Design and Development of an Electromagnetic Shaker

A Final Year Project Report

Presented to

SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING

Department of Mechanical Engineering

NUST

ISLAMABAD, PAKISTAN

In Partial Fulfillment
of the Requirements for the Degree of
Bachelors of Mechanical Engineering

By

Daniyal Safi

Muhammad Talha Bashir

Muhammad Wahag Nizami

Muhammad Ammar Ahmad

EXAMINATION COMMITTEE

We hereby recommend that the final year project report prepared under our supervision by:

DANIYAL SAFI	290823
MUHAMMAD TALHA BASHIR	300311
MUHAMMAD WAHAG NIZAMI	321944
MUHAMMAD AMMAR AHMAD	283698

Titled: "Design and Development of an Electromagnetic Shaker" be accepted in partial fulfillment of the requirements for the award of Mechanical Engineering degree with grade ___

Supervisor: Dr. Zeeshan Saeed	____________________ Dated:
Committee Member:	____________________ Dated:
Committee Member:	____________________ Dated:

______________________ ____________

(Head of Department) (Date)

COUNTERSIGNED

Dated: ________________ __________________________

(Dean / Principal

ABSTRACT

An extensive analysis of the design and development of an electromagnetic shaker is presented in this thesis report. In order to produce controlled vibrations and replicate real-world circumstances, the electromagnetic shaker is a flexible tool that is frequently employed in a wide range of commercial and research applications. The main goal of this research was to create an electromagnetic shaker that could be easily produced locally in Pakistan and was inexpensive and reasonable. The paper starts off with a thorough analysis of the body of research on shaker technologies, concentrating on electromagnetic shakers and their uses. The theoretical basis and guiding principles of the electromagnetic shaker are explored in detail, along with the ideas of magnetic fields, electric currents, and their interactions. Based on the literature review and theoretical analysis, a detailed design methodology for the electromagnetic shaker is presented. The design process includes the selection and sizing of key components, such as the electromagnetic coil and permanent magnets etc. Special attention is given to optimizing the design parameters to achieve desired vibration characteristics, such as amplitude and frequency range. Following the design phase, the report delves into the practical implementation of the electromagnetic shaker. This includes the fabrication of the electromagnet, construction of the shaker assembly, integration of the control and power electronics, and calibration of the system. The results are thoroughly analyzed, and the shaker's performance is compared against industry standards and existing shaker systems. The thesis paper ends with a review of the created electromagnetic shaker's prospective applications and future improvements. The device's adaptability and potential for use in sectors like aerospace, civil engineering, and material testing are highlighted in the report.

ACKNOWLEDGMENTS

We want to express our sincere gratitude and appreciation to Dr. Zeeshan Saeed, our supervisor, for his tremendous advice, inspiration, and continuous support throughout our project. His knowledge, skill, and willingness to impart it have all been crucial to the success of our project. We would also like to thank our Department School of Mechanical and Manufacturing Engineering (SMME) for giving us a supportive learning environment and the tools we required. We have consistently been motivated by the department's dedication to excellence in teaching and research. Additionally, we would like to express our gratitude for the support and contributions from our fellows and coworkers who offered insightful criticism and ideas while the project was being developed. Their input and encouragement were very helpful in forming the final product. We want to express our sincere gratitude to everyone who helped make our project a success. We are grateful to have had the chance to collaborate with such extraordinary people and organizations since their support and direction have played a crucial role in our academic journey.

ORIGINALITY REPORT

ORIGINALITY REPORT

16%	13%	9%	9%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Je-Hoon Kim, Jin-Ho Kim, Sang-Hyun Jeong, Bang-Woo Han. "Design and Experiment of an Electromagnetic Vibration Exciter for the Rapping of an Electrostatic Precipitator", Journal of Magnetics, 2012 Publication	2%
2	www.mdpi.com Internet Source	2%
3	Submitted to Higher Education Commission Pakistan Student Paper	2%
5	www.sandv.com Internet Source	1%
6	Submitted to UOW Malaysia KDU University College Sdn. Bhd Student Paper	1%
7	www.citcea.upc.edu Internet Source	1%
11	Submitted to Fiji National University Student Paper	1%
12	Submitted to University of Lincoln Student Paper	<1%

15	Submitted to Southern University College Student Paper	<1 %
17	Submitted to Universiti Teknologi Malaysia Student Paper	<1 %
18	Song, Chang-Woo, and Seung-Yop Lee. "Design of a Solenoid Actuator with a	<1 %
23	Oriol Gomis-Bellmunt, Lucio Flavio Campanile. "Design Rules for Actuators in Active Mechanical Systems", Springer Science and Business Media LLC, 2010 Publication	<1 %
24	Yang Yu, Lixin Xu, Liang Zhang. "Experimental Study on Variation Rules of Damping with Influential Factors of Tuned Liquid Column Damper", Shock and Vibration, 2017 Publication	<1 %

TABLE OF CONTENTS

NOMENCLATURE

B = Magnetic Field Strength

R = Resistance

L_c = Length of coil

L_w = Length of wire

D_c = Diameter of coil

D_w = Diameter of wire

i = current

K = Stiffness of flexure

F = Total force

CHAPTER 1: INTRODUCTION

MOTIVATION

We have gained a great amount of theoretical information and practical skills in several fields throughout the course of our four years of engineering study. We had a strong desire to use our knowledge and skills to produce something significant and lasting as we neared the end of our academic career. We realized that such a device is not easily accessible or produced locally. This led to one of the key reasons for our decision to design an electromagnetic shaker. We noticed a market gap and were willing to fill it by address this issue by creating an excellent electromagnetic shaker that complies with global standards. We were also enthusiastic about the chance to use our knowledge of mechanical vibrations and their real-world applications. We were also enthusiastic about the chance to use our knowledge of mechanical vibrations and their real-world applications. We were able to explore the nuances of vibration control and frequency response while putting our theoretical understanding into practice by creating an electromagnetic shaker. A significant driving force behind our efforts was the need to produce a cheap electromagnetic shaker. Shaker systems that are currently available are frequently expensive, rendering them unavailable to some companies or educational institutions with tight budgets. We intended to make this technology more available and helpful to a wider number of people by developing an electromagnetic shaker that is both affordable and effective. To summarize, not only did we want to utilize our engineering knowledge practically but also make our contributions to the country’s industrial progress by designing a complex yet essential industrial equipment.

PROBLEM STATEMENT

Due to the scarcity of domestically produced goods in Pakistan, the high price of imported electromagnetic shakers, and the general lack of engineering design knowledge in the country, the design and development of an electromagnetic shaker present major hurdles. First off, there is a huge market gap in Pakistan due to the lack of a native electromagnetic shaker product. Finding trustworthy and effective electromagnetic shakers can be challenging for businesses and academic organizations who need to purchase equipment for vibration testing and simulation. As a result, there is a strong reliance on imported shakers, which may cause delays, increased expenses, and restricted accessibility for potential consumers. Second, a key obstacle to the widespread use of electromagnetic shakers is their expensive import cost. Even the most affordable alternatives on the market have heavy price tags that start at $1,500 USD. Many industries find this expense to be prohibitively costly, especially those with smaller budgets or operations, which makes it difficult for them to efficiently perform vibration testing and research. Furthermore, the situation is made worse by Pakistan's general lack of a culture dedicated to inventing and creating engineering machinery. The nation lacks the necessary infrastructure and technical know-how to produce electromagnetic shakers locally. As a result, there are fewer prospects for technological developments, innovation, and the domestic manufacturing sector to thrive in this particular area. Given these difficulties, it is urgent to overcome Pakistan's dearth of domestically produced electromagnetic shakers. Numerous advantages would result from designing and creating a domestic electromagnetic shaker system, including lower costs, greater accessibility, and improved domestic technological skills. By building a dependable, reasonably priced, and domestically produced electromagnetic shaker, this project intends to close the gap and facilitate domestic research, testing, and industrial applications.

OBJECTIVE

Our project will meet following deliverables:

- Making a cheap electromagnetic shaker that is affordable without sacrificing performance is one of the main goals. The solution is economically feasible and can be created for less money than imported equivalents, making it more accessible to businesses and research institutes with tight budgets.
- A fully working electromagnetic shaker with this architecture will be able to produce regulated vibrations at a variety of operating frequencies. To guarantee dependable and effective operation, the electromagnetic coil and permanent magnets will all be optimized in the shaker's design.
- A wide range of operating frequencies will be provided by the electromagnetic shaker, enabling flexible testing and simulation possibilities. A shaker that can generate vibrations within predetermined frequency ranges to satisfy various testing criteria is the deliverable. The shaker will also provide appropriate amplitudes to appropriately represent real-world conditions.
- Practical tests on compact devices like printed circuit boards (PCBs) will verify the electromagnetic shaker's functionality. The deliverable comprises demonstrating the shaker's capacity to apply controlled vibrations to various parts, showing how useful it is in real-world settings.

CHAPTER 2: LITERATURE REVIEW

1-Helpful Guidelines for Single-Axis Shaker Testing by Roman Vinokur, Westlake Village, California [1]

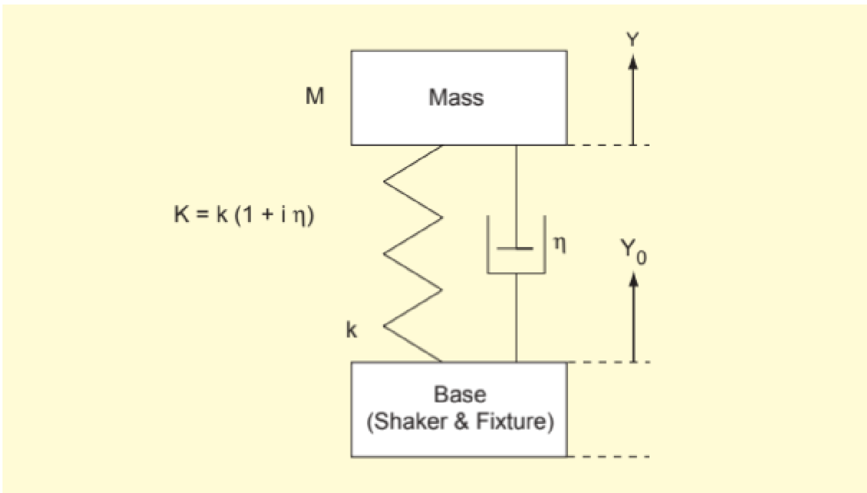


Figure 1 Single Degree of freedom vibration system

In this research paper it was studied and reviewed that several research and design projects use single-axis shakers, which are primarily electrodynamic, for modal analysis, failure modelling, and environmental testing. They are specifically utilized in the automotive and aerospace industries as well as for testing ultra-compact MEMS sensors in tandem with laser vibrometers. A certain factor called the loss factor is to be considered while designing electromagnetic shakers. In general, a variety of energy dissipation processes may control the loss factor. The loss factor for all-metal structures consists of two main parts: (1) the internal loss factor, which manifests in the majority of solid materials under alternating stresses due to hysteresis, and (2) the so-called structural loss factor, which is determined by the absorption of vibration energy at junctions, edges, and adjacent structures. The same is true for structural components like walls, window glazing, ceilings, etc. The structural component typically reduces with frequency, the internal friction component is typically constant, and the total loss factor typically decreases with frequency. It is interesting that all other damping methods and damping in vibratory systems are typically considered viscous in the literature in order to simplify math (hysteresis, etc.).

2- Design and Experiment of an Electromagnetic Vibration Exciter for the Rapping of an Electrostatic Precipitator Je-Hoon Kim, Jin-Ho Kim, Sang-Hyun Jeong, and Bang-Woo Han [2]

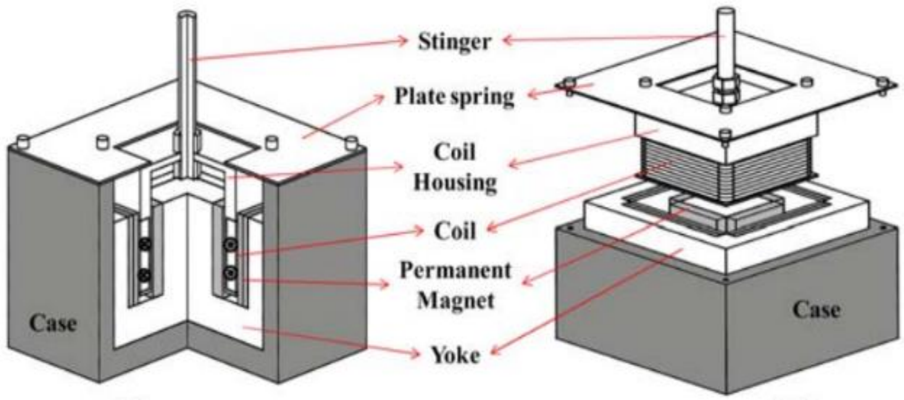


Figure 2 Electromagnetic shaker designed for a subway ventilation system.

In this research paper basically a research project is studied in which an electromagnetic shaker is designed for an Electrostatic precipitator for a subway train system. It consists of a coil, coil housing, case, stinger, and plate spring, as well as an outer steel yoke with 8 large permanent magnets and an inner steel yoke with 4 rectangle-shaped little permanent magnets each. When the PMs are arranged in a double layer, the inner and outer magnets produce an immense magnetic flux density in the air gap. This results in a powerful magnetic force. Hence, compared to a cylindrical electromagnetic vibration exciter, the quadratic electromagnetic vibration produces a stronger excitation force. The permanent magnets in a rectangle form are also simple to produce and magnetize. The moving coil approach is used, in which the magnets and yoke are held in place as the coil travels. The flux produced by the PMs and the sine wave current applied to the coil together provide the Lorentz force, which moves the vibration exciter.

3- Understanding the Physics of Electrodynamic Shaker Performance George Fox Lang and Dave Snyder, Data Physics Corporation, San Jose, California [3]

In this paper it was studied that the voltage/current capabilities of the power amplifier driving an electrodynamic shaker system, along with three kinds of vibration, have a significant impact on the performance envelope. The specified stroke (displacement) of the table, the moving mass and overall shaker mass, the thermal power limit of the coil, and the stress safety factor of the armature are further limiting variables. The small space between the inner and outer poles must be precisely centered for the armature. It must be restrained from all motions except axial motion, which must be permitted. A soft elastic suspension mechanism enables this. Between the load table and the shaker body in tiny shakers, a punctured compliant disc offers radially dispersed cantilevers. In bigger units, the armature is supported and centered by guide rollers, and the axial compliance is provided by separate elastomeric shear elements.

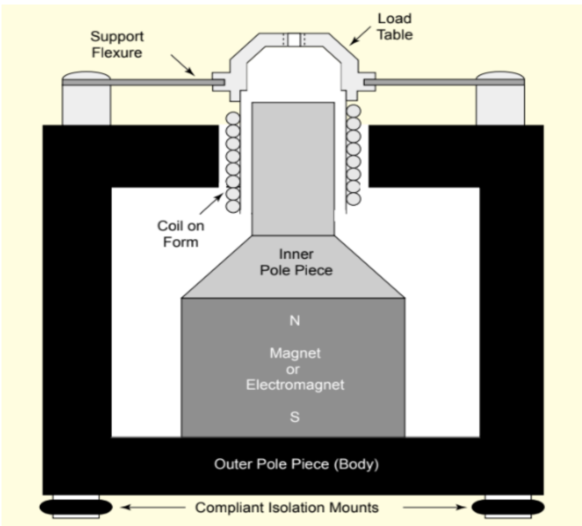


Figure 3 A simple electromagnetic shaker design

The electrical model of the shaker must consider the armature coil's resistance and inductance. The smallest impedance seen at the shaker input terminals is determined by the coil resistance R. Its resistance rises slightly with frequency (because to the skin effect) and rises significantly with temperature (the resistance of copper wire increases by around 40% each 100° C). The tight coupling between the coil and the iron of the pole pieces results in a large coil inductance L, which causes the complicated electrical impedance to rise with frequency.

4- Design of a Solenoid Actuator with a Magnetic Plunger for Miniaturized Segment Robots by Chang-Woo Song and Seung-Yop Lee [4]

This study describes the design of a solenoid actuator that can produce both rectilinear and rotating motions for a multi-segmented robot. The linear and rotating motions of the miniature robot are produced by the in-phase and out-of-phase actuations of a pair of solenoids that control each section. Based on the Biot-Savart law, a theoretical analysis of the actuation force by a solenoid with a magnetic plunger is put into practice. The coil and movable plunger make up the suggested solenoid. The plunger has the electromagnetic inductive coil twisted around it. Instead of the usual metal rods, a permanent magnet (PM) is employed as a plunger to produce a larger actuation force. As a result, the solenoid is subject to two different types of forces. One is the electromagnetic force created as electricity travels into wound coils inside the solenoid. The other is the magnetic force generated by a plunger with a permanent magnet.

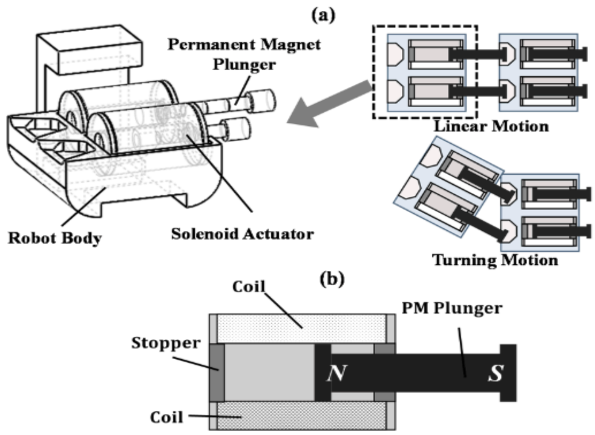


Figure 4 Permanent magnet plunger design

The electromagnetic force generated by the solenoid actuator is proportional to both the current flowing through the coil and the variation in the coil's inductance with respect to the movement of the PM plunger. The inner and outer diameters of the solenoid, the number of coils turns, the air gap, the length of the solenoid, input current, and the remanence of the permanent magnet are some of the design factors that affect solenoid force.

5- Linear electromagnetic actuator modeling for optimization of mechatronic and adaptronic systems by Oriol Gomis-Bellmunt, Samuel Galceran-Arellano, Antoni Sudria`-Andreu, Daniel Montesinos-Miracle, L. Flavio Campanile [5]

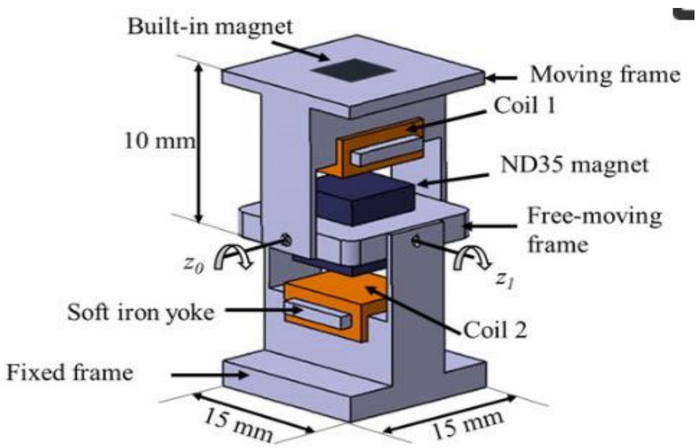


Figure 5 Basic structure of an electromagnetic actuator

In this paper the basics and the design considerations of electromagnetic actuators are discussed. There is a magnetic and electrical circuit in the electromechanical actuators. Because these circuits are linked together, the heat produced in the coils by the Joule effect must pass through a portion of the magnetic circuit. All of the actuator's parts are included in the heat transfer circuit, which is dependent on their individual geometries. Although several materials can be employed in both the electric and magnetic circuits, iron and copper are frequently mentioned while discussing the former. This work implies that the temperature is the factor that restricts the amount of force available, despite the fact that some magnetic (demagnetization, saturation, and magnetization hysteresis) and mechanical (friction and mechanical stress) effects are significant in electromagnetic actuators. Consequently, it is necessary to investigate the heat transfer phenomenon in order to maximize the force. Even though friction, eddy currents, and magnetic hysteresis can all result in losses, resistive losses are the most common in the functioning of the considered actuators, hence only those resistive losses are considered.

6- Research to study Variable Frequency Drive and its Energy Savings by Tamal Aditya [6]

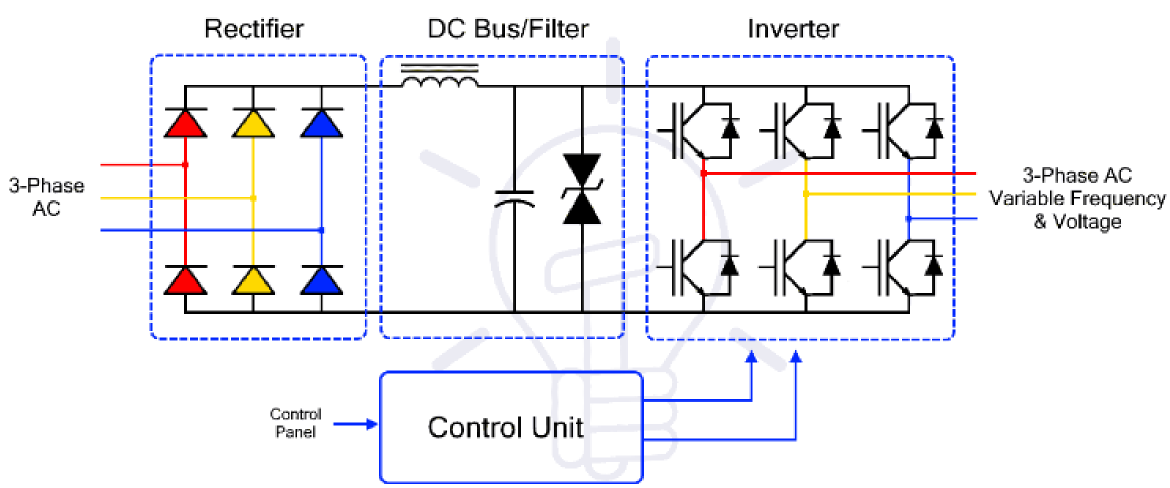


Figure 6 Structure of a Variable frequency drive

Variable Frequency Drives (VFD) change the speed of actuator of the electromagnetic shakers by changing voltage and frequency of the power supplied. In order to maintain proper power factor and reduce excessive heating of the shaker, the name plate volts/hertz ratio must be maintained. First, the supply voltage passes via a rectifier unit, which transforms it from an AC to a DC supply. Next, the three-phase supply is supplied through a three-phase full wave diode, which converts it from an AC to a DC supply. The harmonics produced during the AC to DC conversion are filtered out in the filter section of the DC bus. The inverter part of the last component, which includes six IGBT (Insulated Gate Bipolar Transistor), converts the filtered DC power into a quasi-sinusoidal wave of AC supply that is supplied to the attached induction motor.

7-An Overview of Neodymium Magnets over Normal Magnets for the Generation of Energy by Prof. Parag G Shewane, Abhishek Singh and Mayuri Gite [7]

Figure 7 Neodymium magnet

The most common type of rare-earth magnet is the neodymium magnet, also known as NdFeB, NIB, or Neo magnet. It is a permanent magnet manufactured from an alloy of neodymium, iron, and boron that has a tetragonal crystalline structure. Neodymium magnets are made of metal and, like the majority of metals, have a silver tint. Remanence (Br), which measures the strength of the magnetic field, coercivity (Hci), which measures the material's resistance to demagnetization, energy product (BHmax), which measures the density of magnetic energy, and Curie temperature (TC), which measures the temperature at which the material loses its magnetism, are some significant characteristics used to compare permanent magnets. Neodymium magnets are more powerful than other types of magnets in terms of remanence, coercivity, and energy output, although their Curie temperatures are frequently lower.

8- Pulse Width modulation using Arduino [8]

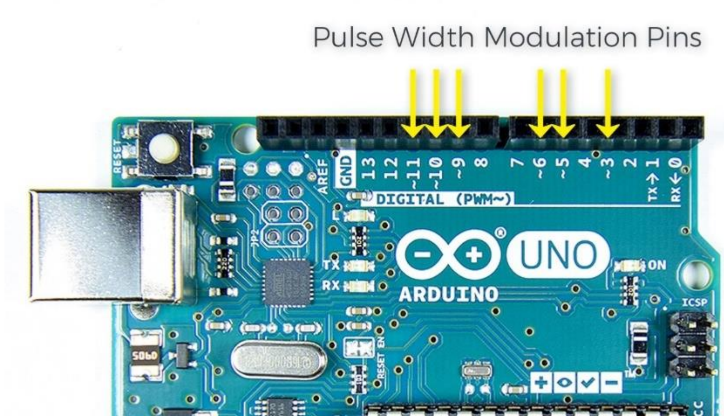


Figure 8 PWM pins on Arduino

By quickly turning the output voltage on and off, pulse width modulation (PWM) via Arduino is a technique used to regulate the average power given to a load. PWM signal generation is supported natively by the Arduino microcontroller board's hardware and software on certain of its digital pins. The following is a brief description of how PWM works with Arduino:

- PWM signals can be produced using specialized digital pins on Arduino boards, known as PWM pins. In addition to the pin number, these pins are marked with the symbol ~ 3, ~5, ~6, etc.).

- To produce the PWM signals, Arduino uses clocks and counters internally. These hardware elements are in charge of timing and managing the output voltage switching.
- Use the proper Arduino programming functions to create a PWM signal on a specified PWM pin. The most popular method is analogWrite(). The PWM pin number and the desired duty cycle are the two arguments that are required.
- The duty cycle is the proportion of the PWM signal's total duration that the signal spends in the "ON" state. It establishes the load's average power delivery. A duty cycle of 50%, for instance, denotes that the signal is "ON" for 50% of the time and "OFF" for the other 50%.
- The Arduino software generates a PWM signal on the selected PWM pin by using timers and counters when you use analogWrite() with the right arguments. A sequence of pulses are produced as a result of the microcontroller's quick switching of the output voltage between HIGH and LOW states.
- The duty cycle controls how wide each pulse is. The pulse width increases with duty cycle, while decreasing duty cycles results in smaller pulses. Based on the selected duty cycle, the microcontroller automatically modifies the pulse width.
- The settings of Arduino's internal timers and counters define the frequency of the PWM signal. For the majority of Arduino boards, 490 Hz is the default frequency.

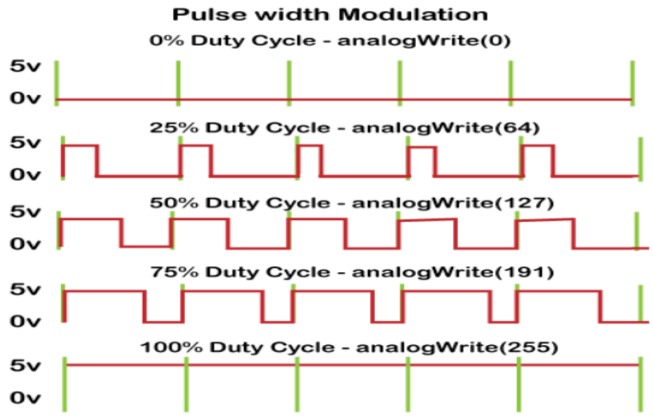


Figure 9 Pulse width modulation

The average power given to a load may be regulated using equipment such as an LED, motor, or any other device, by varying the duty cycle of the PWM signal created by Arduino. This makes it possible to use digital signals for a variety of purposes, such as regulating LED brightness, motor speed, and analog-like output control.

CHAPTER 3: METHODOLOGY

Permanent Magnet

For our project, we selected Neodymium N52 magnet. Neodymium is one the strongest magnetic materials. N52 is the highest grade of neodymium magnets. Using the strongest grade helped us to use the compact dimensions, giving our model an overall portable shape. A stack of 15 magnets were placed, as they were only available in smaller sizez.

Selection of suitable dimension and strength for the magnet was the start of our project. The magnet has following characteristics and dimensions

- Neodymium Grade = N52
- Magnetic Field Strength = 0.58 Tesla
- Magnet Diameter = 25 mm
- Magnet Thickness = 3 mm
- Number of magnets = 15

Figure 10 Cylindrical Block of N52 Magnet

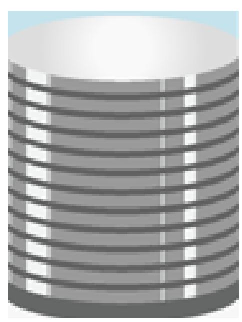


Figure 11 Stack of 15 N52 Neodymium Magnet

Coil

Copper coil is wrapped around aluminium plate in order to construct an electromagnet. Aluminum was chosen due to its non-ferromagnetic properties and so the aluminum plate did not cause electromagnetic interferences & helped avoid eddy currents. The coil was made from **22-gauge copper wire** with a total coil diameter of 32mm and was used in the form of two layers for a strong magnetic field.

Following are the characteristics of the copper wire

- Diameter = 0.642 mm
- Surface Area = 0.327 mm^2
- Resistance = 52.93 Ω/km

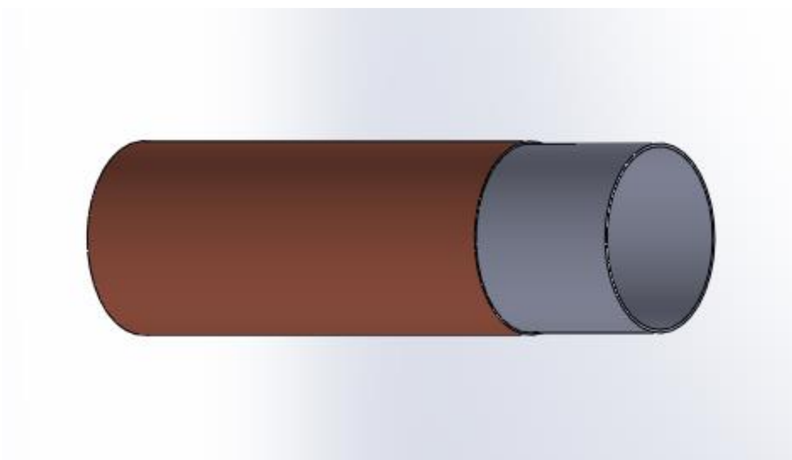


Figure 12 CAD Model of coil & aluminium plate

Construction of coil

The coil was made using copper wire.

- Firstly, the aluminum sheet is wrapped around the a wooden core, and rolled into shape
- The aluminium cylinder is is then gas welded shut into place
- After that, start wrapping the wire.
- As the first layer is finished, apply a thin layer of epoxy over the area to be wrapped around the wire. It will help for the proper adhesion of the wire in making coil
- Wrap the second layer of wire

Following are the characteristics and dimensions of the coil

- Diameter = 32 mm
- Length = 75 mm
- Resistance = 7.93 Ω
- Number of turns = 240
- Number of layers = 2

Figure 13 Coil

Why Aluminium

Aluminum is a lightweight metal when compared to many other metals, which makes it perfect for use in electromagnetic shaker construction. Aluminum's light weight makes it easier to handle, install, and transport the shaker system. Excellent electrical conductivity, a key component of electromagnetic shakers, characterizes aluminum. High electrical conductivity allows effective transfer of electrical energy and reduces power losses when the shaker's coil transmits electric current. Due to its excellent thermal conductivity, aluminum effectively dissipates heat produced during use. This characteristic aids in reducing overheating of the shaker's coil, preserving its functionality and dependability. The natural oxide coating that covers aluminum prevents corrosion and shields the shaker from elements like moisture and humidity.

Flexure Design

Flexure is a mechanical component used in an electromagnetic shaker system & plays an important role in acting as the suspension system for the armature of the shaker. It both supports and allows for a more controlled, linear movement in response to the electromagnetic forces generated by the coil and avoiding the inner walls of the magnetised body.

The flexure also serves as a mechanical isolator, in which it reduces the transmission of vibrations from the shaker to its surroundings & helps minimize any unwanted vibrations or noise that may interfere with the testing or may be unpleasant overall, & provides the necessary support, compliance, and linear isolation that is required for controlled vibrations & contributes to the shaker's overall performance & stability in applications such as vibration testing, research, or industrial processes.

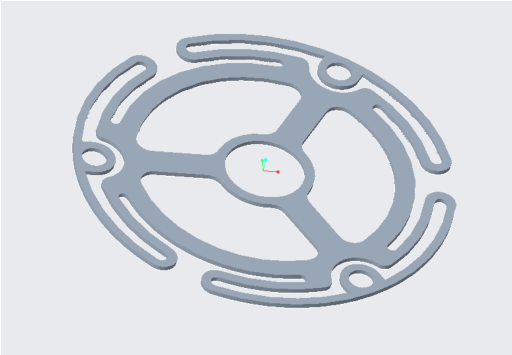


Figure 14 3D Model of Flexture 5

To summarize the fabrication, the flexure was performed by using laser cutting process on an 18-gauge sheet of aluminium (~1.02mm), via a DXF file of the 3D CAD Model of Flexure 5 that was fed into the software of the Laser Cutter.

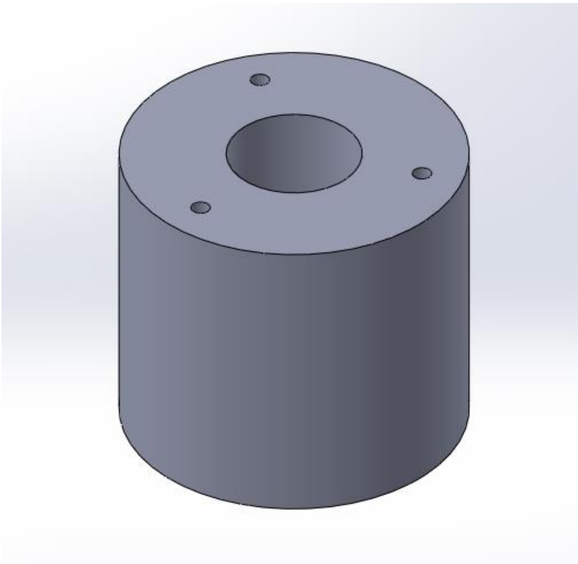
The flexures were fixed onto the body at the 3 nodes using spacers, or in this case 35mm, M5 bolts & nuts for the added feature of adjustable coil position. The centre of the flexure is clamped together with the 3D printed spring support with a locking mechanism.

Magnet Packing (Base Plate & Cover Plate)

The magnet was packed with a Mild Steel casing in order to keep its polarity strong. The polarity of the magnet decreases if there is air surrounding it and no other material.

The base plate acted as the base of the electromagnetic shaker and was screwed to cover plate, a plate to cover and support the electromagnetic shaker. The material for both plates was MS 1045 which is a ferromagnetic material. It was used to make the magnetic field of the magnets stronger. The material was a 90mm in diameter and 100mm in length rod which was cut it into two pieces for both plates. The base plate was 15mm in length and the cover plate was 80 mm in length.

After procurement and cutting of the rod, both plates needed drilling, tapping, and finishing. First the rod needed quenching to make it softer for machining, then a machining specialist did the required machining. The final parts are shown below:



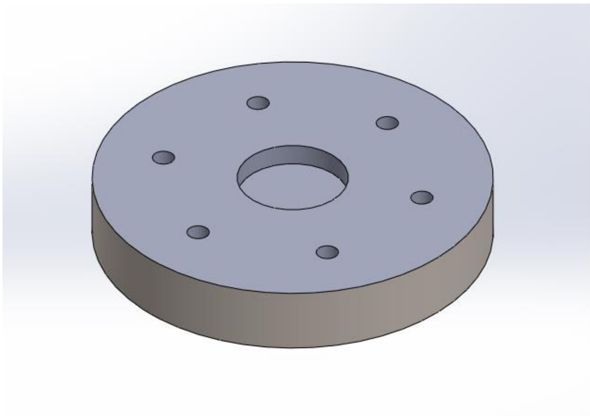


Figure 15 3D Model of Mild Steel Base Plate

Figure 16 3D Model of Mild Steel body

Flexure Supports

Two 3D printed parts were used to support the flexure and to connect the flexure and coil together.

The Material used for 3D printing was PLA. The parts are as shown:

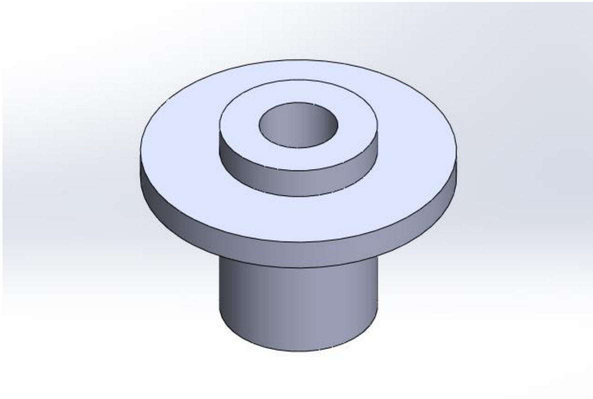


Figure 17 Flexure Support top

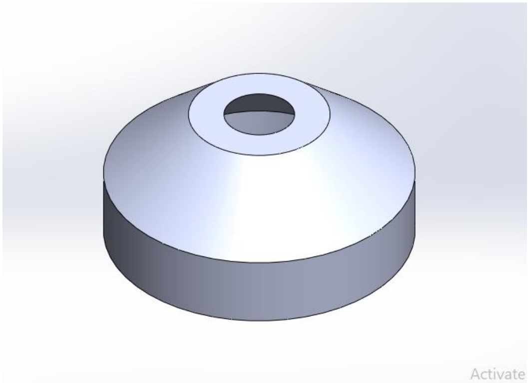


Figure 18 Flexure support bottom

Screws

The screws used for the whole project was M5 screws with different lengths. 6 L-screws of M5 x 25 were used to connect the base and cover plate. 3 hexbolts of M5 x 100 were used to connect the flexure with the cover plate to suspend the coil.

Initially hex-spacers were to be used, however due to both the lack of availability and lack of versatility of coil position adjustment, bolts were used instead.

Figure 19 M5 Hexabolts [9]

Control System

It includes an Arduino UNO, Arduino IDE and L298 Motor driver.

Arduino UNO and IDE

Figure 20 Arduino Uno 3 [10]

Arduino was used as an intermediary for controlling the vibration of the shaker. Arduino ide was used to code and Arduino uno was the device the code was uploaded to control the L298 motor driver for changing the frequency.

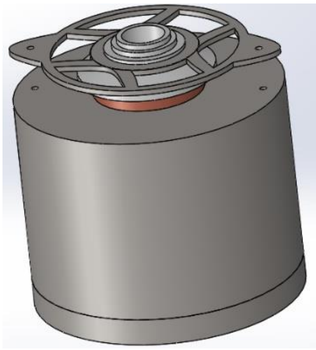
L298 motor driver module

L298 was used to control the power supply to the shaker and tune it to the desired frequency. The motor driver was powered by a 12V (~220V AC) power supply.

Figure 21 Motor Driver Module L298N H-Bridge

Design and Calculations

The design of the prototype started by considering the availability of the permanent magnet in the market and the rest of the components were designed in accordance with it.



- Length of the coil

  The coil length is taken to be 75 mm 0.075 m.

- Design of Flexure

  The flexure was designed by selecting a particular amplitude of vibration x i.e.,

$$x = 1.5\ mm \text{ or } 0.0015\ m$$
$$F = kx$$
$$F = 4000 \times 0.0015 = 6\ N$$

- Total force

  It includes the force required for achieving the amplitude against flexure and weight of armature 1.5 N:

$$\text{Final Force} = \text{Stiffness Force} + \text{Weight of armature}$$
$$\text{Final force} = 6 + 1.5 = 7.5\ N$$

- Required Force

  The required force is calculated as:

$$F = NILB$$
$$F = 240 \times 0.92 \times 0.075 \times 0.65 = 10.764\ N$$

Force on testing material

The force on testing material is calculated as:

$$\text{Force on testing material} = 10.764 - 7.5 = 3.264\ N$$

Final Assembly

First the stack of N52 magnets were placed in the middle of base plate, and the base plate was connected to the cover plate via the 6 hex-bolts at the bottom.

Then the flexure and flexure supports were attached to the coil, & the armature was then connected to the rest of the body, ensuring the spacing of all 3 nodes of the flexures were equidistant.

The wires poking out of the coil are then attached to the control system and the shaker is assembled.

Figure 22 Assembled Electromagnetic Shaker

CHAPTER 4: LIMITATIONS

As many advantages as the electromagnetic shaker boasts, it also comes with a lot limitations. These listed below are some of the major limitations:

Frequency range

The frequency range in which electromagnetic shakers can function successfully is constrained. The current electromagnetic shaker can only achieve upto 50Hz. Any higher, the performance of the shaker would decrease, and even cause permanent damage to the system. The design of the shaker, the weight of the test payload, and the available power supply are some factors that affect the maximum achievable frequency.

Amplitude

The electromagnetic shaker is only capable of a certain amount of displacement (1.5mm), exceeding these limitations while still ensuring the same level of performance is almost impossible for its size and capability.

Maximum power rating

Even though more efficient than conventional shakers, electromagnetic shakers require a large amount of power to operate, and hence limit the use time as power consumption is costly.

L298N H-Bridge Motor Driver Module

The L298N motor driver module displays a big limitation on both the power & current rating, as well as slow heat dissipation, leading to the module burning up after consecutive usage.

Flexure stiffness

The right design of flexure is needed to act as a uniform spring, however more stiffness would cause the maximum amplitude to decrease, and lower stifness would cause uncontrollable non linear motion, leading to damage to the shaker.

Hysteresis

Hysteresis in an electromagnetic shaker refers to the phenomenon where the displacement or movement of the shaker lags behind changes in the input current. This lag is caused by the magnetic hysteresis in the shaker's core material.

When current is applied to the electromagnetic shaker, the magnetic field in the core of the shaker magnetizes and demagnetizes repeatedly. However, due to hysteresis, magnetization does not immediately follow the changes in the applied current. Instead, there is a delay or lag in the magnetization and demagnetization processes.

This hysteresis effect results in a delay between the input current and the resulting displacement or movement of the shaker. The extent of hysteresis depends on the properties of the core material, such as its magnetic permeability and coercivity.

CHAPTER 5: RESULTS AND DISCUSSIONS

Results

We designed and analyzed a moving coil electromagnetic shaker using CAD modeling and finite element analysis (FEA). The shaker was designed to meet the specifications of maximum force of 49.6N and maximum displacement of 3mm.

CAD Model

The shaker was designed using SolidWorks software. The mechanical structure of the shaker consists of a base plate, a moving coil, a magnetic core, and an armature. The base and armature were designed to provide a rigid platform for the shaker, while the moving coil and magnetic core were designed to generate the electromagnetic force required for the shaker's operation.

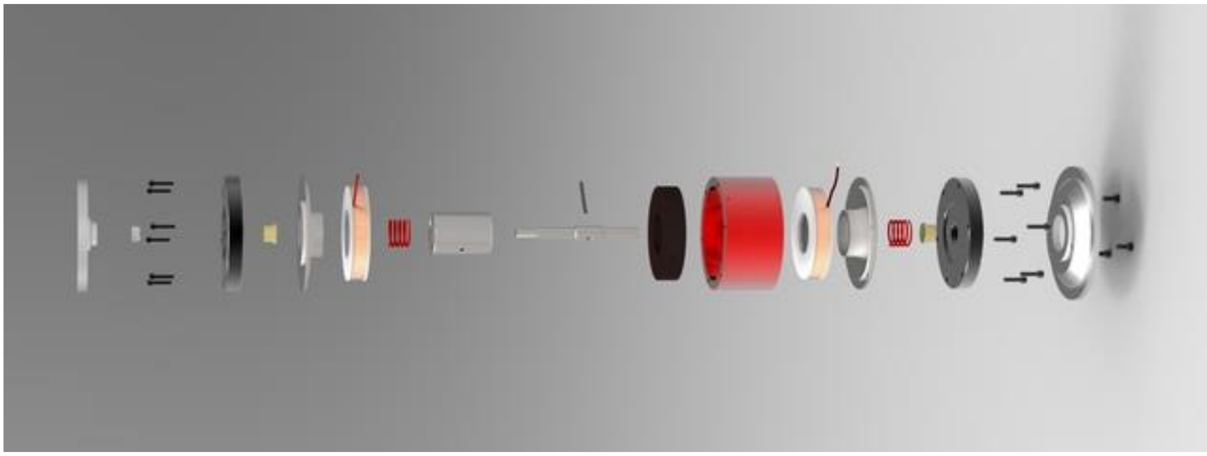


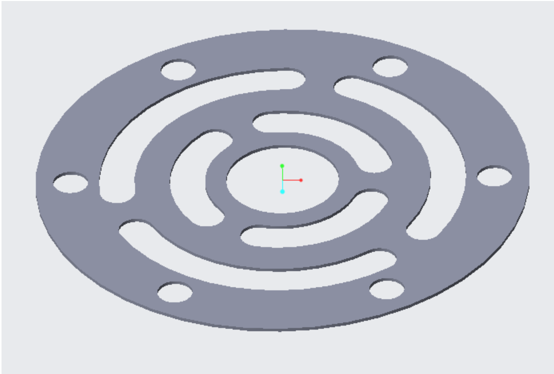
Figure 23 3D CAD Expanded view of model of shaker

FEA Analysis

The FEA analysis was performed using COMSOL software to simulate the shaker's behavior under different operating conditions. The analysis included a static analysis to evaluate the shaker's performance under different loads. The static analysis showed that the shaker could generate a force of 49.6N at a maximum displacement of 3mm. The analysis was mainly on flexure as all the load is being applied to the flexure, it is essential to analyze its behavior to ensure that it can withstand the load and maintain its functionality.

The flexures information is available in APPENDIX I: Table of Flexure

Flexure 1



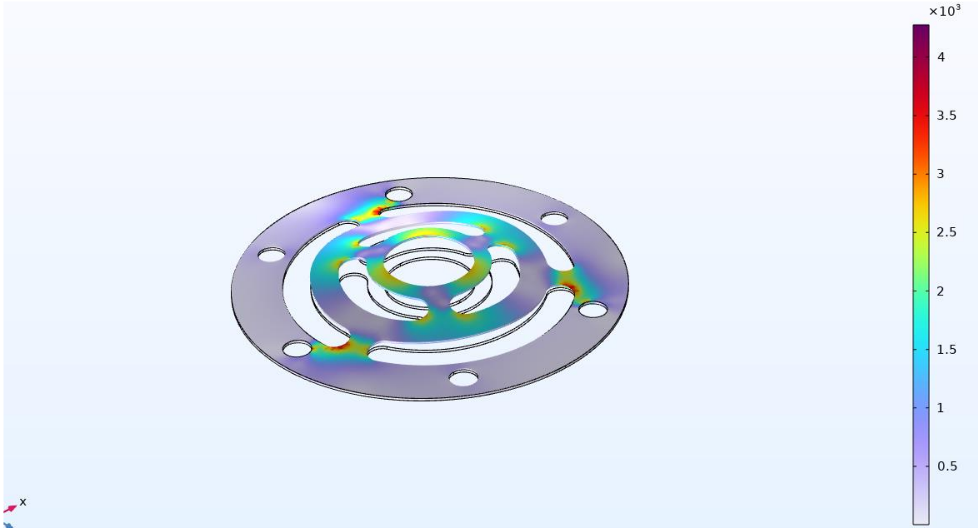


Figure 24 Flexure 1 Stress Analysis

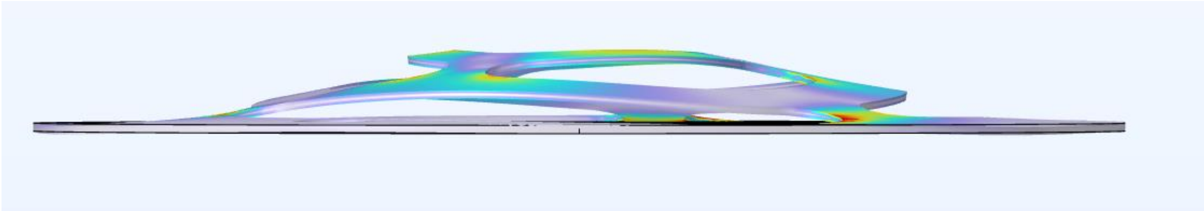
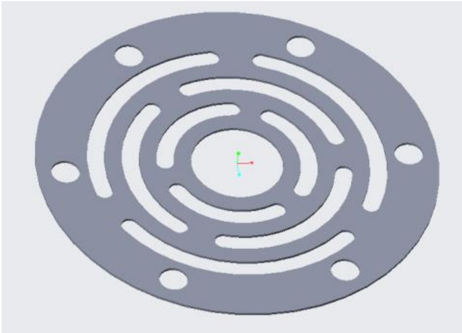


Figure 25 Side View Stress Analysis

Flexure 2



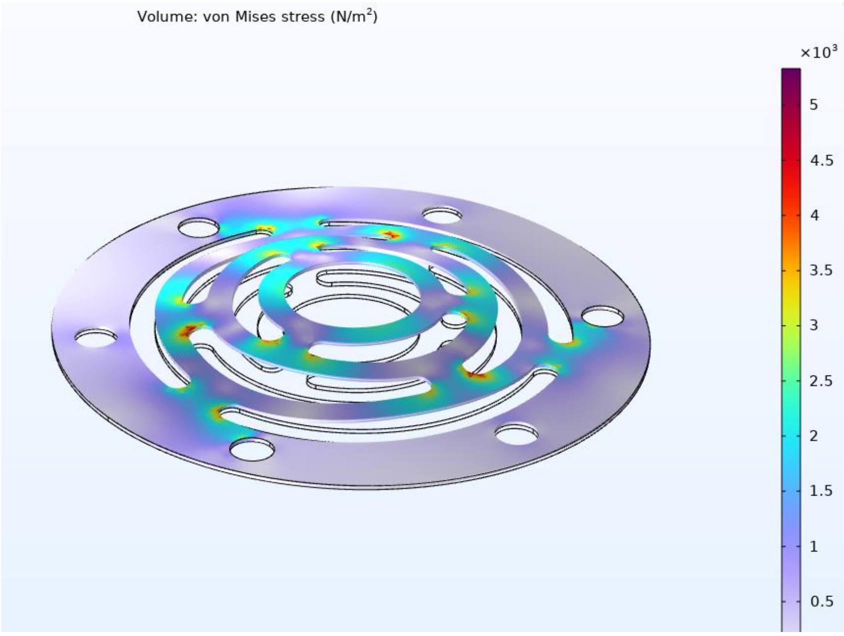


Figure 26 Flex 2 Stress

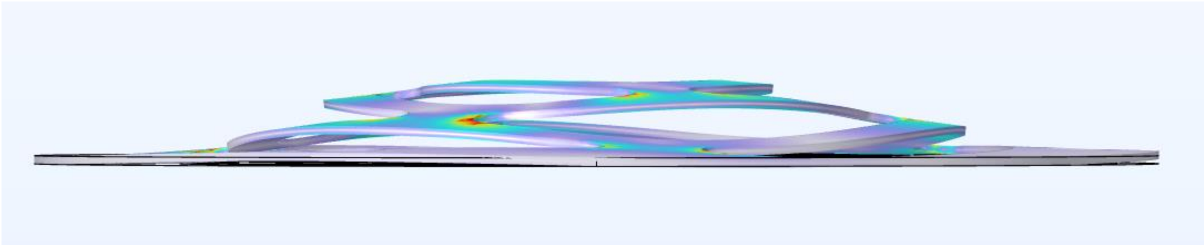
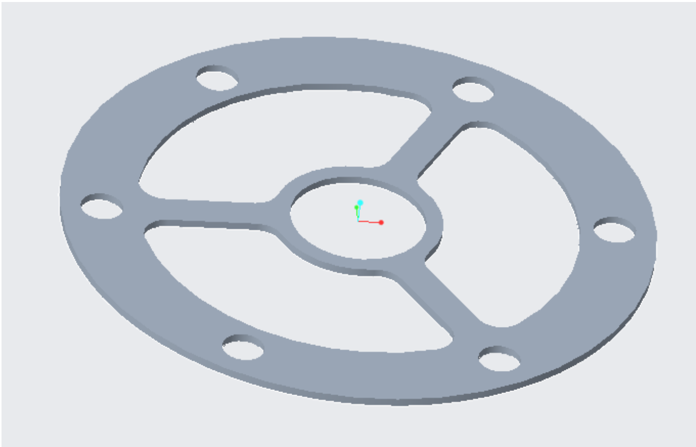


Figure 27 Flex 2 Side View

Flexure 3



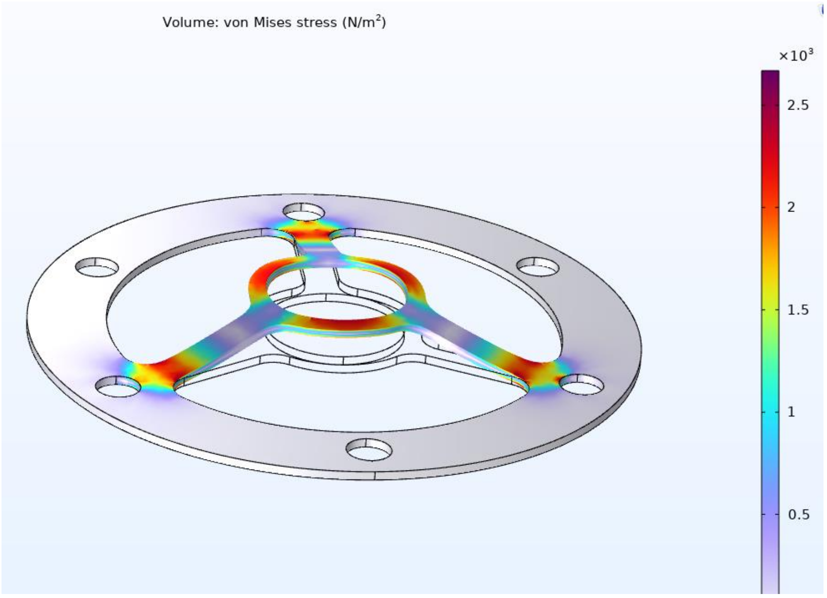


Figure 28 Flex 3 Stress

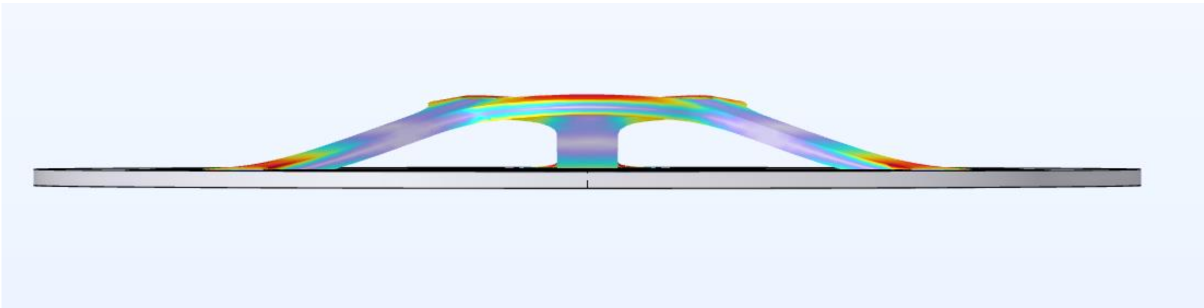
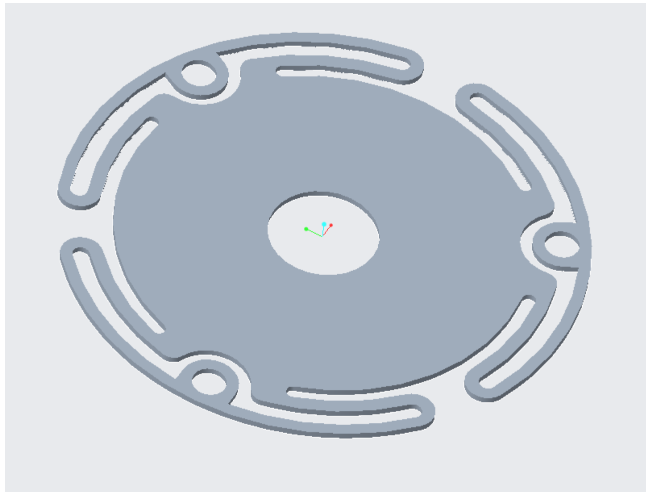


Figure 29 Flex 3 Side view

Flexure 4



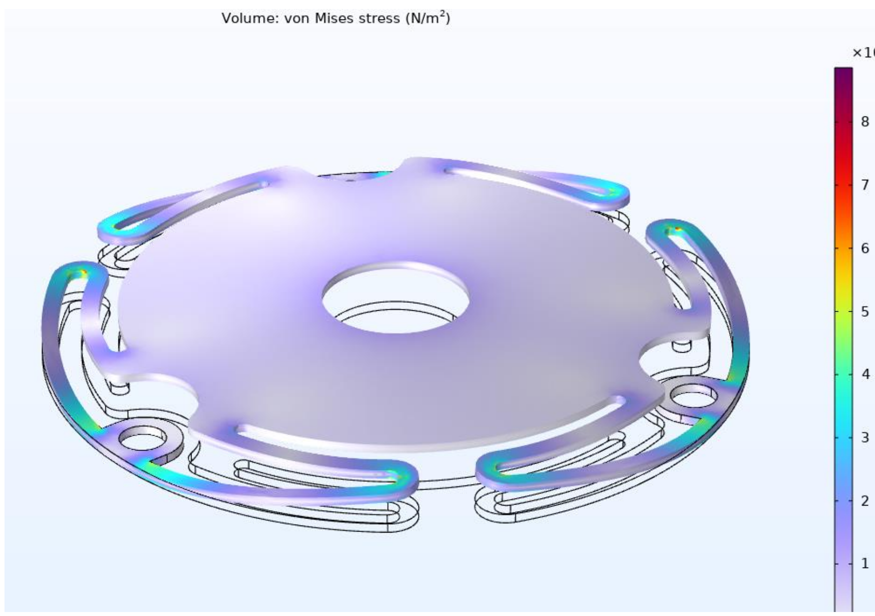


Figure 30 Flex 4 Stress

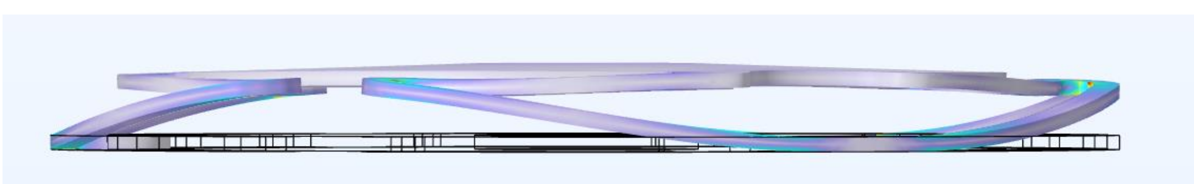
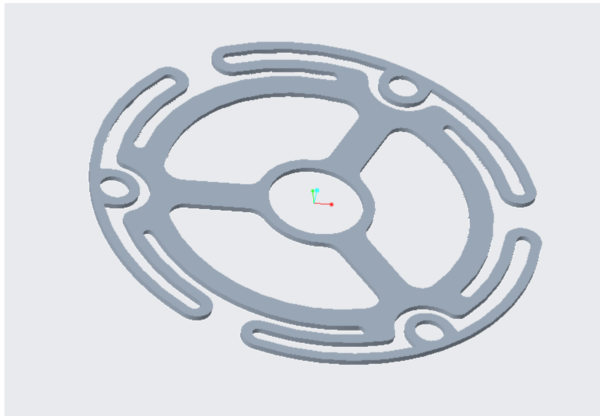


Figure 31 Flex 4 Side View

Flexure 5



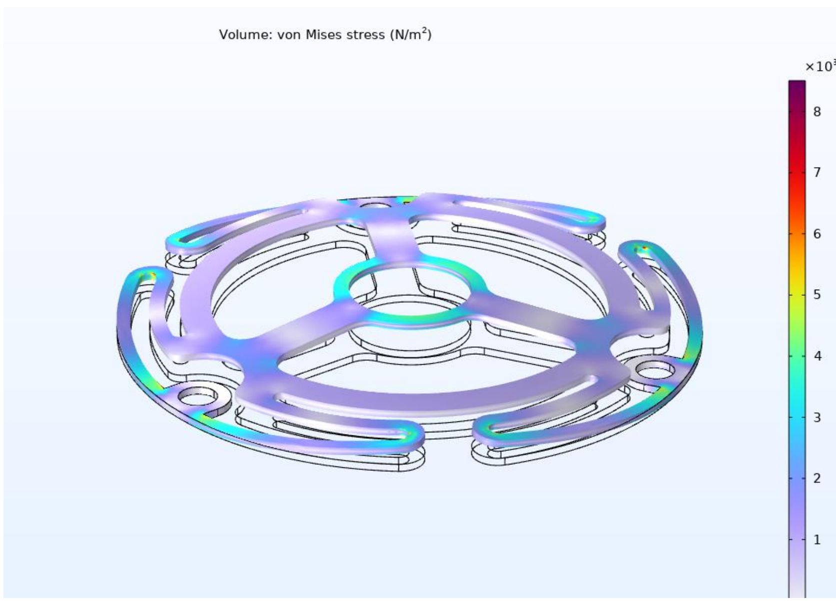


Figure 32 Flex 5 Stress Analysis

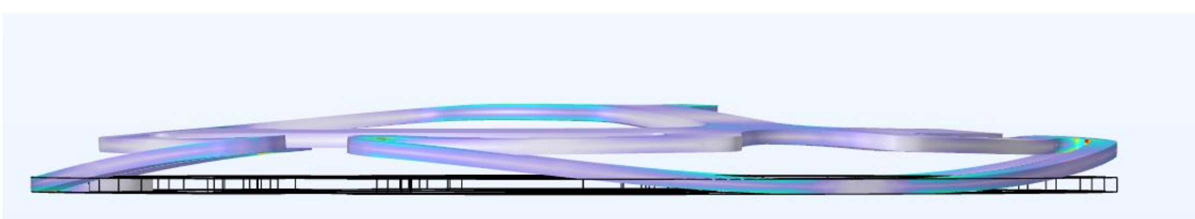


Figure 33 Flex 5 Side View

The analysis showed that the flexure's deformation under load was within the acceptable limits. Several designs of the flexure (spring component) were fabricated using 3D CAD software, and through the process of elimination, these 5 listed above were considered to perform analysis on.

Overall, the CAD design and FEA analysis showed that the moving coil electromagnetic shaker met the required specifications and could generate the desired force and displacement for vibration testing. The shaker's deformation under load was within acceptable limits, indicating that the shaker would be safe and reliable during operation.

Discussion

When comparing our shaker with the shakers available in the market, there are various factors to consider, such as the design, functionality, features, and cost. One of the limitations of our shaker is that it has a relatively small range of frequency of 2-45Hz compared to other shakers of 2-3000Hz available in the market. The frequency range of a shaker determines the range of vibrations it can produce, and it is an essential factor in many vibration testing applications. While our shaker may be suitable for some specific applications, it may not be suitable for applications that require a broader range of frequencies.

For the flexure, Flexure 7-2 was selected as it meets the minimum requirement for amplitude, forces and life cycle for flexure. The complex geometry of the flexure serves its purpose, at even the highest stress points, it was evenly distributed, causing the maximum amplitude to be achieved without causing any concerning structural damage to the flexure, ensuring a decent life cycle of the flexure.

The fabrication of this flexure (to summarise) was performed by using laser cutting process on an 18-gauge sheet of aluminium (~1.02mm), and the flexures were fixed onto the body at the 3 nodes using spacers, or in this case 35mm, M5 bolts & nuts for the added feature of adjustable coil position. The centre of the flexure is clamped together with the 3D printed spring support with a locking mechanism.

However, the advantage of our shaker is that it is custom-designed and tailored to our specific requirements such as maximum loading is 2Kg with the maximum displacement of 3mm. Custom-designed shakers can offer unique features and capabilities that off-the-shelf shakers may not be able to provide. Additionally, our shaker's performance can be optimized using simulation and analysis tools, such as FEA software, to ensure that it meets the desired specifications.

CHAPTER 6: CONCLUSION & FUTURE RECOMMENDATIONS

Conclusion

The electromagnetic shaker is a strong and adaptable tool that has been used extensively in a wide range of industries. It is an effective, wide used instrument in disciplines including materials testing, product development, and research-based analysis due to its capability to produce linear controlled vibrations and oscillations.

The shaker operates via the principles of electromagnetism by using an electromagnetic coil and a permanent magnet to produce a magnetic force field that causes motion in the connected armature. With the help of the control system, by applying a pulse with the input frequency, the motion results in oscillations or vibrations giving rise to vibrations that can be precisely controlled.

Comparing the electromagnetic shaker to other vibration testing modules such as pneumatic & mechanical shaker, it dominates in being both more efficient, hence producing much less energy waste in the form of heat, as well as being much quieter leading to a less noisy work environment. It can also be used to evaluate a variety of manufactured materials & components such as electronics, PCBs, Sensors, & even used for vibration calibration such as with the accelerometer of automotive vehicles due to its ability to generate a wide range of frequencies and amplitudes. The shaker's precise control offer reliable testing results, especially aiding in processes for quality assurance and product development.

In conclusion, the electromagnetic shaker offers versatile vibration testing through its varying frequency, and hence is essential in quality assurance in the industry. We further anticipate more advancements and improvements in electromagnetic shaker designs as technology constantly evolves, broadening its uses and widening its capabilities, as well as increasing its overall availability within local markets.

A Limitation of the shaker is that it is still a work in progress and may not be fully optimized. Shakers available in the market have typically undergone extensive research and development, resulting in optimized designs that meet specific requirements. In contrast, our shaker is still in the development phase, and it may require further refinement to improve its performance, functionality, and reliability.

Future Recommendations

Though the technology for the electromagnetic shaker is still changing and improving, several additional features could be introduced along with the shaker to offer more versatility. Due to the size complications with the force produced, more research could be done to reduce both size and weight of the entire shaker while still producing the same results.

Another recommendation would be to produce variants of the shaker, fabricating small scale for lab purposes, large scale for larger geometries such as aerospace or car parts, and a mid-sized one as well for anything in between.

Increase in frequency range is a must, despite exceeding the goal of 10Hz, this current shaker was only capable of reaching 50Hz and hence with more research, especially into the control system, it could lead to even higher frequencies without breakdown or structural failure.

Further optimization of the control system could be done with the help of Artificial Intelligence to completely optimize the shakers capabilities and achieve higher frequencies and efficiencies.

Some more extra options could include introducing a range of additional testing platforms, such varying in size, geometry (curved, clamps, etc) and the ability to add several layers. Other features may also be developed which includes changing amplitude, random vibration feature and even the ability to have presets for vibration conditions like cars, aerospace, earthquake, etc.

REFERENCES

1. Roman Vinokur, Westlake Village, California

   "Helpful Guidelines for Single-Axis Shaker Testing"

2. Je-Hoon Kim, Jin-Ho Kim, Sang-Hyun Jeong, and Bang-Woo Han

   "Design and Experiment of an Electromagnetic Vibration Exciter for the Rapping of an Electrostatic Precipitator"

3. George Fox Lang and Dave Snyder, Data Physics Corporation, San Jose, California

   "Understanding the Physics of Electrodynamic Shaker Performance"

4. Chang-Woo Song and Seung-Yop Lee

   "Design of a Solenoid Actuator with a Magnetic Plunger for Miniaturized Segment Robots"

5. Oriol Gomis-Bellmunt, Samuel Galceran-Arellano, Antoni Sudria`-Andreu, Daniel Montesinos-Miracle, L. Flavio Campanile

   "Linear electromagnetic actuator modeling for optimization of mechatronic and adaptronic systems"

6. Tamal Aditya "Research to study Variable Frequency Drive and its Energy Savings"

7. Prof. Parag G Shewane, Abhishek Singh and Mayuri Gite

   "An Overview of Neodymium Magnets over Normal Magnets for the Generation of Energy"

8. Pulse Width modulation using Arduino Reference Image: https://www.circuitbasics.com/how-to-use-pulse-width-modulation-on-the-arduino/

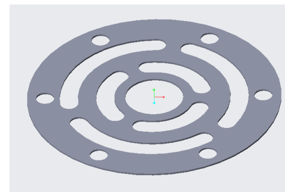
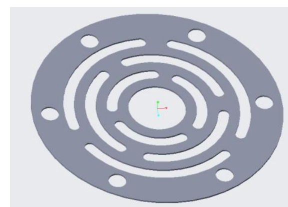
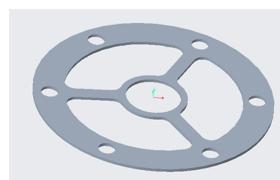
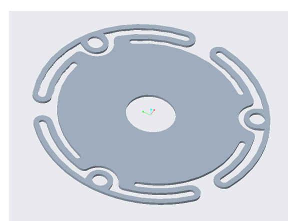
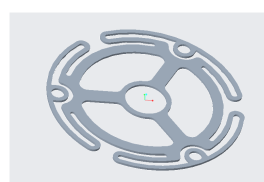
9. Reference Image:

a. Plain Stainless Steel M5 Hexabolts https://sg.rs-online.com/web/p/hex-bolts/0520093

b. Image Reference: Arduino Uno R3 https://electrobes.com/product/arduino-uno-r3/

c. Image Reference: L298N HBridge Motor Driver Module for Arduino https://electrobes.com/product/l298n-h-bridge-motor-driver-module/

APPENDIX I: TABLE OF FLEXURES

Flexure Name	**Material**	**Image**
Flex 1	Stainless Steel	
Flex 2	Stainless Steel	
Flexure 3	Stainless Steel	
Flexure 4	Aluminium	
Flexure 5	Aluminium	

APPENDIX II: ARDUINO CODE FOR CONTROL SYSTEM

```
// Code for Control System
int enA = 3;
int in1 = 4;
int in2 = 5;

int frequency = 50;

void setup() {
  pinMode(enA, OUTPUT);
  pinMode(in1, OUTPUT);
  pinMode(in2, OUTPUT);
  digitalWrite(in1, LOW);
  digitalWrite(in2, LOW);
}


void loop() {
  speedControl();
  delay(500/frequency);
}


void speedControl() {
  digitalWrite(in1, LOW);
  digitalWrite(in2, HIGH);
  for (int i = 0; i < 251; i++) {
    analogWrite(enA, i);
    delay(2/frequency);
  }
  digitalWrite(in1, LOW);
  digitalWrite(in2, LOW);
}
```

APPENDIX III: PARAMETERS

PARAMETER	VALUE
Power Rating	19.2 W
Frequency	1-49Hz
Maximum Displacement	1.5 mm
Current	1.6Amp
Voltage	12V
Coil Diameter	32mm
Coil Length	75mm
Coil Turns	240 (2 layers)
Power Supply Rating	12V, 4Amps

APPENDIX IV: USER MANUAL

- Upload the code to Arduino using the Arduino IDE.
- The code controls the frequency of the vibrations. For a different frequency, set the desired value of frequency in the code and then upload it again
- Set the connections of microcontroller, coil and Arduino correctly and shaker should start working.