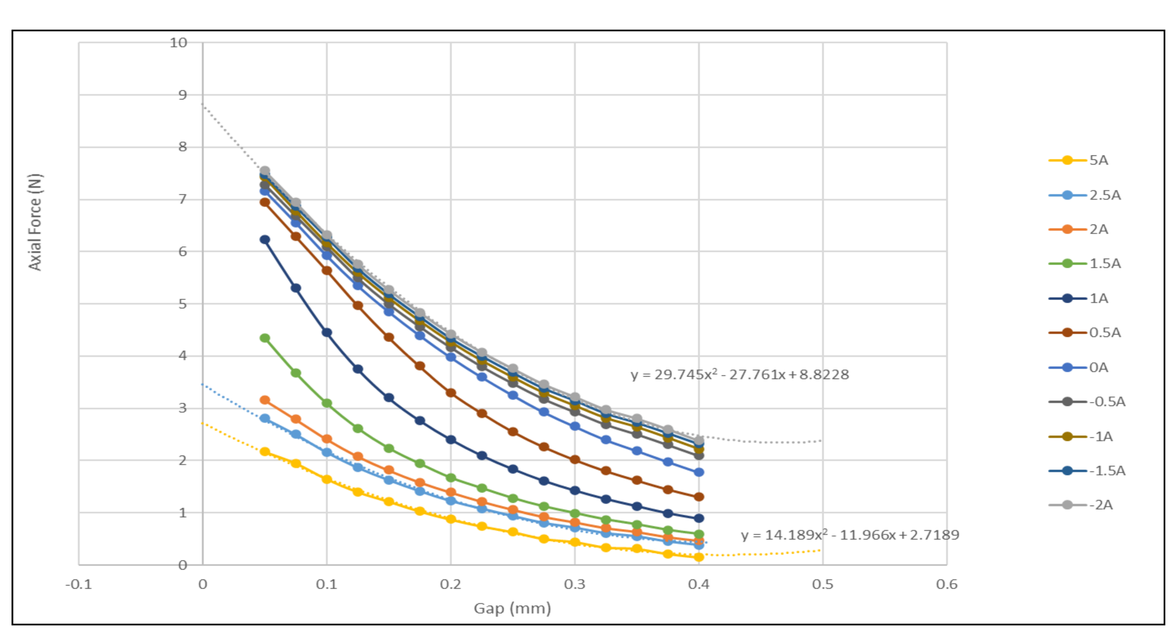

Figure 7: Induced axial force per gap distance for different current values

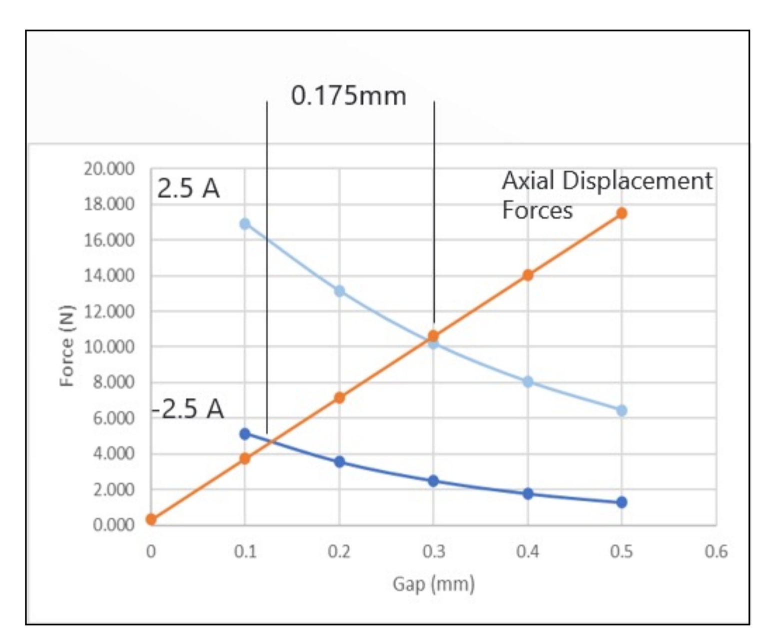

Figure 8: Axial force and current-induced force per gap distance

Discussion

Figure 5 illustrated that increasing the axial displacement of the rotor would increase the force in the axial position. As a result, the magnitude of the current-induced axial force required to stabilize the entire magnetic levitation system would also increase.

Figure 6 highlighted the inverse relationship between axial displacement and radial magnetic forces. Increasing the axial displacement of the rotor would decrease the stabilizing radial forces between the PM rings on the casing and the shaft, thus decreasing the magnetic levitation capability of the system.

Figure 7 demonstrated how the decay of current-induced force on the rotor over axial distance could be modeled by a quadratic function. Additionally, Figure 7 also illustrated that while a greater range between positive and negative current would produce a larger range of controllable axial displacement, the max current value cannot exceed 5 A.

Conclusion

We observed that varying the current between 2.5 A and -2.5 A on the active Maglev component would produce the most stable magnetic levitation system. This operation parameter would also create a controllable gap of 0.175 mm as demonstrated in Figure 8. The gap is about 22 times larger than the thickness of a single red blood cell (0.008 mm), thus reducing the risk of hemolysis. Future works on increasing the gap between the rotor and the active Maglev bearing component could be done to further decrease the risk of damaging blood cells while the device is running.

Acknowledgement

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References

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