Levitation and Drive Control –

Left Ventricular Assist Device (LVAD)

Final Project Report

Submitted to the APJ Abdul Kalam Technological University

in partial fulfillment of requirements for the award of degree

Bachelor of Technology

in

Electronics and Communication Engineering

by

Ajay J. Thampy (TVE17EC005)

Midhun P. (TVE17EC027)

Sreejith S. (TVE17EC049)

Vipin Chandran M. (TVE17EC061)

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

COLLEGE OF ENGINEERING TRIVANDRUM

KERALA

June 2021

DECLARATION

We, **Ajay J. Thampy (TVE17EC005), Midhun P. (TVE17EC027), Sreejith S. (TVE17EC049)**, and **Vipin Chandran M. (TVE17EC061)**, hereby declare that the Final project report **Levitation and Drive Control of a Left Ventricular Assist Device (LVAD)**, submitted for partial fulfillment of the requirements for the award of degree of Bachelor of Technology of the APJ Abdul Kalam Technological University, Kerala is a bonafide work done by us under supervision of **Prof. Sindhu N**.

This submission represents our ideas in our own words and where ideas or words of others have been included. We have adequately and accurately cited and referenced the original sources.

We also declare that we have adhered to ethics of academic honesty and integrity and have not misrepresented or fabricated any data or idea or fact or source in our submission.We understand that any violation of the above will be a cause for disciplinary action by the institute and/or the University and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been obtained. This report has not been previously formed the basis for the award of any degree, diploma or similar title of any other University.

Trivandrum
—DATE—

Ajay J. Thampy (TVE17EC005)
Midhun P. (TVE17EC027)
Sreejith S. (TVE17EC049)
Vipin Chandran M. (TVE17EC061)

DEPT. OF ELECTRONICS & COMMUNICATION ENGINEERING

COLLEGE OF ENGINEERING TRIVANDRUM

2020 - 21

CERTIFICATE

This is to certify that the report entitled **"Levitation and Drive Control of a Left Ventricular Assist Device (LVAD)"** submitted by **Ajay J. Thampy (TVE17EC005), Midhun P. (TVE17EC027), Sreejith S. (TVE17EC049)**, and **Vipin Chandran M. (TVE17EC061)**, to the APJ Abdul Kalam Technological University in partial fulfillment of the B.Tech. degree in Electronics and Communication Engineering is a bonafide record of the project preliminary work carried out by them under our guidance and supervision. This report in any form has not been submitted to any other University or Institute for any purpose.

Prof. Sindhu N
Assistant Professor (Guide)
Department of ECE,
College of Engineering Trivandrum.

Prof. Joaquim Ignatious Monteiro
Associate Professor, (Co-ordinator)
Department of ECE,
College of Engineering Trivandrum.

Dr. Biji Jacob
Professor, (Head of Department),
Department of ECE,
College of Engineering Trivandrum.

Acknowledgement

We take this opportunity to express our deepest sense of gratitude and sincere thanks to everyone who helped us to complete this work successfully. We express our sincere thanks to **Dr. Jayakrishnaraj G.**, Head of Department, Electronics and Communication Engineering, College of Engineering Trivandrum for providing us with all the necessary facilities and support.

We would like to express our sincere gratitude to **Prof. Joaquim Ignatious M.** and **Prof. Sajith Vijayaraghavan**, department of Electronics and Communication Engineering, College of Engineering Trivandrum for their support and co-operation. We would like to place on record our sincere gratitude to our project guides **Prof. Sindhu N.**, Assistant Professor, Electronics and Communication Engineering, College of Engineering and **Mr. Ratheesh K.**, Scientist-Engineer, Spacecraft Systems Group, ISRO Inertial Systems Unit, for the guidance and mentorship throughout the course.

Finally we thank our families, and friends who contributed to the successful fulfilment of this project preliminary work.

Ajay J. Thampy (TVE17EC005)
Midhun P. (TVE17EC027)
Sreejith S. (TVE17EC049)
Vipin Chandran M. (TVE17EC061)

Abstract

Heart failure (HF) is a frequent cause of inpatient admissions. A left ventricular assist device (LVAD) is a mechanical pump that we use for patients who have reached end-stage heart failure. A LVAD is implanted inside a person's chest to help a weakened heart pump blood. It augments blood flow to the body and shares workload of the Left Ventricle. Unlike a total artificial heart, the LVAD doesn't replace the heart. It just helps it do its job. The critical distinguishing factor between the second- and third-generation LVADs is the employment of contact versus noncontact bearings, respectively. The latter employs the technology known as magnetic levitation, which allows for rotation without friction or wear. The goal of this design is to further minimize the prothrombotic sites while enhancing efficiency and durability of a third generation Left Ventricular Assist Device.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

Left Ventricular Assist Device (LVAD) is a surgically implantable mechanical pump that is attached to the heart. An LVAD is different from an artificial heart. An artificial heart replaces the failing heart completely whereas an LVAD works with the heart to help it pump more blood with less work. It does this by continuously taking blood from the left ventricle and moving it directly to the aorta, which then delivers oxygen-rich blood throughout the body. The device is placed in the left ventricle (main chamber of the heart) to pump oxygen-rich blood throughout the body. This chapter presents the objectives and scope of our work.

1.1 Objectives

We divide our project into three main parts: i) Levitation, ii) Drive electronics, and iii) Monitoring. The objective of the work is to implement a magnetically levitated wheel rotating at a desired rpm. It should be capable of functioning all day with an output voltage of 14V to 18V and deliver power of 8.8W for 11hrs. Due to the power constraints, sensors like Hall sensors cannot be used, thereby making utilisation of the back emf generated to control the motor using ICs. The machine should have 90 percentage survival rate and should extend its life for at-least 10 years. It should be available to all at a reasonable cost.

1.2 Scope

The scope of our project is in the implementation of a Left Ventricular Assist Device (LVAD) which can improve survival and quality of life of patients with end-stage heart failure. Apart from the apparent advantage of not having to wait for a suitable donor, there are several advantages to using an LVAD. For instance, unlike cadaver transplants that require the intake of immuno-suppressants, to facilitate organ acceptance, patients with the implanted device need take only one simple blood thinning medicine to ensure the free flow of blood. Another noteworthy advantage of the an LVAD is that the device can be removed if the left ventricle recovers in due course of time. It is the only solution for patients who can't find a donor or may not survive a transplant.

Chapter 2

Literature Review

A shift from the concept of totally artificial heart as heart replacement, towards the development of single chamber pumps as cardiac support, initiated the area of left ventricular assist devices (LVAD). [3] This chapter presents a literature survey of the technical papers and commercially available LVADs.

2.1 First generation ventricular assist devices

The first ventricular assist devices generated additional blood flow in parallel with the particular ventricle. They were either pneumatically or electrically driven membrane pumps, generating pulsatile flow with artificial heart valves as inlet and outlet. Connected to the heart via cannulas, these pumps can be used either as isolated left-, right- or biventricular assist devices. If used for biventricular support, pump chambers have to be positioned extracorporeal due to the size. [3]

The first generation of LVADs were known as pulsatile because, like a normal heart, they had a detectable beat. Blood flowed into an artificial chamber and was squeezed out to the rest of the body. A version called HeartMate I (Figure 2.1) that did so using air, with power coming from a large, external machine, became the first LVAD approved by the U.S. Food and Drug Administration. [1] Another company, Novacor, also received FDA approval for a first-generation LVAD. Although the HeartMate I was a game changer for heart failure patients, they have many drawbacks. They caused thrombosis or the risk of bleeding and there is a need for strict anticoagulation. [4]

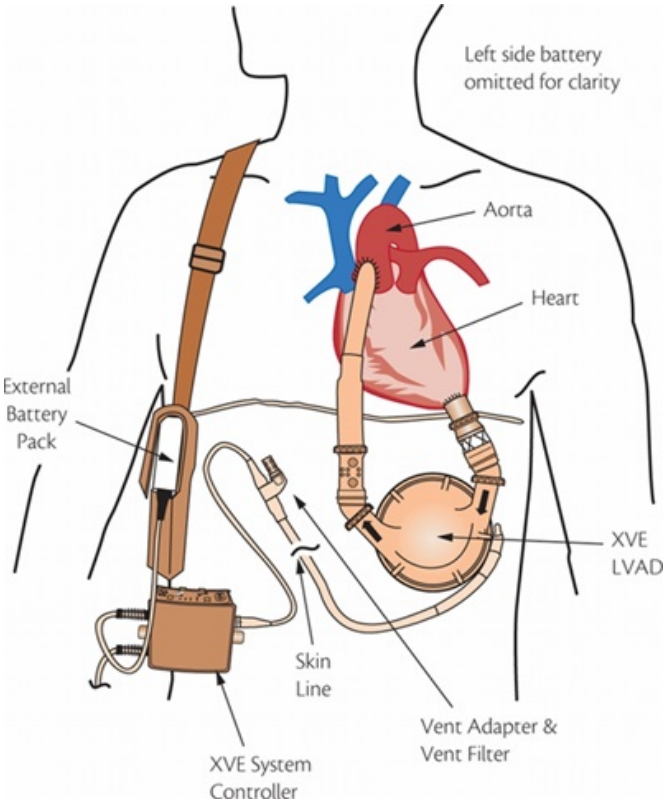

Figure 2.1: How patients connected to the HeartMate I [1]

2.2 Second generation ventricular assist devices

The next wave of LVADs went from a pump to a stream, commonly called a continuous flow. The HeartMate II does this using a rotating screw. Blood comes into the chamber and twists through a device that is smaller and more comfortable than its predecessor. The development of continuous flow centrifugal pump devices improved patient outcome by reducing size and susceptibility for infections. In addition, significant noise reduction enhanced quality of life. [1]

The most frequently used second generation LVAD is the Heartmate II (Figure 2.2). The device consists of a propeller surrounded by a metal case, referred to as impeller. The combined mechanical and magnetical positioning of the impeller increases the durability up to a minimum of five years. [3] Since FDA approval in 2008, the Heartmate II can be used either as bridge to transplant or since 2010 as destination therapy. This provides patients with a better quality of life, including good mobility and restoration of endorgan function, in some cases even allowing them to return to

work. [3] Some patients from the original clinical trials of Heartmate II, 10 years ago, are still alive, so the longevity of this LVAD is yet to be determined.

The incidence of thromboembolic events is relatively low for the HeartMate II and ranges from 3 to 6 events per 100 patient-years. [5] In the randomized destination therapy trial of the HeartMate II versus the HeartMate I, the hemorrhagic and ischemic stroke rates (at 0.06 and 0.07 events per patient-year) tended to be lower in comparison to HeartMate I (at 0.10 and 0.12 events per patient-year) [5]. Other second-generation devices (DuraHeart, VentrAssist) show somewhat higher incidence of neurological complications [6]. The incidence of driveline and pump infection is still remarkable, ranging from 13 to 27% [7]. In comparison to severe device-related infections with first-generation pumps, those with second-generation devices seldom lead to fatal outcomes. [8]

Figure 2.2: How HeartMate II recipients are connected to the LVAD [1]

2.3 Third generation ventricular assist devices

The latest concept in ventricular assist devices is an improved method of continuous flow. It is based on centrifugal force, with electromagnets spinning the blood. With

introduction of third generation LVADs, another significant reduction in size could be achieved. The leading example is the LVAD by HeartWare. The HeartWare Ventricular Assist System, made by HeartWare, does this using a chamber that is small and with no mechanical bearings. It also fits differently, attaching directly to the heart. Due to its reduced size, even a biventricular implantation is possible. [1] Designed as radial pump with magnetic and hydraulic positioning, no wear-out is to be expected with an estimated durability of 10 years. [3]

The HVAD Pump (Figure 2.3), part of the HeartWare Ventricular Assist System, is a small centrifugal flow pump with a displacement volume of 50 ml and an output capacity of 10 L/min. [8] A unique wide-blade impeller is suspended by hybrid passive magnets and hydrodynamic forces. There are no points of mechanical contact within the pump, effectively ensuring a wearless system. The design integrates two motor stators for single-motor fault protection to increase reliability. [9] External system components include the microprocessor-based controller, a monitor, lithium-ion battery packs, alternating current and direct current power adapters, and a battery charger. Physiologic control algorithms are incorporated for safe operation. [8] Preclinical life cycle tests have shown the HVAD to be highly reliable. This system design offers reliability, portability, and ease of use for ambulatory patients [10]. The device size and the integrated inflow cannula allow it to be implanted completely in the pericardial space, directly adjacent to the heart, thereby avoiding the abdominal surgery generally required to implant competing devices. [11]

Figure 2.3: The HeartWare HVAD (right), and its miniaturized version [1]

Chapter 3

Design and Implementation

Mechanical circulatory support devices have become an important treatment tool for acute and chronic heart failure, since heart transplantation cannot meet the demands because of a lack of available donor organs. This chapter presents an overview on the levitation, drive electronics and monitoring of a third generation Left Ventricular Assist Device (LVAD) which augments blood flow to the body and shares workload of the Left Ventricle.

3.1 Levitation

Levitation systems utilized in third-generation rotary blood pumps suspend the moving impeller within the blood field without any mechanical contact. The magnetic and hydrodynamic levitation of the impeller without any contact bearings with the pump is the major advancement of the third-generation pumps. [3] The suspended impeller reduces heat generation, increases endurance and also the spiral groove hydrodynamic bearing are a backup in case primary magnetic bearing fails (in larger size LVAD pumps). The rotation speed is 1800-4000 rpm with 10 l/min maximum flow rate.

The electromagnetically suspended and electronically controlled bearings (Figure 3.1) support the load using magnetic levitation without any physical contacts. Magnetic Bearings have distinct advantages over conventional bearings due to the non-contact operation. They have a long life and are compatible to harsh environments like vacuum. There is a reduced power losses due to less friction and also negligible

hear generation in the rotor. Under normal condition, completely passive stable six degrees of freedom (DOF) contactless magnetic bearing cannot be realized. In practice, atleast one axis has to be controlled actively by means of electromagnets. In our implementation, we plan to use a two-axis actively controlled impeller.

The levitation system uses two eddy current sensors (gap sensor), an instrumentation amplifier, a controller and a power amplifier. For the purpose of the power amplifier, IC SA160 has been identified. The SA160 is a pulse width modulation amplifier that can supply 10 A continuous current to the load. The PWM circuitry is internal leaving the user to only provide an analog signal for the motor speed/direction. The internal PWM frequency can be programmed by an external integrator capacitor. [12] The design aims to have a gain margin above 12 dB and a phase margin above 30 degrees.

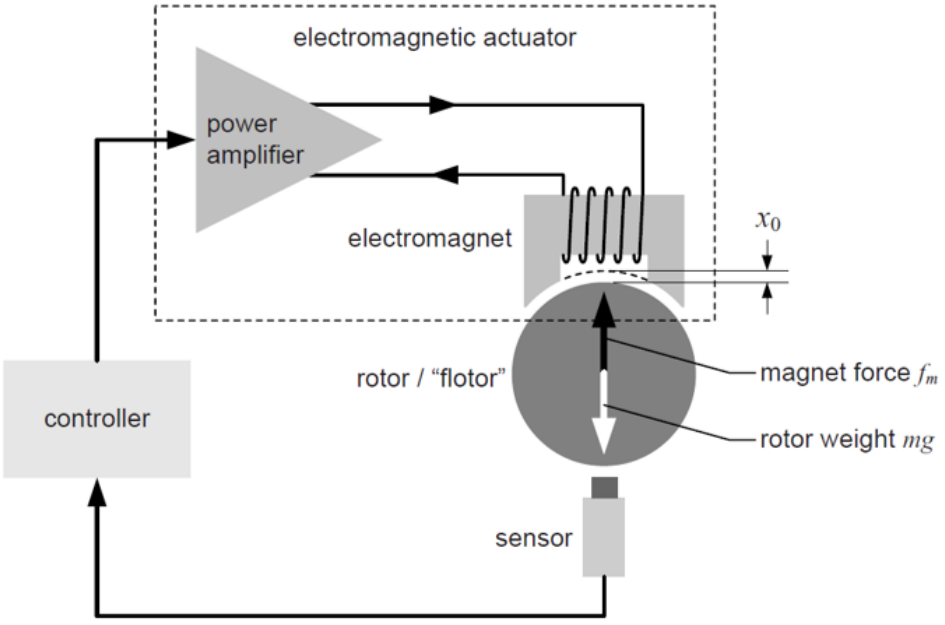

Figure 3.1: The basic magnetic bearing control loop and its elements

3.2 Drive electronics

The drive electronics will be done using a 3-phase motor driver IC having sinosidal feed current waveform and a sensorless back emf-based commutation scheme. The drive should have the capability to run the motor in the speed range of 1800 rpm to

4000 rpm with an accuracy of ± 2 rpm. The IC DRV10983 will be used to drive the brushless motor. A sinosoidal motor is preferred over a DC motor as it does not cause ripples in the blood.

The DRV10983 can provide continuous drive current up to 2 amperes. The motor speed and the other control parameters (such as torque limit and closed loop gain) of the control register of DRV10983 chip are set by dsPIC33 through a serial I^2C link. The dsPIC33E family of Digital Signal Controllers (DSCs) offers performance of up to 70 MIPS, flexible peripherals and a complete ecosystem of software and hardware tools. [13]

3.3 Monitoring

We intend to have a miniature monitoring system (Figure 3.2) to monitor the important health parameters of the LVAD, such as battery indication, speed, power and levitation status. It also includes necessary alarm signals. The program written in dsPIC should also have the capability for monitoring internal circuit parameter values during testing and debugging.

Figure 3.2: Monitoring in a ventricular assist device [2]

The proposed block diagram for the system including the levitation electronics, drive electronics and the monitoring system is shown in Figure 3.3.

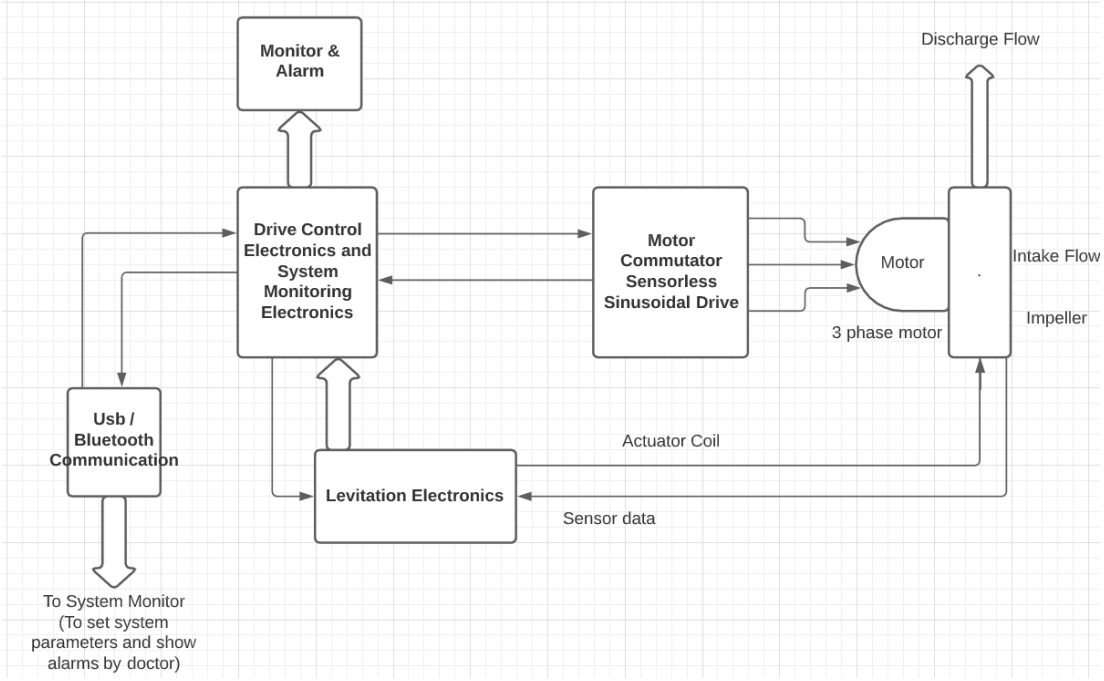

Figure 3.3: Block diagram of the system

Chapter 4

Project timeline

This chapter presents the schedule for implementation of our project.

Table 4.1: Schedule for implementation

SL NO.	MONTH	SCHEDULE
1	September 2020	Literature survey of commercially available LVADs
2	October 2020	Formulation of objectives and work plan
3	November 2020	In-depth study of the work and design for implementation
4	December 2020	Identification and study of the tools and components used in the work
5	January 2021	Implementation of minor programs and applications to familiarize working with the tools and components
6	March 2021	Preparing the detailed plan and design of the Levitation circuitry for the work
7	April 2021	Design of the Drive Electronics and Monitoring circuitry for the work
8	May 2021	Final development of the product and testing

Chapter 5

Work done & Interim results

We familiarized with ICs SA160, DRV10983 and dsPIC33E which will be used during the implementation of levitation and drive electronics of the Left Ventricular Assist Device. We used the MPLAB Code Configurator (MCC) and tried out basic programs like LED blinking. Currently, we are working on implementing I^2C, in order to establish communication between the dsPIC and DRV IC using MCC.

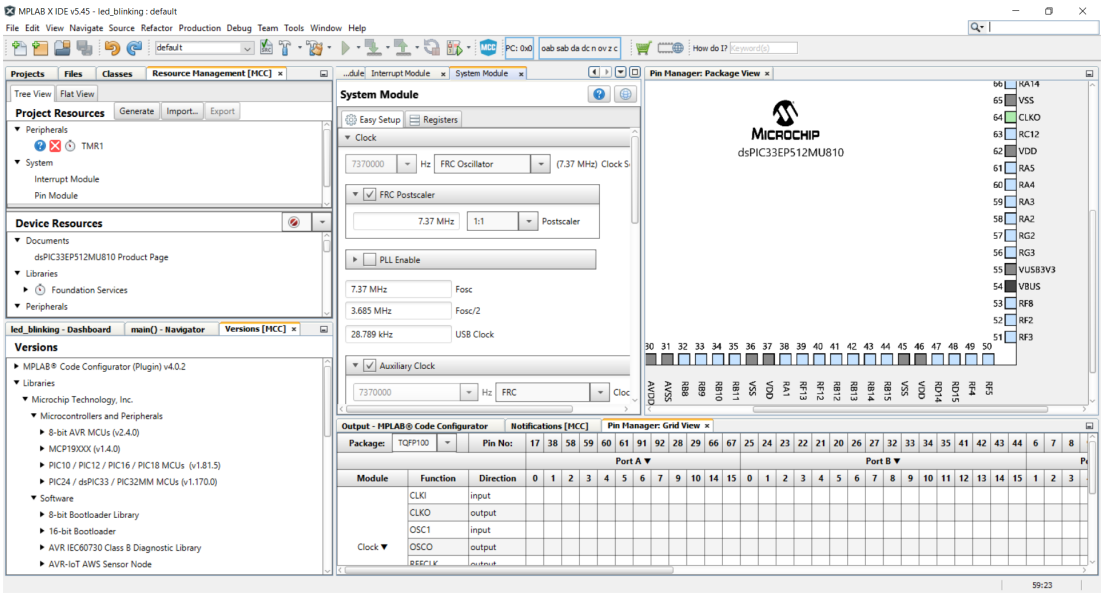

Figure 5.1: Using MCC for LED blinking at a desired frequency

References

[1] "The past, present and future of the device keeping alive carew, thousands of hf patients," www.heart.org. [Online]. Available: https://www.heart.org/en/news/2018/06/13/the-past-present-and-future-of-the-device-keeping-alive-carew-thousands-of-hf-patients

[2] C. A. Thunberg, B. D. Gaitan, F. A. Arabia, D. J. Cole, and A. M. Grigore, "Ventricular assist devices today and tomorrow," *Journal of Cardiothoracic and Vascular Anesthesia*, vol. 24, pp. 656–680, 08 2010.

[3] A. Prinzing, U. Herold, A. Berkefeld, M. Krane, R. Lange, and B. Voss, "Left ventricular assist devices—current state and perspectives," *Journal of Thoracic Disease*, vol. 8, pp. E660–E666, 08 2016. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4999658/

[4] R. Gianluca, S. Francesco, and F. Giuseppe, "Past and present of cardiocirculatory assist devices: a comprehensive critical review," *Journal of Geriatric Cardiology*, vol. 9, pp. 389–400, 01 2013.

[5] M. S. Slaughter, J. G. Rogers, C. A. Milano, S. D. Russell, J. V. Conte, D. Feldman, B. Sun, A. J. Tatooles, R. M. Delgado, J. W. Long, T. C. Wozniak, W. Ghumman, D. J. Farrar, O. H. Frazier, and H. I. Investigators, "Advanced heart failure treated with continuous-flow left ventricular assist device," *The New England Journal of Medicine*, vol. 361, p. 2241–2251, 12 2009. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/19920051/

[6] M. Morshuis, A. El-Banayosy, L. Arusoglu, R. Koerfer, R. Hetzer, G. Wieselthaler, A. Pavie, and C. Nojiri, "European experience of duraheart™

magnetically levitated centrifugal left ventricular assist system," *European Journal of Cardio-Thoracic Surgery*, vol. 35, p. 1020–1028, 06 2009. [Online]. Available: https://academic.oup.com/ejcts/article/35/6/1020/473475

[7] J. K. Kirklin, D. C. Naftel, R. L. Kormos, L. W. Stevenson, F. D. Pagani, M. A. Miller, K. L. Ulisney, J. T. Baldwin, and J. B. Young, "Second intermacs annual report: More than 1,000 primary left ventricular assist device implants," *The Journal of Heart and Lung Transplantation*, vol. 29, p. 1–10, 01 2010. [Online]. Available: https://www.jhltonline.org/article/S1053-2498(09)00821-3/fulltext

[8] J. Garbade, H. B. Bittner, M. J. Barten, and F.-W. Mohr, "Current trends in implantable left ventricular assist devices," Cardiology Research and Practice, 05 2011. [Online]. Available: https://www.hindawi.com/journals/crp/2011/290561/

[9] R. Hetzer, T. Krabatsch, A. Stepanenko, E. Hennig, and E. V. Potapov, "Long-term biventricular support with the heartware implantable continuous flow pump," *The Journal of Heart and Lung Transplantation*, vol. 29, p. 822–824, 07 2010. [Online]. Available: https://www.jhltonline.org/article/S1053-2498(10)00148-8/fulltext

[10] J. A. LaRose, D. Tamez, M. Ashenuga, and C. Reyes, "Design concepts and principle of operation of the heartware ventricular assist system," *ASAIO Journal*, vol. 56, p. 285–289, 07 2010. [Online]. Available: https://journals.lww.com/asaiojournal/Fulltext/2010/07000/Design_Concepts_and_Principle_of_Operation_of_the.3.aspx

[11] G. M. Wieselthaler, G. ODriscoll, P. Jansz, A. Khaghani, and M. Strueber, "Initial clinical experience with a novel left ventricular assist device with a magnetically levitated rotor in a multi-institutional trial," *The Journal of Heart and Lung Transplantation*, vol. 29, pp. 1218–1225, 11 2010.

[12] "Apex microtechnology - power operational amplifers - pwm amplifiers - voltage references :: Sa160 - 10a h-bridge motor driver," www.apexanalog.com. [Online]. Available: https://www.apexanalog.com/products/sa160.html

[13] “dspic33e dscs - 70 mips — microchip technology,” www.microchip.com. [Online]. Available: https://www.microchip.com/design-centers/16-bit/dspic33e