Design and development of an exciter or shaker

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by

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<u>CERTIFICATE</u>

*This is to certify that the work contained in this project report entitled "**Design and development of an exciter or shaker**" is a bonafide work of **Pridhvin P** (**Roll No. 200103087**) and **Muhammed Salim** (**Roll No. 200103080**), carried out in the Department of Mechanical Engineering, Indian Institute of Technology Guwahati under my supervision and that it has not been submitted elsewhere for a degree.*

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Abstract

This paper presents the design and development of an electrodynamic shaker The design process involves defining the specifications, selecting the magnetic circuit, designing the coil, choosing the vibration plate,optimizing the design,developing a control for the exciter and finalizing the design. The electrodynamic exciter should meet the requirements of the application, including frequency range, acceleration levels, displacement, and input voltage. The magnetic circuit, coil and vibration plate should be carefully designed to provide high magnetic flux density, conductivity, and stiffness, respectively. The final design should be tested to ensure that it meets all the specifications and requirements.

Declaration

We declare that this written submission represents our ideas in our own words and where other's ideas or words have been included, we have adequately cited and referenced the original sources. We also declare that we have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in our submission. We understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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Chapter 1

Introduction

This report focuses on the "Design and Development of an Exciter or Shaker," a vital element in vibrational testing for structural analysis. Vibrations are key to assessing the performance of structures like aerospace components and automotive systems. Our project aims to intricately explore and develop a high-performance exciter by merging theoretical principles with practical considerations. Emphasizing factors such as frequency range, amplitude, and precision control, we integrate innovative materials and advanced control systems to optimize the exciter's efficiency. Through this report, we aim to contribute valuable insights to the field of mechanical engineering, advancing vibrational testing technologies.

1.1 What is shaker?

A shaker or an exciter is a mechanical device designed to generate controlled vibrations in structures, components, or materials for various purposes such as durability testing, modal analysis, and seismic studies. Shakers play a crucial role in simulating real-world conditions to assess the resilience and performance of structures. There are different types of shakers, each tailored for specific applications.Electrodynamic shakers, for instance, employ electromagnetic principles to generate controlled vibrations, making them versatile and widely used in laboratory settings. Hydraulic shakers utilize hydraulic force for generating vibrations and are often employed in large-scale testing environments. Shakers serve as indispensable tools in engineering and research, providing valuable insights into the dynamic behavior and durability of materials and structures.

1.2 Types of shaker

1.2.1 Electrodynamic Shaker

Electrodynamic shakers utilize electromagnetic principles to generate controlled vibrations. They consist of a coil and a magnet system that produces forces proportional to the electrical current flowing through the coil.Electrodynamic shaker is Widely employed in vibration testing for automotive, aerospace, and electronics industries. Ideal for modal analysis, durability testing, and simulation of real-world conditions due to their versatility and ability to cover a broad frequency range.

1.2.2 Hydraulic Shaker

Hydraulic shakers use hydraulic force to induce vibrations. They typically involve a hydraulic actuator that moves a piston to generate controlled oscillations.Hydraulic shaker is Commonly used for larger-scale testing, such as earthquake simulation and testing of structures like bridges and buildings.Hydraulic shakers are known for their high force capabilities, making them suitable for applications requiring substantial power.

1.2.3 Direct Drive Shaker

Direct drive shakers eliminate the need for a separate armature and electromagnetic field by directly attaching the payload to the moving coil, resulting in a simpler design.Drive shaker is Ideal for applications demanding high-force output and rapid frequency changes. Commonly utilized in applications requiring precise control, such as aerospace and defense testing, where accuracy and responsiveness are crucial for reliable results.

1.3 Electrodynamic shaker

The electrodynamics shaker functions to deliver a force proportional to the current applied to its voice coil. These devices are used in such diverse activities as product evaluation, stress screening, squeak-and-rattle testing and modal analysis. These shakers may be driven by sinusoidal, random or transient signals based upon the application. They are invariably driven by an audio-frequency power amplifier and may be used “open loop” (as in most modal testing) or under closed-loop control where the input to the driving amplifier is servo-controlled to achieve a desired motion level in the article under test.The magnetic circuit is made from soft iron which also forms the body of the vibration machine.The body is magnetically energized, usually by field coils as shown in Figure 1.1

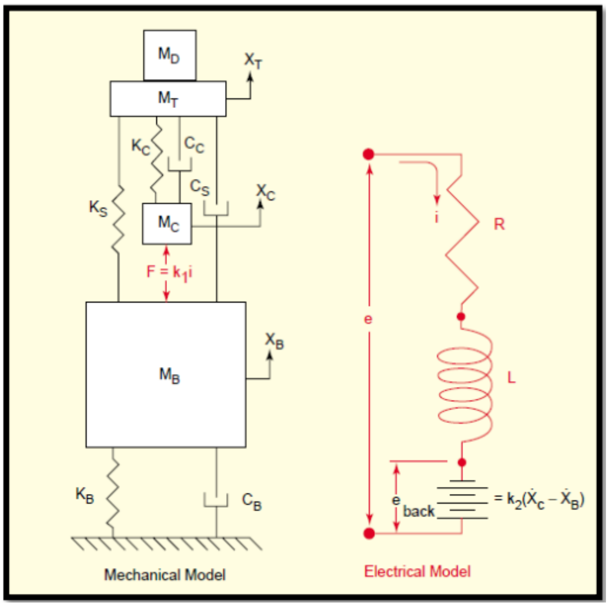


Figure 1.1: Mechanical and Electrical model taken from [1]

1.4 Literature Review

1.4.1 Summary

Combining [1] and [2] provides a complete overview of electrodynamic shakers. [1] focuses on designing these exciters, explaining how they work by emphasizing the role of the magnetic circuit in creating strong magnetic fields. It also presents detailed mechanical and electrical models, including parameters like armature coil resistance and inductance, and provides solutions to system equations that relate mass motions, driving voltage, and applied current. This literature is praised for its clear explanations and diagrams, making it highly valuable for engineers and researchers interested in electrodynamic exciter development.

[2] complements this by explaining how to model electrodynamic shakers using lumped parameter techniques. It simplifies the shaker system into mechanical and electrical components and demonstrates practical modeling through experiments using sensors to isolate different shaker movements. These experiments aid in accurately estimating parameters, allowing for the creation of virtual shaker models like the BK4809. The article is well-organized and accessible, serving as an excellent resource for understanding shaker modeling techniques and experimental approaches for parameter estimation. Together, these sources offer a thorough understanding of electrodynamic shakers, from design principles to practical modeling applications, essential for those working in vibration testing and exciter development. The literature review encompasses two papers focused on the development and implementation of advanced acceleration controllers for electrodynamic shakers powered by switching-mode

AC power sources (ACPS) to enhance vibration testing applications.

[3] addresses the need for efficient alternatives to traditional linear audio power supplies for electrodynamic shakers. It introduces a sophisticated acceleration control scheme utilizing a high-performance current-controlled PWM inverter. This control system integrates feedback, feedforward, and robust control techniques to achieve accurate waveform tracking and amplitude regulation, effectively mitigating harmonic vibrations caused by switching-mode power. Theoretical foundations, practical implementation details, and experimental results demonstrate the effectiveness of the proposed approach in improving current and acceleration control characteristics across varying load conditions and frequencies.

[4] presents a comprehensive digital acceleration controller for sinusoidal vibration tests using ACPS-fed electrodynamic vibration machines. It highlights the limitations of conventional AC linear power supplies and advocates for the advantages of switching-mode inverters in terms of efficiency and size reduction. The proposed control methodology incorporates robust model reference adaptive algorithms (RMRAC) within the voltage control loop to address parameter variations, harmonic vibrations, and resonances. Advanced control strategies enhance acceleration feedback control to minimize undesired effects on vibration performance. Detailed system architecture, dynamic modeling, and experimental results validate the system's effectiveness in achieving accurate acceleration tracking and robust closed-loop control within specific frequency ranges.

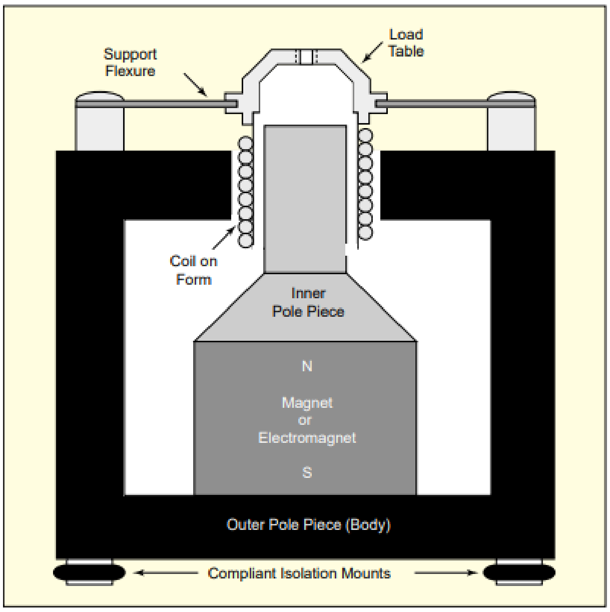


Figure 1.2: An image of an electrodynamic shaker taken from [1]

1.4.2 Key areas for further research

A critical area for future investigation involves integrating design considerations with advanced modeling techniques to enhance our understanding of electrodynamic shaker behavior under diverse operational conditions. [1] primarily focuses on design aspect of these exciters, while [2] emphasizes modeling using lumped parameter techniques. Bridging these areas could provide valuable insights into optimizing shaker performance and efficiency.

Additionally, there is a need for more extensive experimental validation of specific design choices discussed in the literature. Detailed experimental testing would validate these design decisions and contribute to improving the practical implementation of design principles in electrodynamic shaker development.

Furthermore, exploring the robustness and generalizability of lumped parameter models across various shaker types and operational scenarios is essential. While [2] discusses parameter estimation for a specific shaker model, future research should focus on evaluating the reliability and applicability of these models in broader contexts. This investigation would contribute to advancing the effectiveness and versatility of shaker system modeling techniques.

The reviewed literature highlights specific areas that present opportunities for further research and development in the field of vibration testing control systems. Firstly, both papers concentrate on controlling vibration within defined frequency ranges (e.g., 5 Hz to 2 kHz and 20 Hz to 200 Hz). However, there is a notable gap in exploring the performance and adaptability of the proposed controllers at higher frequencies, specifically up to 2000 Hz, which is crucial for expanding the applicability of these systems across a broader range of vibration testing applications. Secondly, while the second paper introduces adaptive control strategies like RMRAC, additional investigation is warranted to evaluate the scalability and robustness of these strategies under diverse operating conditions and varying dynamic loads. Lastly, insights into practical implementation challenges, such as system scalability, real-time implementation constraints, and seamless integration with existing industrial setups, are essential for enhancing the feasibility and practical deployment of these advanced control systems in industrial settings. Addressing these gaps will contribute to advancing the effectiveness, versatility, and real-world applicability of vibration testing control technologies.

This method enables the extraction of parameters of the shaker despite high damping, low mass coupling, and strong attenuation.The literature provides detailed descriptions of the experimental setup and the two methods used to determine the mechanical parameters of the shaker.The results obtained from both methods are presented and discussed in detail.The synthesized body response is found to correctly reproduce the body response, while the table synthesized curve does not match the measured impact.The blocking structure method is found to be an alternative method that can be used to extract the parameters of the shaker

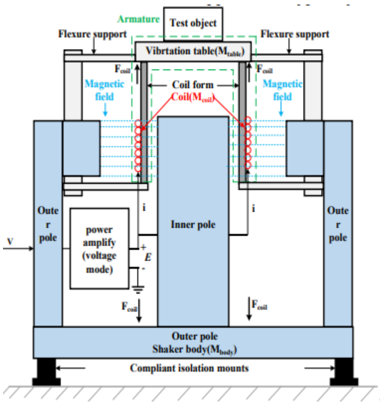


Figure 1.3: An image of an electrodynamic shaker taken from [2]

despite high damping,low mass coupling, and strong attenuation.Overall, the literature provides a thorough explanation of the experimental setup, methods, and results.The figures and tables are clear and informative, aiding in the understanding of the material presented.

1.5 Motivation

The motivation behind choosing the "Design and Development of an Exciter or Shaker" for my BTP project stems from a genuine passion for advancing mechanical engineering. Vibrational testing is foundational for structural analysis in various industries, and the exciter is a key player in this domain. This project presents a unique opportunity to apply theoretical knowledge to real-world challenges, aligning with my academic interests and offering a chance to contribute tangibly to vibrational testing methodologies. I am driven by the potential impact on structural dynamics understanding and the opportunity to explore innovative materials and cutting-edge control systems. This BTP signifies the convergence of academic curiosity, practical application, and the aspiration to contribute meaningfully to mechanical engineering's future.

1.6 Objective

The primary objective of the "Design and Development of an Exciter or Shaker" BTP project is to conceive, design, and prototype a high-performance vibrational exciter for structural analysis. Key goals include formulating a comprehensive design plan, creating a functional prototype with advanced materials and control systems, evaluating performance under varied conditions, contributing insights to mechanical engineering knowledge, and demonstrating practical applications in vibrational testing. This project aims to advance understanding in exciter design and make a substantial impact on structural analysis methodologies.

1.7 Arrangment of the report

This first chapter provides an overview of the subject matter, introducing the concept of a shaker and its various types, including electrodynamic, hydraulic, and direct drive shakers. Additionally, it outlines the motivation behind the research, presents the objectives, and discusses the arrangement of the report.

In second chapter, the model used in the study is described, along with the methodology employed. This includes the derivation of the equation of motion, literature review, experimental setup, parameter determination, force analysis, equation conversion, ODE solving with MATLAB, input signal exploration, and analysis and interpretation of results.

Third chapter focuses on the control system of the shaker, detailing the control algorithm, its functioning, acceleration regulation loop, ACPS output voltage control loop, measurement and feedback mechanisms, execution on a PC-compatible platform, and the use of a PID controller. Additionally, it presents a Simulink model and discusses the electrical components involved, along with results and outputs, and concludes with key findings.

Each chapter delves into specific aspects of the research, providing a comprehensive understanding of the study's methodology, findings, and conclusions..

Chapter 2

Model and Methodology

After examining three literature sources, it's clear that vibration testing models vary in complexity. One literature uses a four-degree-of-freedom model with added intricacy, while the other two opt for simpler three-degree-of-freedom models. one literature employs flexure supports to connect the coil form to the body, ensuring stability during vibration testing. Thisinnovative approach addresses issues linked to simpler models. Using flexure supports offers a practical way to maintain stability without sacrificing performance.Adopting flexure supports appears as a promising technique for reliable and precise vibration testing.So we are taking the model similiar to the one we found in the [2].

2.1 Model

We are considering an electrodynamic shaker with 3 Degree of Freedom (3DOF)

2.1.1 Description

The electrodynamic shaker model we're exploring in [2] is pretty straightforward. Picture a coil wrapped around a tube, hanging between magnets, and hooked up to a disk. When we run current through the coil, it creates a force that gets sent to the test object on the table, generating a back-and-forth electrical force proportional to speed. This model is known for being simple and budget-friendly, making it a handy tool for vibration testing.Now, the literature zeroes in on a particular type of model called the lumped parameter model. It's a three-degree-of-freedom system, blending a 2-degree-of-freedom mechanical system with a 1-degree-of-freedom electrical system. The article dives into figuring out the mechanical and electrical details needed for virtual shaker modeling, using the BK4809 as an example.To back up their points, the authors did some hands-on experiments. They used data acquisition systems to measure how things like displacement and acceleration change using sensors on the objects they were testing. Interestingly, they blocked certain movements to make sure they were getting accurate readings for each degree of freedom.In a nutshell, [2] gives a deep dive into the electrodynamic shaker model, especially honing in on the lumped parameter model and the nitty-gritty process of figuring out key details for virtual shaker modeling.The article's well-organized and easy-to-follow structure, along with helpful figures, makes it a great read for anyone curious about vibration testing and electrodynamic shakers.

2.1.2 Derivation of equation of motion

Force analysis
3 Degree of Freedom (3 DOF)
Forces acting on Table:

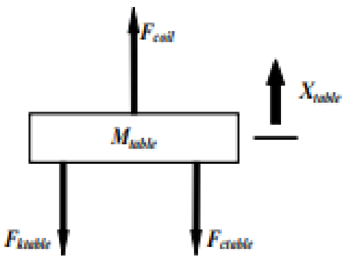


Figure 2.1: Forces on the table (taken from [2])

$$-F_T k - F_T c + F_{\text{Coil}} = M_T \ddot{X}_T \tag{1}$$

$$F_T k = K_T (X_T - X_B) \tag{2}$$

$$F_{Tc} = C_T (\dot{X}_T - \dot{X}_B) \tag{3}$$

$$F_{\text{Coil}} = B_{\text{il}} \tag{4}$$

$$M_T \ddot{X}_T + C_C (\dot{X}_T - \dot{X}_B) + K_T (X_T - X_B) + Bil = 0 \tag{5}$$

Forces acting on the Body:

$$-F_{\text{Coil}} - F_{Tk} - F_{Tc} - F_{Bk} - F_{Bc} = M_B \ddot{X}_B \tag{6}$$

$$F_{Bk} = K_B X_B \tag{7}$$

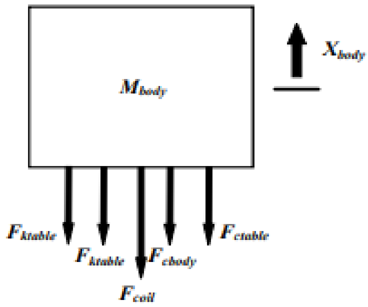


Figure 2.2: Forces on the body (taken from [2])

$$F_{Bc} = C_B \dot{X}_B \tag{8}$$

$$M_B \ddot{X}_B + C_T(\dot{X}_B - \dot{X}_T) + C_B \dot{X}_B + K_T(X_B - X_T) + K_B X_B + B_{\text{il}} = 0 \tag{9}$$

Considering the electric circuit:

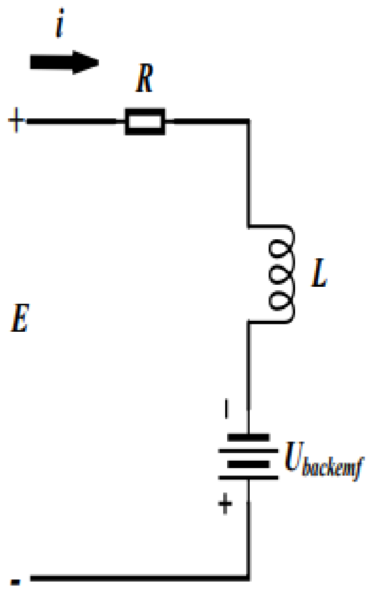


Figure 2.3: Electric Circuit (taken from [2])

$$E_{\text{back emf}} = \text{constant}(\dot{X}_C - \dot{X}_B) \tag{10}$$

$$E_{\text{back emf}} + L\frac{di}{dt} + iR = E_{\text{Input}} \tag{11}$$

Converting equations using Laplace transformations:

$$M_T \ddot{X}_T + C_C(\dot{X}_T - \dot{X}_B) + K_T(X_T - X_B) + BI(s)L = 0 \tag{12}$$

Laplace for Eq (12):

$$M_T S^2 X_T(s) + C_C S(X_T(s) - X_B(s)) + K_T(X_T(s) - X_B(s)) + BI(s)L = 0 \tag{13}$$

$$(M_T S^2 + C_C S + K_T)X_T(s) - X_B(s)(C_C S + K_T) + BLI(s) = 0 \tag{14}$$

$$M_B \ddot{X}_B + C_T(\dot{X}_B - \dot{X}_T) + C_B \dot{X}_B + K_T(X_B - X_T) + K_B X_B + BLI(s) = 0 \tag{15}$$

Laplace for Eq (15)

$$M_B X_B(s)S^2 + C_T S(X_B(s) - X_T(s)) + C_B X_B(s)S + K_T(X_B(s) - X_T(s)) + K_B X_B(s) + BLI(s) = 0 \tag{16}$$

$$X_B(s)(M_B X_B(s)S^2 + (C_T + C_B)S + (K_B + K_T)X_B(s)) - X_T(s)(C_T S + K_T) + BLI(s) = 0$$

$$\mu_{\text{ emf}}(\dot{X}_T - \dot{X}_B) + L\frac{dI}{dt} + IR = E_{\text{Input}} \tag{17}$$

$$X_T = \frac{X_B(C_C S + K_T - (M_B X_B S^2 + (C_T + C_B)S + (K_B + K_T)))}{(M_T S^2 + C_C S + K_T) - (K_B + K_T)} \tag{18}$$

2.2 Methodology

2.2.1 Literature Review

- Begin with an extensive literature review, focusing on electrodynamic shaker models and their applications in vibration testing. Pay particular attention to lumped parameter models, their components, and the determination of mechanical and electrical parameters.

2.2.2 Experimental Setup:

Set up the electrodynamic shaker system, following the principles outlined in the literature. This involves creating a coil wound around a tube, suspended between magnetic poles, and connected to a disk. Familiarize yourself with the specifics of the BK4809 system used in the literature.

2.2.3 Parameter Determination:

Apply the methodology described in the literature to determine the values of mechanical and electrical parameters required for virtual shaker modeling. This may involve conducting experiments using data acquisition systems to measure displacement and acceleration data through sensors on related objects.

2.2.4 Force Analysis:

Analyze the forces acting on both the vibration table and the shaker body using the derived equations. Consider the three degrees of freedom for the shaker system and the interplay between mechanical and electrical components.

2.2.5 Equation Conversion:

Apply Laplace transformations to convert the force equations into the Laplace domain. This step is crucial for solving the system of equations using mathematical tools like MATLAB.

2.2.6 ODE Solving with MATLAB:

Utilize MATLAB to solve the system of ordinary differential equations (ODEs) obtained from the Laplace-transformed force equations. Implement the appropriate numerical methods and algorithms for solving dynamic systems.

2.2.7 Input Signal Exploration:

Investigate the system's response to different input signals, such as sinusoidal, random, or transient signals. Vary the input parameters, including amplitude and frequency, to observe how the shaker system behaves under different conditions.

2.2.8 Analysis and Interpretation:

Analyze the results obtained from MATLAB simulations. Explore how the system responds to various input signals and interpret the dynamic behavior of the electrodynamic shaker. Consider factors such as resonance, damping, and overall system stability.

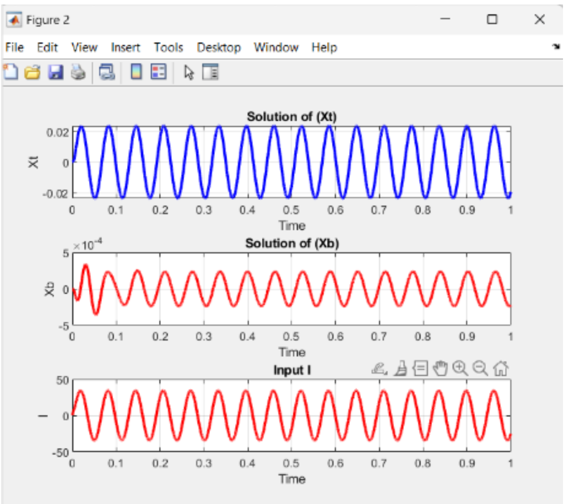
2.2.9 Comparison with Literature:

Compare the findings with the literature review, ensuring that the simulated behavior aligns with the expected characteristics of electrodynamic shaker models described in relevant sources.

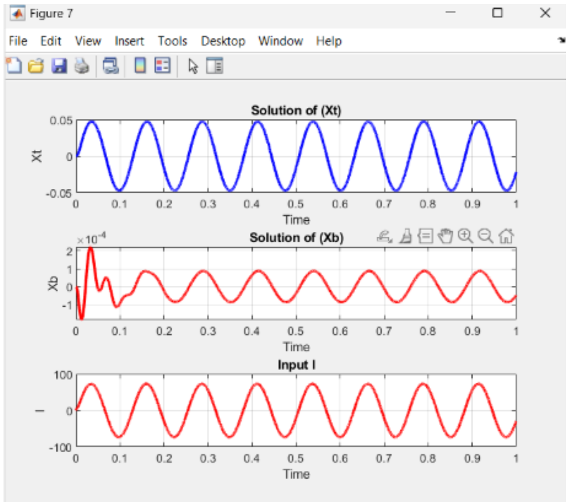
2.3 Results

2.3.1 Outputs:

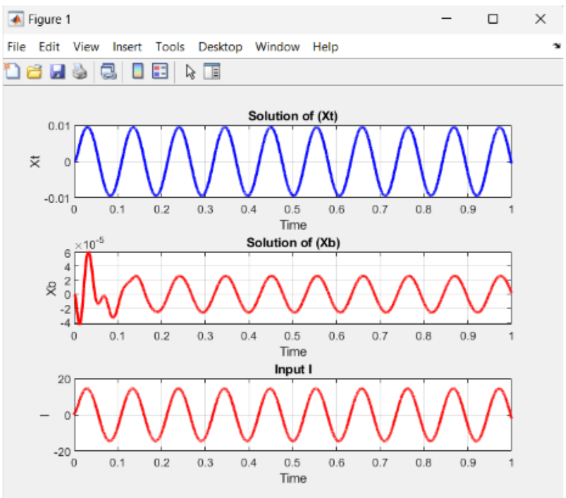
By solving the above mentioned code in MATLAB we got the following outputs for different inputs:



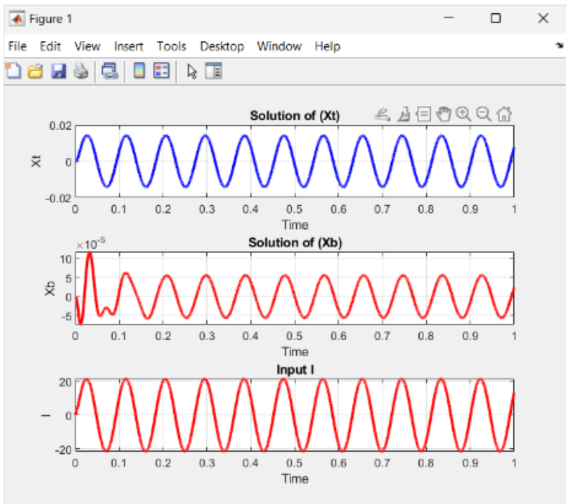
(a) For Einput=50sin(70t)



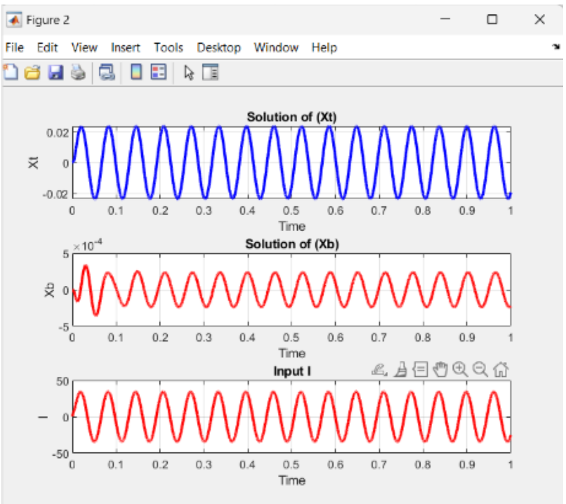
(b) For Einput=100sin(50t



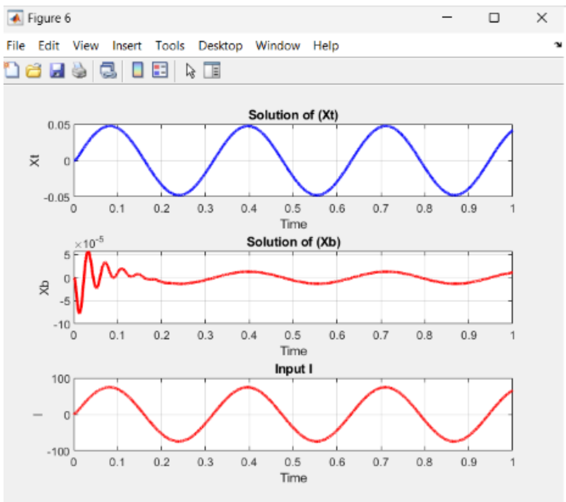
(c) For Einput=20sin(60t)



(d) For Einput=30sin(70t)



(e) For Einput=50sin(70t)



(f) For Einput=100sin(20t)

Chapter 3

Shaker control system

3.1 Introduction

Vibration testing plays a crucial role in assessing the structural integrity and performance of mechanical and electronic systems. The need for precise control over vibration exciters or shakers is paramount to ensure accurate and reliable testing outcomes. Traditional linear audio power supplies used with electrodynamic shakers have limitations in terms of efficiency and size, motivating the exploration of switching-mode power amplifiers. However, these new power amplifiers introduce challenges such as harmonic vibrations, highlighting the necessity for advanced control strategies. This thesis focuses on designing and implementing an innovative control system for electrodynamic shakers to address these challenges, aiming to enhance waveform regulation, reduce harmonic vibrations, and improve overall testing accuracy and efficiency. By leveraging recent advancements in control theory and power electronics, this research seeks to contribute to the advancement of vibrational testing methodologies and the broader field of mechanical engineering.

3.2 Control Algorithm

Adaptive control is a crucial type of control utilized in shaker systems to enhance performance across varying conditions and dynamic loads. Unlike traditional fixed-gain controllers, adaptive control systems adjust their parameters based on real-time feedback, enabling them to adapt to changing system dynamics and uncertainties. In the context of shaker control, where test conditions can vary significantly, adaptive control plays a pivotal role in maintaining accurate and stable vibration profiles.

One common approach within adaptive control is model reference adaptive control (MRAC), which is designed to track a desired model response despite uncertainties in the system dynamics. In the context of shaker control, MRAC can effectively handle parameter variations and disturbances, providing a more reliable and accurate control strategy compared to conventional methods. This adaptive framework allows the shaker system to achieve superior performance across a broader range of operating frequencies and conditions, which is essential for comprehensive vibration testing.

The implementation of adaptive control in shaker systems requires careful consideration of algorithm design and practical implementation. Researchers and engineers aim to strike a balance between computational complexity and real-time responsiveness to ensure effective adaptation without compromising system stability. By leveraging adaptive control techniques, shaker systems can achieve higher levels of efficiency, reliability, and precision, contributing to advancements in vibration testing methodologies and structural analysis in various industries.

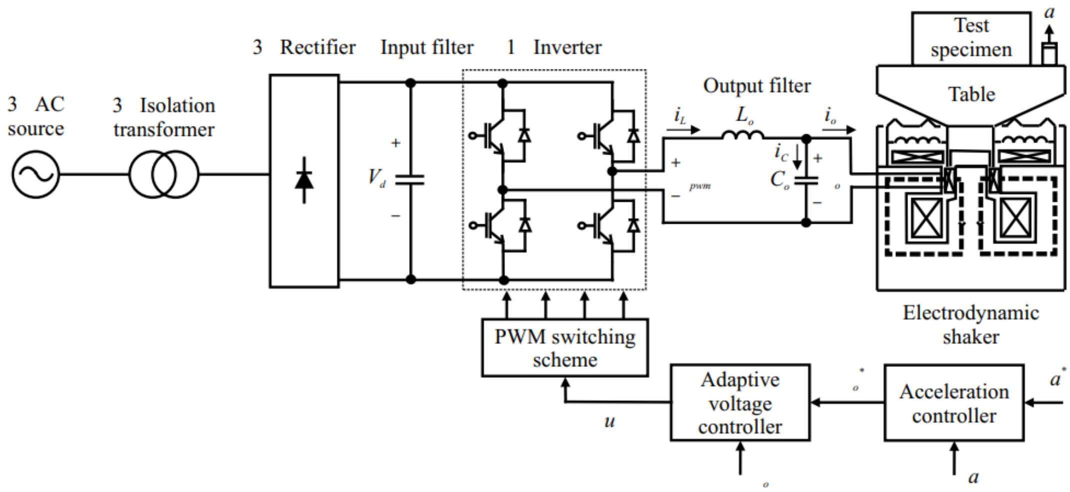


Figure 3.1: Shaker Control (taken from [3])

3.3 How it works

The control algorithm for the shaker system utilizing adaptive control involves a sophisticated interaction between two key control loops: the acceleration regulation loop and the ACPS (AC Power Source) output voltage control loop. This setup is facilitated by a voltage-controlled unipolar PWM (Pulse Width Modulation) inverter, an LC (inductor-capacitor) output filter, and the electrodynamic vibration machine.

3.3.1 Acceleration Regulation Loop

The first control loop, responsible for acceleration regulation, is crucial for generating the desired vibration characteristics. It operates by generating a reference voltage based on the desired acceleration profile. This reference voltage is then used as an input to the ACPS control loop.

3.3.2 ACPS Output Voltage Control Loop

The ACPS output voltage control loop receives the reference voltage from the acceleration loop. Its primary function is to adjust the output voltage of the PWM inverter accordingly. The goal is to match the output voltage with the desired reference voltage to achieve the targeted acceleration profile.

3.3.3 Measurement and Feedback

The entire control strategy relies on measuring and utilizing feedback from two main variables: the output voltage and the vibration acceleration .These measurements are essential for assessing the system's performance and ensuring that the desired vibration characteristics are achieved.

3.3.4 Execution on PC-Compatible Platform

The control strategy is executed on a PC-compatible platform, likely using dedicated control software or programming tools. This platform provides the necessary computational power and flexibility to implement complex control algorithms in real-time.

3.3.5 PID controller

A PID (Proportional-Integral-Derivative) controller is a feedback control mechanism used to adjust a control input based on the difference (error) between a desired setpoint and the measured value of a process variable. The controller uses three components to calculate its output. Proportional (P) Term: The output is proportional to the current error. A higher proportional gain (Kp) leads to a stronger response to error but can cause overshoot or oscillations. Integral (I) Term: Accumulates the error over time and corrects based on this accumulated value. The integral gain (Ki) affects how aggressively the controller reacts to persistent errors. Derivative (D) Term: Considers the rate of change of the error. The derivative gain (Kd) helps dampen rapid changes in error, improving system stability. The overall control output $u(t)$ is the sum of these three terms:

$$u(t) = Kp \times e(t) + Ki \times \int e(t)\, dt + Kd \times \frac{de(t)}{dt}$$

PID controllers are widely used due to their simplicity and effectiveness in controlling various systems. However, tuning the PID gains is essential to balance responsiveness, stability, and robustness in different control applications, including shaker control systems used in vibration testing.

3.4 Simulink Model

A Simulink model was developed to simulate the control system for the electrodynamic shaker,The model represents the dynamic behavior of the system, allowing for virtual testing and validation of the control strategies before physical implementation. Within the Simulink environment, blocks representing the control algorithms were interconnected to simulate the flow of signals and control actions. This model enables the analysis of system responses to different input conditions, such as varying frequencies and load scenarios, providing insights into stability, performance, and overall effectiveness of the proposed control approach. By using Simulink, complex control systems can be visualized, refined, and optimized prior to real-world deployment, ensuring robustness and reliability.

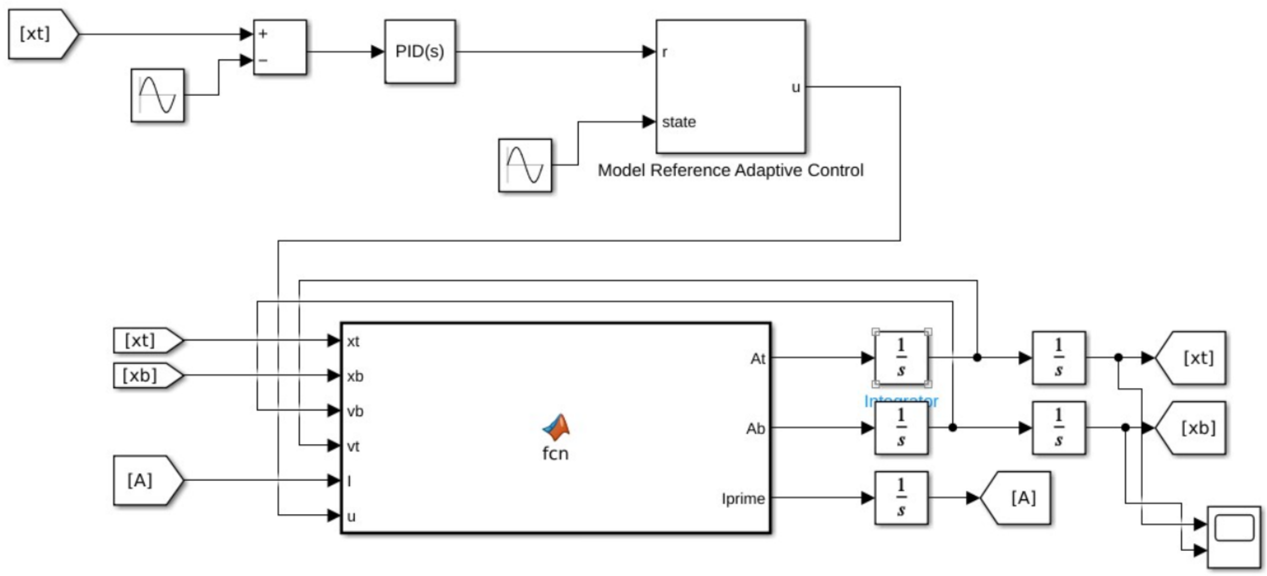


Figure 3.2: Simulink Model

3.5 Electrical components

3.5.1 Soft Starting Circuit

The soft starting circuit is employed to protect the rectifier from inrush current when the AC power source is initially turned on. It gradually increases the voltage supplied to the system, reducing stress on components like the rectifier.

3.5.2 3 kVA Three-Phase Insulated Transformer

This transformer is used to step up or down the voltage levels of the incoming three-phase AC supply to a suitable level for subsequent processing by the rectifier and PWM inverter.

3.5.3 PWM Inverter

The PWM inverter is responsible for converting the DC voltage from the rectifier into a controlled AC output with variable frequency and amplitude. It utilizes Insulated Gate Bipolar Transistor (IGBT) technology for efficient switching.

3.5.4 LC Filter

The LC filter is integrated into the system to reduce the harmonic content in the output voltage generated by the PWM inverter. It smooths out the waveform and minimizes distortion, ensuring cleaner sinusoidal voltage output.

3.6 Result and output

The simulation results obtained from the developed Simulink model showcase the performance of the control system for the shaker. The graphs depicting the outputs reveal key insights into the behavior of the system under different operating conditions. Specifically, the plotted waveforms illustrate the controlled acceleration response and the corresponding AC power source output voltage within the defined frequency range. The waveforms demonstrate the effectiveness of the implemented control algorithms in accurately regulating the acceleration and voltage outputs, highlighting the system's stability and responsiveness. These graphical representations serve as visual evidence of the successful design and simulation of the shaker control system, validating its capability to achieve precise control over vibration characteristics during testing scenarios. The results obtained from the simulation provide valuable insights for further analysis and optimization of the control strategies employed in the shaker system.

3.7 Conclusion

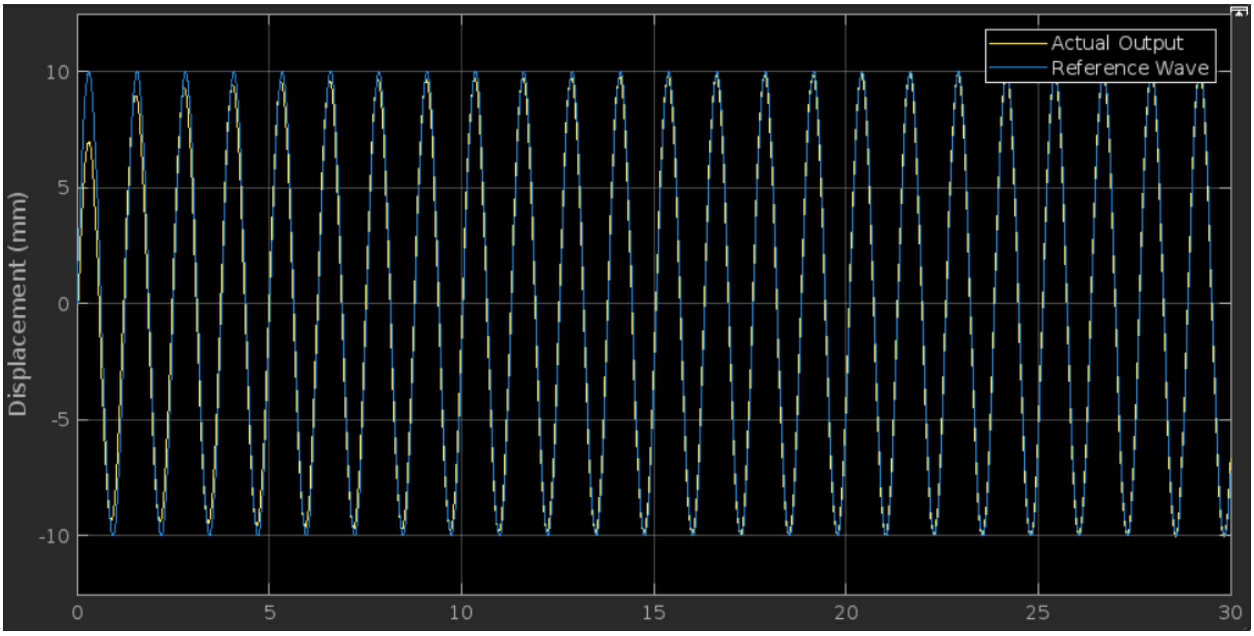
The investigation into the electrodynamic shaker system has culminated in significant advancements in the field of vibration testing and control. The developed control system has showcased impressive capabilities in achieving precise acceleration and voltage regulation across specific frequency ranges. This achievement is particularly noteworthy as it addresses critical requirements for conducting accurate and reliable vibration tests, essential for various industries such as automotive, aerospace, and structural engineering.

The successful integration of a voltage-controlled PWM inverter and adaptive control strategies has been pivotal in enhancing the system's robustness, enabling it to effectively handle dynamic load conditions. This robustness is crucial for ensuring consistent and reliable performance under varying operational scenarios, thereby increasing the system's versatility and applicability in real-world settings.

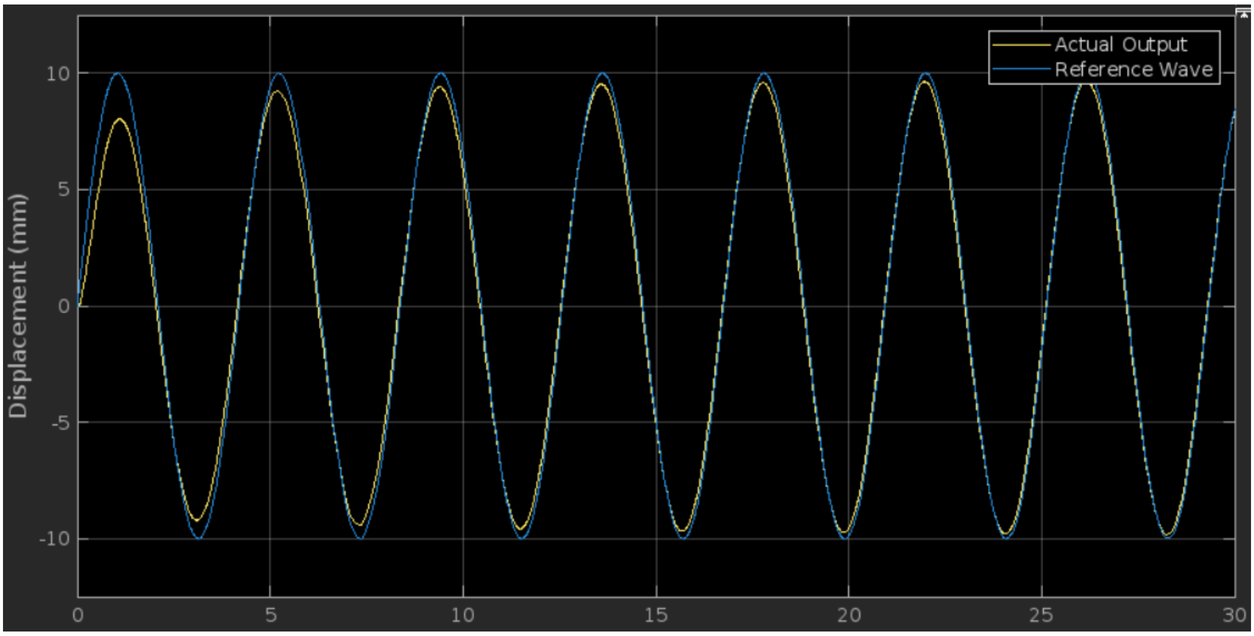
Experimental validation has provided concrete evidence of the system's effectiveness, demonstrating its ability to generate accurate sinusoidal waveforms and maintain precise acceleration levels. These results not only validate the theoretical framework but also highlight the practical feasibility and reliability of the developed control system.

Looking ahead, further refinement of control algorithms is warranted to extend the system's capabilities to higher frequencies and address any remaining practical implementation challenges. By continuously improving the system's performance and overcoming technical hurdles, its applicability in real-world vibration testing scenarios can be further enhanced.

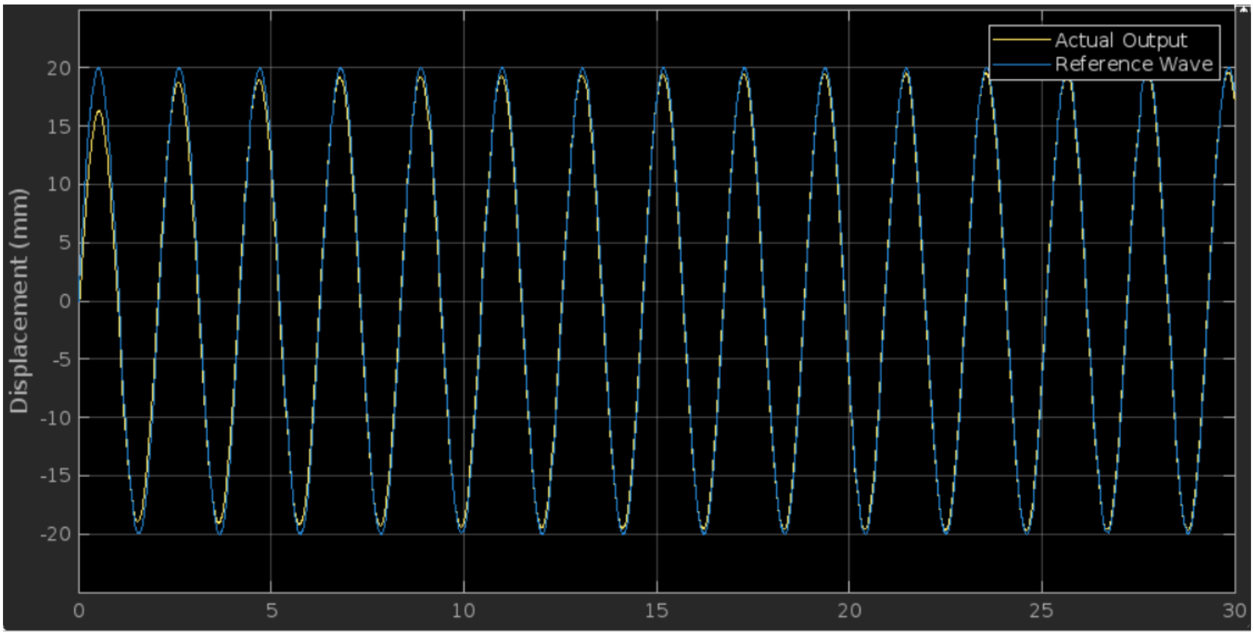
Overall, the advancements achieved through this research have significant implications for the fields of mechanical engineering and structural dynamics understanding. The ability to accurately control and manipulate vibration levels is crucial for optimizing the design and performance of various mechanical systems, ultimately leading to safer, more efficient, and reliable products and structures.



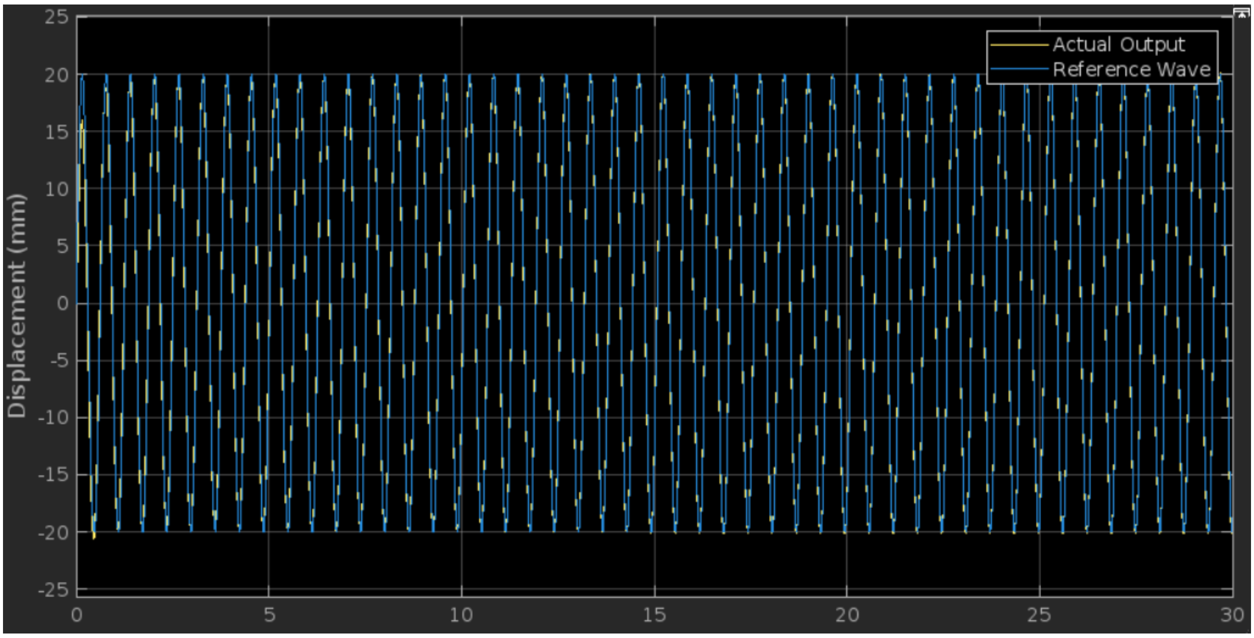
(a) Amplitude=10,frequency=5rad/s



(b) Amplitude=10,frequency=1.5rad/s



(c) Amplitude=20,frequency=3rad/s



(d) Amplitude=20,frequency=10rad/s

References

1. George Fox Lang and Dave Snyder, Understanding the physics of electrodynamic shaker performance,Data Physics Corporation, San Jose, California,2001
2. Jinpeng Li, Ke Deng, Gang Wang, Gangming Zhang, Zhiqing Bai and Lu Yang. An Effective Small Electrodynamic Shaker Modeling Method ,1Aerospace Science Industry Corp Defense Technology RT Center, Beijing ,China,2022
3. Jonathan Martino, Kristof Harri Virtual. Shaker modeling and simulation, parameters estimation of a high damped electrodynamic shaker, Royal Military Academy, Belgique, 2019

4. Thin-Huo Chen and Chang-Ming Liaw,Vibration Acceleration Control of an Inverter-Fed Electrodynamic Shaker,National Science Council,Taiwan,1998
5.Leandro Della Flora,Hilton Abılio Grundling, Vibration Acceleration Control of an AC Power Source-Fed Electrodynamic Shaker, Universidade Federal de Santa Maria Grupo de Eletronica de Potencia e Controle,2005
6. Lucas Martini,Real-time control of an electrodynamic shaker,Tesi Di Laurea Magistrale In Elettronica dei sistemi digitali,2006

Bibliography

[1] George Fox Lang and D. H. Snyder. Understanding the physics of electrodynamic shaker performance. *Sound and Vibration*, 35:24–33, 2001.

[2] George Fox Lang and D. H. Snyder. Understanding the physics of electrodynamic shaker performance. *Sound and Vibration*, 35:24–33, 2001.

[3] George Fox Lang and D. H. Snyder. Understanding the physics of electrodynamic shaker performance. *Sound and Vibration*, 35:24–33, 2001.

[4] George Fox Lang and D. H. Snyder. Understanding the physics of electrodynamic shaker performance. *Sound and Vibration*, 35:24–33, 2001.