Vibration Analysis of a Side Load Washer Machine
Final Report

by

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ME 410: Vibration Theory
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October 11, 2023

1. Introduction & Objectives of Project

We propose conducting a comprehensive vibration analysis of a side load washer machine to identify and mitigate any potential vibration-related issues. The analysis aims to ensure the washer's performance, durability, and user experience by minimizing excessive vibrations during operation. This proposal outlines the selection of the device, a photo/drawing of the device, how the system works, why we chose this, the significance of the vibration analysis of the system, the preliminary drawing of the system, and the concepts and methods used to model and analysis the system.

I. Selection of the device / Why we chose this

Choosing a side load washer for vibration analysis is a practical and strategically valuable decision due to the widespread use of these appliances, the potential for product improvement, and the positive impact on user satisfaction and safety. Additionally, it aligns with the appliance industry's regulatory, environmental, and competitive considerations.

II. Photo of device

LG 4.5-cu ft High-Efficiency Stackable Front-Load Washer [1]

III. How the system works

The vibration system in a washing machine is designed to handle and control the vibrations generated during its operation. Excessive vibrations can lead to noise, instability, and potential damage to the machine and its surroundings. To mitigate these issues, washing machines are equipped with various components and mechanisms to manage and dampen vibrations [2]:

1. Balancing Mechanisms: These mechanisms are crucial for maintaining the stability of the washing machine drum during spinning. They include:

   - Counterweights: Often located within the drum or around the outer casing, counterweights help balance the drum's weight. They are strategically placed to offset the uneven distribution of laundry inside the drum.

   - Suspension System: Washing machines typically have a suspension system with shock absorbers and springs. This system absorbs and dampens vibrations caused by the drum's rotation.

2. Load Balancing: Modern washing machines often employ sensors and algorithms to detect unevenly distributed loads. If an imbalance is detected, the machine may adjust the spin speed or drum rotation to redistribute the laundry more evenly.

3. Vibration Sensors: Some advanced washing machines are equipped with vibration sensors that continuously monitor the level of vibration during operation. If vibrations exceed acceptable levels, the machine may automatically adjust the spin cycle or take other corrective actions to reduce vibrations.

4. Variable Speed Motors: Washing machines may have variable speed motors that allow for precise control of drum rotation speed. Adjusting the speed of the drum during spinning can help reduce vibrations.

5. Rubber Dampers and Insulation: Rubber dampers and insulation materials are used to isolate vibrations and minimize noise transmission to the surrounding environment. These components are strategically placed between the machine's components and its exterior casing.

6. Stabilizing Feet: Washing machines are often equipped with adjustable stabilizing feet that can be leveled to ensure that the machine sits flat on the floor. Proper leveling helps reduce vibrations.

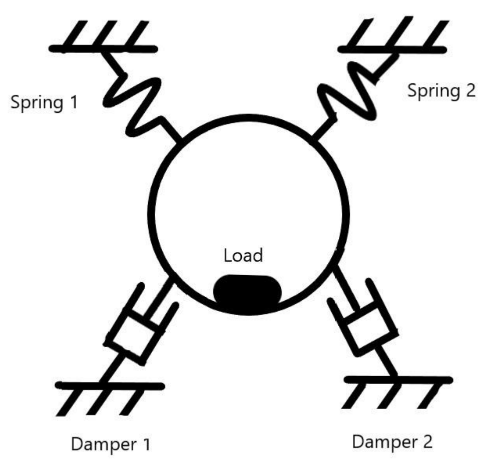
7. Washer Design: The overall design of the washing machine, including the shape and materials used in the drum and casing, can affect its vibration characteristics. Manufacturers may incorporate vibration-reducing design features.

These components and mechanisms aim to minimize vibrations and noise, ensuring that the washing machine operates smoothly and does not disturb its surroundings. While it is not possible to completely eliminate all vibrations, the combination of these features and systems helps to manage and control them effectively, providing a better user experience and prolonging the lifespan of the washing machine.

IV. Significance of the vibration analysis of the system

The significance of vibration analysis in a washing machine system lies in its potential to improve user experience, ensure product quality and safety, reduce maintenance costs, enhance energy efficiency, and contribute to environmental sustainability. It is a vital aspect of product development and quality control in the appliance manufacturing industry.

V. Preliminary drawing



VI. Concepts and Methods

Vibration analysis in engineering and mechanical systems involves the study of oscillatory or vibrational motion, which can have various causes and effects. Here are some key concepts and methods used in vibration analysis [3]:

1. Vibration Basics:

- Vibration: Vibration is a repetitive back-and-forth motion of an object or system about an equilibrium position. It can occur in various forms, including translational (linear) and rotational (angular) motion.

- Frequency: measures how often a vibration cycle repeats per unit of time. It is typically expressed in Hertz (Hz) and is inversely related to the period (the time for one cycle). Higher frequencies indicate faster oscillations.

- Amplitude: refers to the maximum displacement from the equilibrium position during vibration. It measures the "size" or magnitude of the vibration motion.

- Mode Shapes: In complex systems, there can be multiple modes of vibration, each associated with a specific frequency and pattern of motion. These are referred to as mode shapes.

2. Types of Vibration:

- Free Vibration: occurs when a system vibrates with an initial displacement and no external forces acting on it. The system oscillates at its natural frequency.

- Forced Vibration: results from the application of external forces or excitations to a system at a specific frequency. The system responds to these external inputs.

- Resonance: a phenomenon where a system vibrates at or near its natural frequency when subjected to an external force of the same frequency. This can lead to excessive vibrations and potential damage.

3. Methods of Vibration Analysis:

- Modal Analysis: This is used to determine the natural frequencies, mode shapes, and damping characteristics of a vibrating system. It helps identify critical modes that may require attention in design or analysis.

- Frequency Domain Analysis: vibrations are analyzed in terms of their frequency components. Techniques like Fourier analysis can decompose complex vibrations into sinusoidal components.

- Time Domain Analysis: analysis involves studying vibrations in the time-based waveform. Time-domain methods are useful for analyzing transient vibrations and non-periodic events.

- Transient Analysis: focuses on how a system responds to sudden changes or disturbances. It helps understand the system's behavior during start-up, shut-down, or other transient conditions.

- Harmonic Analysis: deals with vibrations at specific harmonic frequencies, which are integer multiples of a fundamental frequency. It is commonly used in the analysis of periodic vibrations.

- Random Vibration Analysis: deals with non-periodic or random vibrations, such as those caused by environmental factors. It is used in applications like structural analysis for aerospace and automotive engineering.

4. Measurement and Instrumentation:

- Accelerometers: are sensors that measure acceleration (including vibrations). They are commonly used to collect vibration data from mechanical systems.

- Strain Gauges: measure mechanical deformation and can be used to detect structural vibrations and stress.

- Data Acquisition Systems: These systems collect, store, and process vibration data from sensors. They often include software for analysis and visualization.

5. Vibration Control and Mitigation:

- Damping: is the process of dissipating energy to reduce vibrations. Damping materials or devices are used to absorb or dissipate vibrational energy.

- Isolation: Vibration isolation techniques involve isolating a vibrating system from its surroundings to prevent vibrations from being transmitted.

- Design Modifications: Design changes can be made to reduce vibrations, such as adjusting component stiffness, adding counterweights, or improving structural integrity.

Vibration analysis is a crucial tool in various fields, including mechanical engineering, structural engineering, aerospace engineering, and automotive engineering, among others. It helps ensure the safe and efficient operation of systems and machinery while minimizing the adverse effects of vibrations.

2. Theory & Procedure

In Phase II, we will discuss the development of a simplified one-degree-of-freedom (DOF) vibration model for the side-load washing machine. As per our project proposal, we have identified the need to simplify our initial vibration system and model, and this report outlines the procedure for doing so, setting up the equation of motion, and providing a solution to this simplified model.

By simplifying our model to a one-degree-of-freedom model, we can determine what manner of damping is necessary to ensure that the washing machine will function as intended. To do so, we will be making calculated assumptions based on known factors about the system. This is important in ensuring that consumers will avoid purchasing or using improperly damped washing machines because the vibrations will shake the machine violently, causing an excess of noise as well as creating a potential for damage to items left in contact with it for extended periods of time, such as shelving units or drying machines.

I. Simplification of Vibration System

To create a one-DOF vibration model for the side-load washer machine, we have undertaken the following steps:

- Identifying the Main Vibration Source: We first identified the primary source of vibration in the side-load washer machine. In this case, the unbalanced load inside the washing drum is the predominant cause of vibration.

- Selecting Key Parameters: We selected the key parameters affecting the vibration behavior. These include the mass of the unbalanced load, the spring constant of the suspension system, and the damping coefficient.

- Eliminating Complexities: We simplified the model by neglecting secondary factors and components that contribute minimally to vibration. These could include internal components like bearings and belts, which may introduce additional DOFs but have less impact on the overall vibration.

- Creating a Simplified Diagram: We represented our one-DOF vibration model with a simplified diagram (Figure 1) that captures the essential components and their interactions.

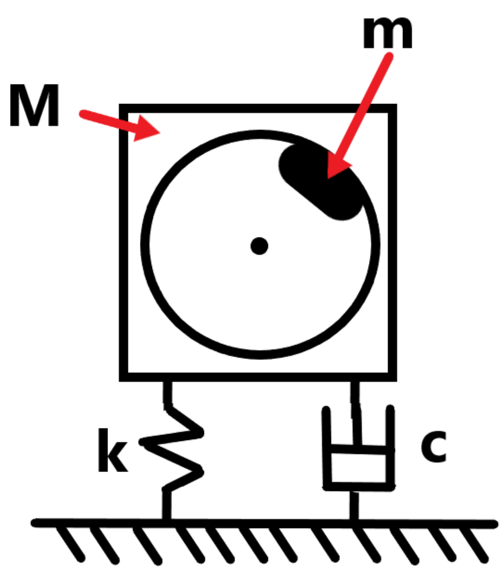


Figure 1: Simplified One-DOF Vibration Model

II. Equation of Motion

With our simplified one-DOF vibration model in place, we derived the equation of motion using principles from Chapter 2 of our course materials. The equation of motion for a one-DOF vibration system can be expressed as:

$$m\ddot{x} + c\dot{x} + kx = F(t) \quad (1)$$

Where:

m is the mass of the unbalanced load,

c is the damping coefficient,

k is the spring constant of the suspension system,

x is the displacement from the equilibrium position,

$\ddot{x}$ represents the second derivative of x with respect to time (acceleration),

$\dot{x}$ represents the first derivative of x with respect to time (velocity), and

F(t) represents any external forces or disturbances acting on the system.

III. Solution Procedure

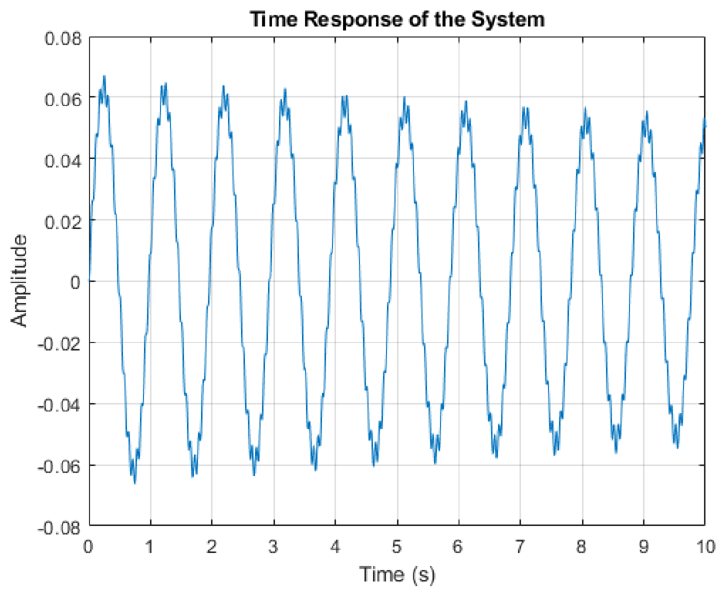
To solve the equation of motion, we will use appropriate methods such as the mass of the whole system (M), the mass of the load (m), the spin speed (N in RPM), the radius of the drum (r), the natural frequency of the washer machine (ω_n) and mass (f_n), and the damping ratio of the system (c). The specific solution method will be determined in the next phase of our project, and the procedure will be documented accordingly in our final report.

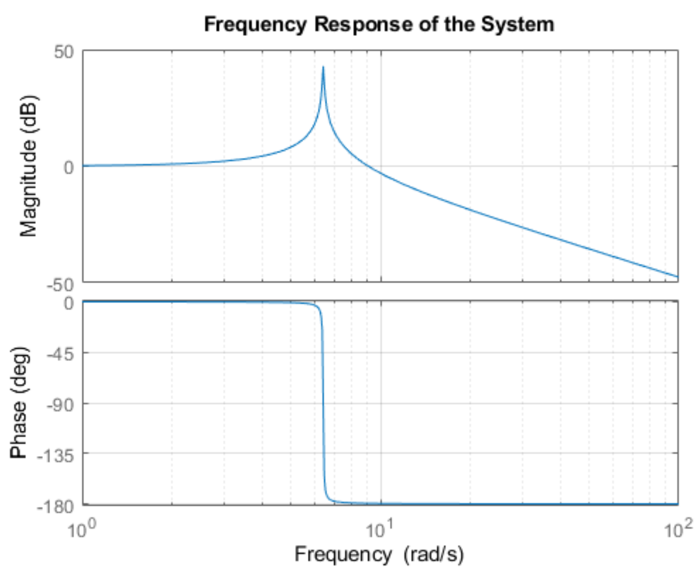
3. Simulation Results And Analysis

In the simulation in MatLab (found in the appendix), assumptions were made: The radius assumes that the drum is 20” in diameter with the notion that the total width of the washer machine is 27”. This gives room for other components inside the outer shell of the washer machine. The weight of the drum is assumed at 30 pounds, based on the total weight of the machine [1].

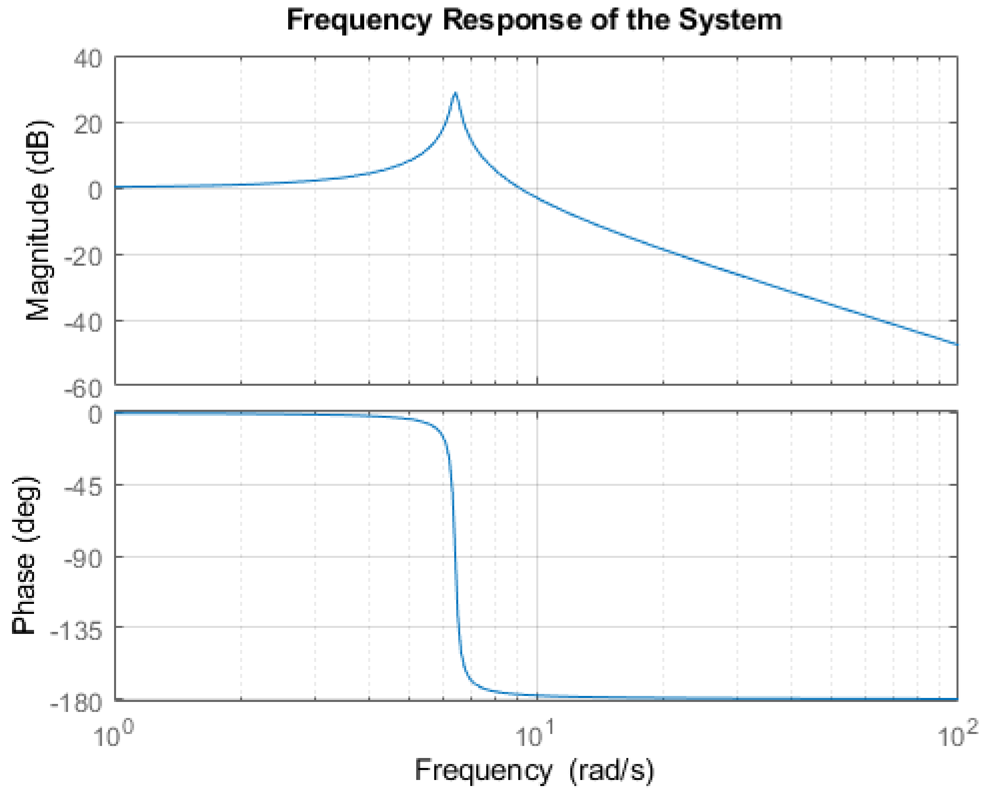
Fine-tuning the damping ratio is a crucial aspect of optimizing the efficiency and performance of mechanical systems such as washing machines. This analysis demonstrates that the damping ratio plays a significant role in controlling the system's response to external inputs. The choice of an appropriate damping ratio should be made considering the balance between stability, efficiency, and vibration control.

In the first trial, the damping coefficient is set to 0.005, and the figures below show the time & frequency response of the system.

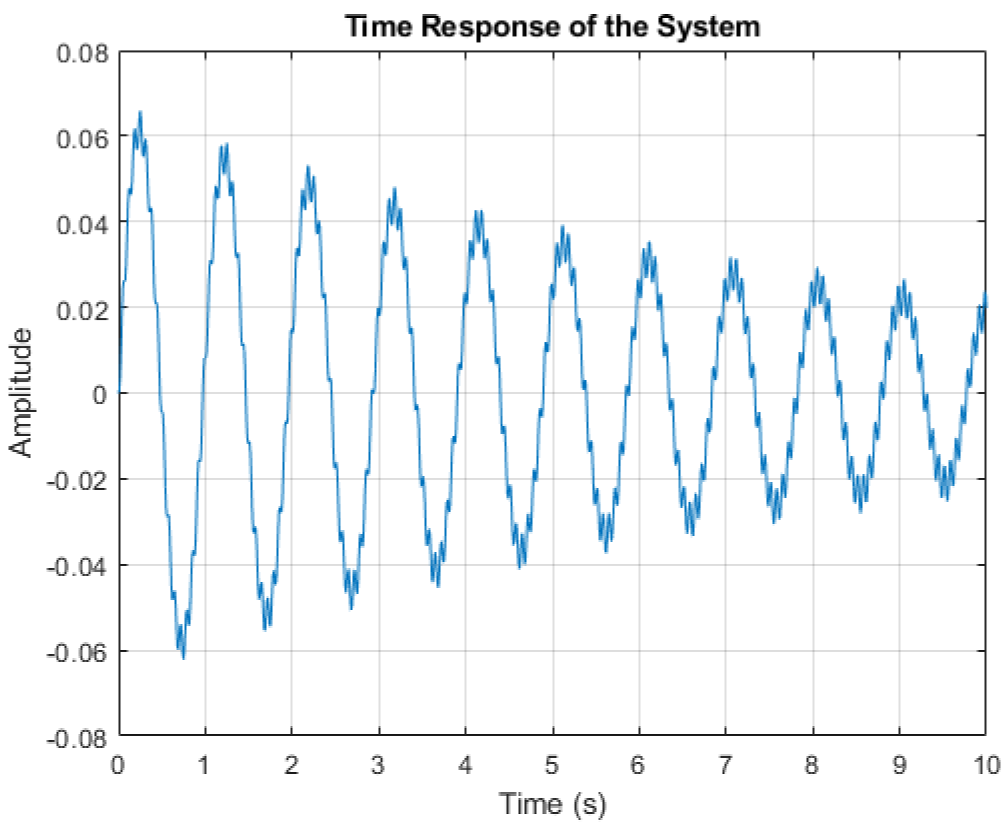




In the second trial, the damping ratio is increased to 0.025 (shown below):

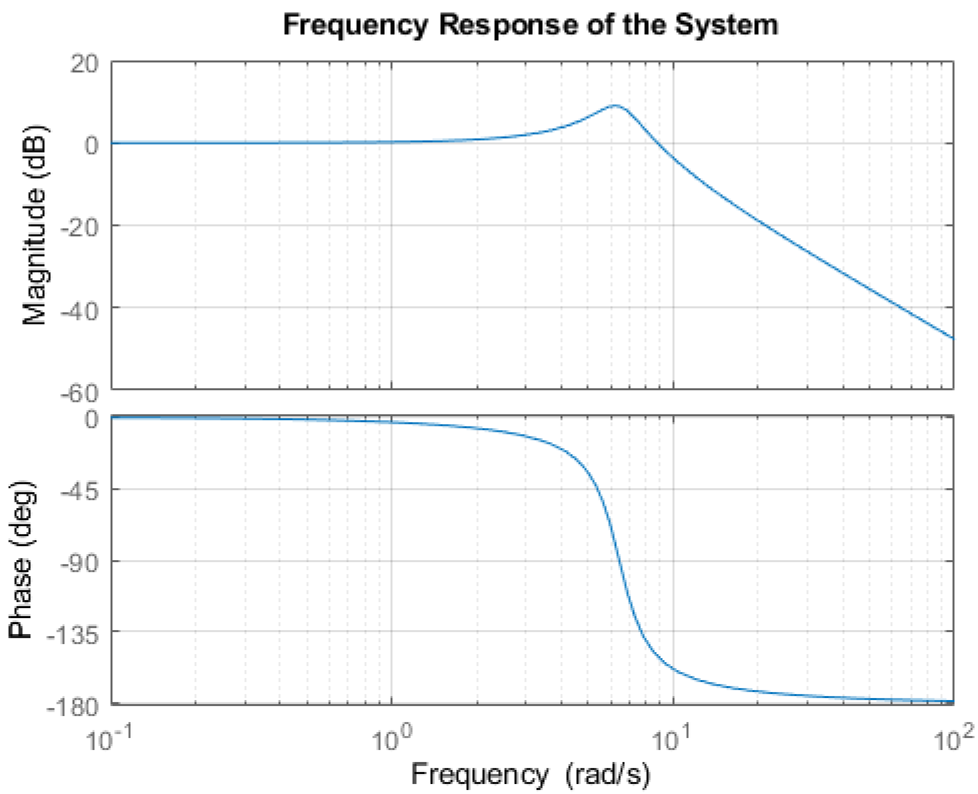


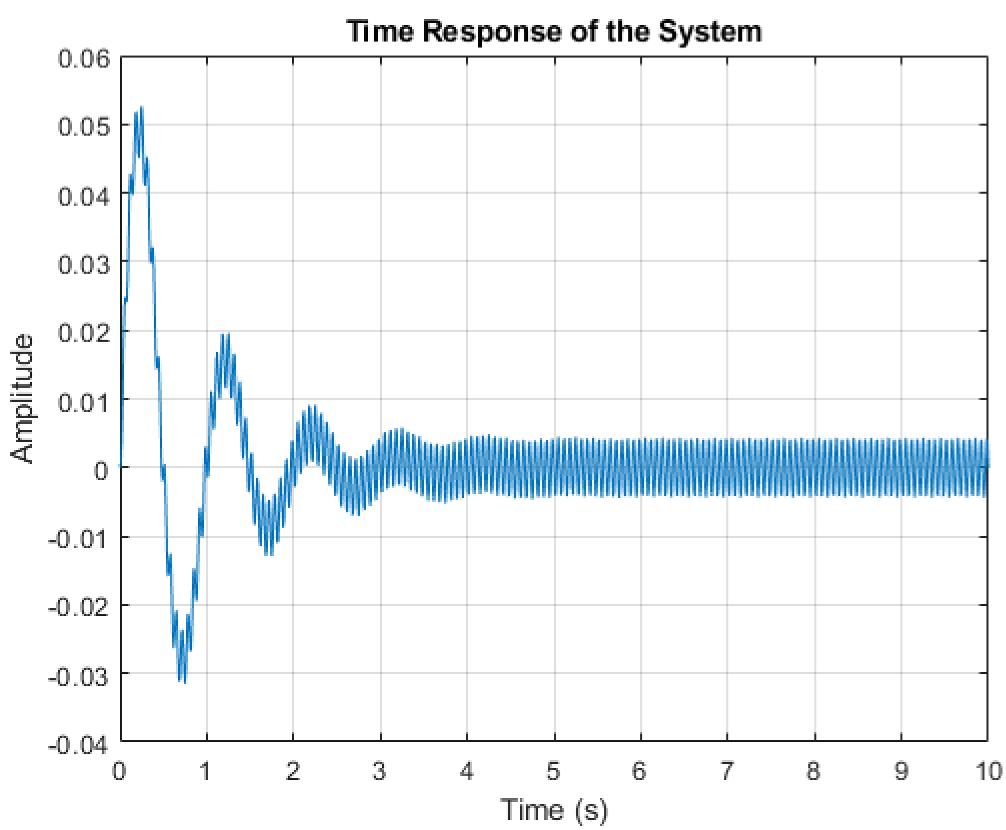
Frequency Response of the System
Magnitude (dB)
40
20
0
-20
-40
-60
Phase (deg)
0
-45
-90
-135
-180
10^0
10^1
10^2
Frequency (rad/s)



Time Response of the System
Amplitude
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
0
1
2
3
4
5
6
7
8
9
10
Time (s)

In the last trial, the damping ratio was closer to 1 and set at 0.25 (shown below):


Frequency Response of the System
Magnitude (dB)
20
0
-20
-40
-60
Phase (deg)
0
-45
-90
-135
-180
10^{-1}
10^{0}
10^{1}
10^{2}
Frequency (rad/s)


Time Response of the System
Amplitude
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
0
1
2
3
4
5
6
7
8
9
10
Time (s)

Simulation Studies:

To analyze the effects of varying damping ratios on the side-load washing machine, we conducted a series of simulations. We explored three specific damping ratio scenarios: low damping ($\zeta = 0.005$), moderate damping ($\zeta = 0.025$), and high damping ($\zeta = 0.25$). These scenarios were chosen to represent a range of possible damping conditions that the washing machine might encounter in practical use.

Low Damping ($\zeta = 0.005$):

In the first simulation scenario with low damping, the washing machine's response exhibited a higher degree of sustained vibration. This condition can be undesirable, as it may lead to excessive noise and instability during operation. Low damping allows the system to continue oscillating for an extended period before returning to its equilibrium position. This sustained oscillation can potentially result in disturbances to items in contact with the machine and reduced user satisfaction.

Moderate Damping ($\zeta = 0.025$):

In the second simulation scenario with moderate damping, the system's response demonstrated a more controlled and damped oscillation. This level of damping strikes a balance between stability and vibration control, providing a reasonable response to external forces. It is important to note that this scenario may be considered close to critical damping, a condition that ensures a rapid return to equilibrium without overshooting. Such damping may be suitable for practical washing machine applications as it minimizes noise and potential damage.

High Damping ($\zeta = 0.25$):

In the last simulation scenario with high damping, the washing machine's response showed a rapid return to equilibrium with minimal oscillation. This level of damping is highly effective in controlling vibrations, but it may also be overly conservative. Extremely high damping may lead to a reduction in the machine's overall efficiency, as the system expends a significant amount of energy to overcome the damping effects. However, it guarantees minimal vibration and noise, which is essential for maintaining user satisfaction and preventing potential damage.

Practical Implications:

The analysis of the damping ratio in our simulations highlights the importance of striking a balance between stability, energy efficiency, and vibration control in the design of washing machines. The choice of an appropriate damping ratio is a critical design decision, as it directly impacts user experience, product quality, and energy consumption.

The findings from our analysis suggest that moderate damping is a reasonable compromise for washing machines. It provides effective vibration control, reducing noise and potential damage, while still allowing for efficient operation. However, it is crucial to further investigate and fine-tune the damping coefficient based on specific design considerations, such as the machine's structural integrity and the characteristics of the internal load.

4. Conclusion

In this report, we presented the initial stages of our project aimed at conducting a comprehensive vibration analysis of a side-load washing machine. We outlined the selection of the device, described how the system works, highlighted the significance of the vibration analysis, and provided a preliminary drawing of the system. Additionally, we introduced key concepts and methods in vibration analysis, which serve as the foundation for our project.

In the second phase of our project, we discussed the simplification of the vibration system into a one-degree-of-freedom (DOF) model, emphasizing the importance of proper damping to ensure the washer's intended functionality and user satisfaction. We outlined the steps taken to create this simplified model and derived the equation of motion for it.

Furthermore, we conducted a simulation to explore the impact of different damping ratios on the system's response. These simulations illustrated the critical role that damping plays in controlling vibrations, enhancing efficiency, and ensuring the machine's stability.

With the knowledge and insights gained from this project, we aim to contribute to the development of washing machines that offer improved user experiences, product quality, energy efficiency, and environmental sustainability. Our commitment to this endeavor reflects our dedication to innovation, safety, and the enhancement of everyday appliances.

5. References

[1] "LG 4.5-cu ft High-Efficiency Stackable Front-Load Washer (White) ENERGY STAR." Lowe's. https://www.lowes.com/pd/LG-4-5-cu-ft-High-Efficiency-Stackable-Front-Load-Washer-White-ENERGY-STAR/1002544016?cm_mmc=shp-_-c-_-prd-_-app-_-ggl-_-SS_APP_174_Laundry_Priority-Items-_-1002544016-_-local-_-0-_-0.

[2] Bhhardwaj, A, 2014, "A Study of Vibration Control Methods for Front Loaded - Washing Machine" *IJRMEE vol. 1 Issue: 2*, pp. 47-48.

[3] Rao, Singiresu S. *Mechanical Vibrations*, 5th ed. Pearson Education Inc, 2011.

[4] Cunningham B. Simulating Vibration and Noise in a Washing Machine. COMSOL Blog. Published January 15, 2015. https://www.comsol.com/blogs/simulating-vibration-and-noise-in-a-washing-machine/#:~:text=We%20can%20note%20that%20the,at%20the%20set%20rotational%20velocity.

6. Appendix

This is the Matlab code used to find results.

```
clear;clc;

% Define system parameters
M = 85.00321;  % Mass of the whole system (kg)
m = 6;  % Mass of the load (kg)
N = 1300;  % Spin speed (RPM)
r = .254;  % Radius of the drum (m) assuming drum is 20" diameter
n = 15;  % Natural frequency of the washer machine (Hz)
fn = 13.61; % Mass of drum assuming 30 pounds (kg)
c = 0.005;  % Damping ratio of the system assuming

% Convert RPM to rad/s
```

```
omega = 2*pi*N/60;

% Calculate natural frequency of the system
wn = sqrt((M + m) * 9.81 / (M * r));

% Calculate damping coefficient (assuming critical damping)
zeta = c / (2 * sqrt((M + m) * 9.81 * r / (M * r)^2));

% Define the transfer function of the system
num = [wn^2];
den = [1, 2*zeta*wn, wn^2];
sys = tf(num, den);

% Generate a frequency response plot
figure;
bode(sys);
title('Frequency Response of the System');
grid on;

% Calculate and plot the time response of the system
t = 0:0.01:10; % Time vector
u = sin(2*pi*n*t); % Input signal (excitation)
[y, t] = lsim(sys, u, t);

figure;
plot(t, y);
title('Time Response of the System');
xlabel('Time (s)');
ylabel('Amplitude');
grid on;
```

Published with MATLAB® R2022b