# DEVELOPMENT OF AN ACTIVE MAGNETIC LEVITATION SYSTEM FOR The USE IN A ROTARY BLOOD PUMP

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***Abstract* – Ventricular Assist Devices (VADs) are mechanical blood pumps used to treat patients with heart failure. Magnetic and hydrodynamic bearings are used in these devices to improve durability and potentially reduce thrombolytic or haemolytic events. This paper focuses on the development of a small active hybrid magnetic bearing and motor for a Left Ventricular Assist Device (LVAD). The force capacity and positioning of the suspension components were determined with experimental results. A prototype was constructed and successfully levitated.**

## I. INTRODUCTION

Ventricular Assist Devices are mechanical blood pumps, which are used to augment the cardiac output of a failing heart. These devices have been the focus of research for over 50 years and in this time have undergone a significant evolution of their technology. Earlier devices typically utilised volume displacement pumps to provide pulsatile support. These first generation devices were typically bulky and suffered from reliability issues associated with their mechanical components. These issues lead to the use of continuous flow rotary pumps in VADs [1]. Mechanical contact bearings were initially used to suspend the rotating impeller in the pump casing; however these were often identified as elements associated with haemolysis and thrombolytic events. Recent devices have employed hydrodynamic and magnetic bearing designs to provide complete suspension of the rotor. With complete suspension of the rotor these devices have the potential to extend the expected operational life past 10 years.

Axial flux motors have been a popular choice for centrifugal blood pumps due to the large surface area due to the impeller shape [3]. However, one of the major drawbacks of these types of motors is the generation of significant axial attractive forces towards the motor stator. A number of methods have been proposed for overcoming this including; double motors in conjunction with hydrodynamic and passive bearings (“Ventrassist”, Ventracor Pty Ltd & “HVAD”, Heartware International Inc.) and active magnetic bearings (“DuraHeart”, Terumo Heart Inc. & “Levacor”, World Heart Inc.) [2].

Due to their large air gaps, active magnetic bearings have the potential to provide larger clearance gaps in the pump casing as well as stability over a wider operational range. However the extra components often increase the size and complexity of these devices. The two clinically available devices which feature an active magnetic levitation system both have an outside diameter of over 72mm making them large in comparison to other devices on the market.

This project details the initial development of a small active magnetic bearing and motor system for use in a centrifugal LVAD. The design of the device is outlined in Fig. 1. The proposed VAD features a double shrouded centrifugal impeller designed to provide 5L/min at 100mmHg while operating at 2600RPM. An axial flux PM motor acts on one side of the suspended impeller, while an active magnetic bearing is placed on the opposite side to balance and stabilise the axial and tilt forces. Radial stability will be provided through passive magnetic reluctance from the motor and bearing.

## II. METHOD

The magnetic levitation system is required to overcome all hydraulic forces generated in the pump casing in addition to any external disturbance forces. Due to the double shrouded impeller the axial hydraulic forces generated over the rotor are be small in comparison to the magnetic suspension forces.

The axial flux PM motor is required to supply torque to the rotor for a wide range of operating conditions. Full cardiac support from the device at 2600RPM requires a torque of approximately 16mNm. The initial motor design features 18 stator coils and 16 neodymium iron boron (NdFeB) permanent magnets (PM) with a 1mm back iron on the rotor and stator side.

The active hybrid magnetic bearing (HMB) is shown in Fig. 1 and consists of an integrated 4 pole stator with concentrated windings and a rotor target made of a back iron and an axially magnetized NdFeB PM ring. The PMs produce a bias flux in the magnetic circuit. This flux produces a bias force which, if matched to the expected motor force, can be used to reduce the power required by the levitation system [4]. The position at which the HMB bias force and the motor force balance exactly is referred to as the zero-power point. Excitation of the electromagnets can be controlled independently and will augment or cancel the bias flux to increase or decrease the force produced by each individual magnetic bearing pole. Reversal of the excitation current direction between geometrically opposite HMB poles will generate a tilt moment on the rotor. Three eddy current sensors (PU-07-036-201, AEC, Kanagawa, Japan) positioned on the motor side of the device are used to determine the rotor position (axial position and the 2 planar tilt axes). The motor drive and levitation controller was implemented on the dSPACE (DS1104, dSPACE, Paderborn, Germany) data acquisition system. The levitation controller consists of 4 independent PID controllers for each MB pole, the parameters of which are manually tuned.


Fig.1. Active hybrid magnetic bearing components; rotor with bias PM (Left) and 4 pole stator (right).

### A. *Force Capacity Analysis*

Finite Element Method (FEM) simulations were performed on both the motor and magnetic bearing systems. These results were used to determine the efficiencies, force capacity and saturation of the cores.

Empirical force measurements were made of the motor and magnetic bearing system using a micrometer slide and force transducer (Nano17, ATI ,NC, USA). The axial attractive force and efficiency of the motor and was measured at air-gaps between 0.8mm and 2mm. The axial force and tilt moment generated by the magnetic bearing were measured at air-gaps between 0.8mm and 2mm and excitation currents from 0A to 2A. These forces were used to determine the motor and magnetic bearing air-gaps such that magnetic zero-power point is located in the casing.

### B. *Levitation Prototype*

A prototype was created to validate the existence of the zero-power point calculated from the force measurements and to test levitation performance. The prototype featured an initial impeller and volute design.

## III. RESULTS

### A. *Force Capacity Analysis*

FEM analysis was performed on the initial designs. It was determined from these results that the core was not saturated under normal conditions. The attractive forces determined by the FEM simulation were consistently higher than the empirical measurements; however this is typical and was expected.

Fig. 2 shows the attractive force of both the active magnetic bearing and the motor for varying axial air-gaps positions. Although there is an infinite combination of motor and MB air-gaps that would produce a magnetic zero-power point, smaller air-gaps were chosen to increase system efficiency. Consequently the theoretical magnetic zero-power point chosen is a motor air-gap of 1mm and a bearing air-gap of 1.1mm.

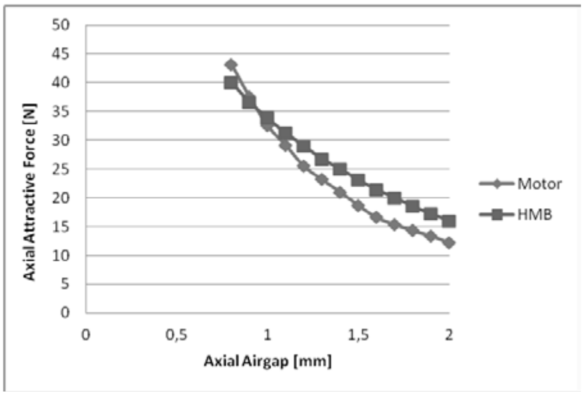


Fig.2. Axial force capacity of the motor and magnetic bearing. Intersection of the two force curves indicates the theoretical magnetic zero-power point.

### B. *Levitation Prototype*

The prototype was created with a constrained axial movement of +/- 0.15mm. The levitation prototype confirmed that the magnetic zero-power point was located in the pump casing. Levitation in air was not possible due to instability; however with fluid (100% water) the higher dampening coefficient made it possible to achieve static levitation of the rotor over the range of +/-0.1mm. The closed loop performance of the levitation system requires further optimisation as there was significant oscillations and instability in the system.

## IV. DISCUSSION

The axial force generated by the proposed motor has been determined through numerical simulation and empirical measurements. A 4 pole active HMB was designed to balance the axial forces generated by the motor as well as any disturbance forces. The air-gaps of the motor and HMB were chosen such the axial forces were balanced creating a zero-power point and high motor efficiency. A levitation prototype was successfully created and static levitation was achieved. Future work will be focused on the optimisation of the control algorithm to achieve more stable levitation and rotation.

## REFERENCES


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