Mass Spring Damper System

AHSANULLAH UNIVERSITY OF SCIENCE

& TECHNOLOGY

Group - 3

Project Report

Department : Mechanical and Production Engineering

Program : B.Sc. in Mechanical Engineering

Year/Semester : 3rd Year / 2nd Semester

Course No. : ME_3202

Section: B

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CHAPTER-1

INTRODUCTION

A spring-mass-damper system, also known as a mass-spring-damper system, is a mechanical system composed of three main components: a mass, a spring, and a damper. These components are interconnected to form a system that exhibits dynamic behavior when subjected to external forces or disturbances.

Mass: The mass is a physical object with mass “m” that experiences acceleration when subjected to forces. In the context of the system, the mass represents the object or structure whose motion is being analyzed or controlled.

Spring: The spring is an elastic component characterized by its stiffness or spring constant “k”.

Damper: The damper, also known as a dashpot, is a mechanical component that dissipates energy by resisting the motion of the mass. It is characterized by its damping coefficient “c”.

1.1-Main Objective

The primary objective of a spring-mass-damper system is to control the motion or vibration of a mechanical system by providing a means to absorb, dissipate, or store energy. By adjusting the properties of the spring, mass, and damper (such as stiffness, mass value, damping coefficient), engineers can tailor the system's response to meet specific requirements. The objectives can vary depending on the application, including:

Vibration Isolation: Minimize the transmission of vibrations from one part of a structure to another, such as isolating sensitive equipment from external vibrations.

Vibration Absorption: Reduce unwanted vibrations within a system to improve performance, stability, and comfort, such as in vehicle suspension system.

Shock Absorption: Protect sensitive components from sudden shocks or impacts, such as in vehicle bumpers or seismic isolation systems for buildings.

1.2-Methodology

Methodology refers to a number of steps or methods used to do a particular research or project. In this case, the project has been done according to a provided guideline by the authority under the term **Informed Design Process** (IDP) [11]. The steps in sequence are provided below:

- **Clarifying Problem, Specifications & Constraints:**

The first step of designing the Mass-spring-damper system was to identifying the problem that is going to be solved then the design specifications as in the measurements and materials which will be our starting point. Also identification of the constraints is part of this step.

- **Researching & Investigating:**

Several research papers and available data on the internet and other sources, had to be gone through to get more idea about said project.

- **Generating Alternative Design:**

For this step some designs of the mass-spring-damper has been presented varying basedon different parameters. The design was made with the goal to increase the efficiency and sustainability.

- **Choosing & justify Optimal Solution:**

Among all the design that has been done, the one with the highest efficiency and sustainability has been chosen. To justify the chosen one, hand calculation was done using resources from **Shigley's** book.

- **Developing a Prototype:**

The final prototype has been designed by altering the measurements here and there.

- **Testing & Evaluating:**

Various simulation was run on the final prototype to figure out how the mass-spring-damper system would react under different situations.

- **Redesigning the Solution:**

After the previous step a redesigning was required by altering the measurements.

- **Communicating Achievements:**

The last step was to showcase the design which achieved the goal of being a proper Mass Spring Damper.

CHAPTER-2

Design specifications & constraints

2.1-Problem Statement

In today's world Mass-Spring-Damper is a very essential device. But most of these but most of these spring-mass-damper models assume linear behavior, which might not always hold true in real-world scenarios where non-linearities exist. [1]

So, the project is designing a Mass-Spring-Damper system that can be applicable for real-world applications.

2.2-Problem Specifications

The specification of a spring-mass-damper system typically involves defining various parameters and constraints related to the system's behavior and performance. Some common problem specifications for a spring-mass-damper system include:

- Mass (m)
- Spring constant (k)
- Damping coefficient (c)
- External forces
- Initial conditions
- Boundary conditions

2.3-Constraints

The design of the springs for the mass-spring-damper system project is impacted by essential constraints that influence its workability and utility. These comprise:

- **Physical Constraints**: These are limitations imposed by the physical properties of the components in the system. For example, the maximum displacement or compression of the spring, the maximum velocity or acceleration of the mass, and the maximum damping capacity of the damper are all physical constraints.

- **Energy Constraints**: Spring-mass-damper systems are subject to energy constraints, particularly in terms of conservation of energy. Energy dissipation due to damping should be balanced with the energy stored in the spring and the kinetic energy of the mass.

- **Geometric Constraints**: The geometric layout and arrangement of components in the system can impose constraints on its behavior.

- **Material Constraints**: The material properties of the components, such as the stiffness of the spring material, the mass distribution of the mass, and the damping characteristics of the damper material, can impose constraints on the system's behavior.

- **Dynamic Constraints**: Dynamic constraints refer to limitations on the system's response to external stimuli or disturbances. These constraints may include limitations on the system's bandwidth, response time, or ability to track desired trajectories or reference signals.

CHAPTER-3

Research & Investigation

In this step the goal is to attain in-depth information on the spring and damper design for the Mass Spring Damper system. Though no papers or research have been found with the same idea or topic, several paper studies and investigations have been done. From these, different topics have been studied which have been helpful in the analysis, evaluation and creation of the springs. The papers are described below:

3.1-Paper 1

Name - SEISMIC PERFORMANCE OF MASS DAMPERS FOR TYPICAL BUILDING STRUCTURES IN BANGLADESH **[3]**

Designed & Developed by - Tanzila Tabassum & Khondaker Sakil Ahmed at 2015 in Bangladesh

- Investigated how typical building structures behave against potential earthquakes.
- Focused on the effectiveness of different type dampers against different well known earthquake motion.
- A series of finite element model was constructed to investigate the influence of different parameters of damper using ETABS 2015.
- The research was successful (Seismic performance of building can be improved by providing energy dissipating device (damper) as the modal time period is increased.)

Mode Number/ Shape	Time Period (sec) Without Damper	Time Period (sec) With Exponential Damper	Percent Increased (%)
1	1.389	1.635	18
2	1.285	1.552	21
3	0.219	1.288	5
4	0.428	0.461	8
5	0.396	0.434	10
6	0.376	0.392	4

Table 3.1 -Increment of building time period

Kind of Response of Structure	Without Damper	Bilinear Damper	Percent Reduction %	Friction Dampers	Percent Reduction %
Moment Values (kip-ft) for EQY	282.8	100.04	65	93.77	69
Moment Values (kip-ft) for WINDY	271.73	73.18	73	70.54	74
Shear Values (kip) for EQY	38.52	19.510	49	18.56	52
Shear Values (kip) for WINDY	37.118	14.439	61	14.046	74

Table 3.2 - Moment and shear value reduction

3.2-Paper 2

Name - Directional mass dampers for buildings under wind or seismic loads.[4]

Designed & Developed by - Seshasayee Ankireddi and Henry T.Y. Yang

- Three passive damper configurations are studied for buildings:
  - Unidirectional Dampers oriented to the story principal axes
  - Dampers with a single mass attached to spring-dashpot elements laid out at 90/120 to each other.

- A simple damper design procedure was presented to minimize a weighted combination of RMS building responses, using the concept of structure-constrained feedback control.
- Focused on control of translational responses of tall buildings with various plan shapes using passive dampers.
- Bidirectional & Tri-directional dampers are quite effective for all wind directions considered; they can reduce accelerations by 21% and displacements by about 14%.
- Under unidirectional loading, simple unidirectional rooftop dampers may not be capable of effectively controlling vibrations for all possible directions of the wind/earthquake excitations.

3.3-Paper 3

Name- Analysis of an Isolation System with Vertical Spring-viscous Dampers in Horizontal and Vertical Ground Motion[5]

Designed & Developed by – Deog-Jae Hur & Sung-Chul Hong

Feature:

- Proposal of a new RIS system with vertical spring-damper for horizontal and vertical vibration improvement;
- The relationship between the design parameters of the behavior characteristics of the spring-dampers;
- The control of resonance and design parameters.

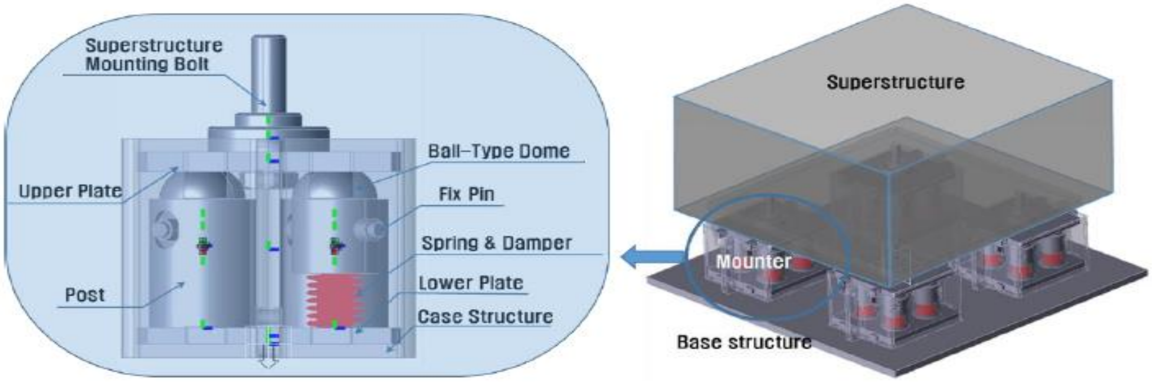

Figure 3.1- Configuration and installation diagram of the proposed vibration isolation mounting system.

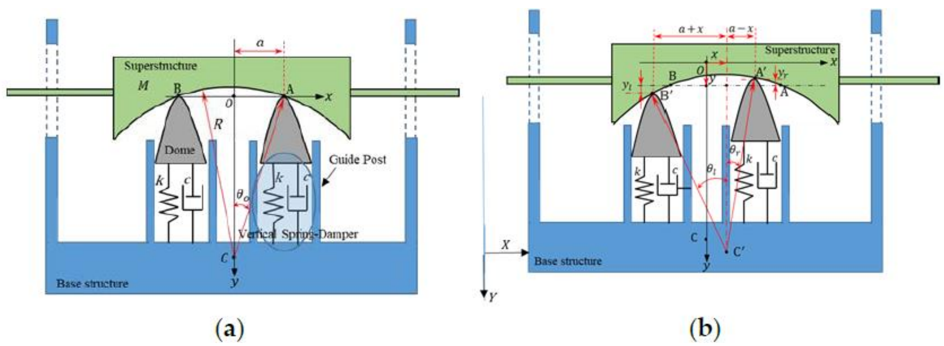

Figure 3.2- Model of isolator system with double spring-dampers:
(a) Geometry configuration.
(b) Displacement relationship of motion.

3.4-Investigation

Name - Understanding the Spring Mass Damper system [6]

Spring Mass Damper:

The mass-spring-damper model consists of discrete mass nodes distributed throughout an object and interconnected via a network of springs and dampers.

Damping Factor:

In a spring-mass-damper system, the damping factor is a parameter that represents the level of damping or resistance to motion within the system. It is typically denoted by the symbol "ζ" (pronounced "zeta").

Critical Damping:

In a spring-mass-damper system, critical damping refers to a specific damping level where the system returns to its equilibrium position in the shortest amount of time without oscillating.

CHAPTER-4

Alternative designs

To go ahead, three types of design has generated with different parameters and characteristics. They are,

Alpha (α)
Kai ($\varkappa$)
Phi (ϕ)

4.1- Alpha (α)

PARAMETERS:

Material : Stainless steel

C : 50 N.s/m

Weight : 1Kg

4.2- Kai ($\varkappa$)

PARAMETERS:

Material : High carbon steel

C : 80 N.s/m

Weight : 1Kg

4.3- Phi (*φ)*

PARAMETERS:

Material : Stainless steel

C : 110 N.s/m

Weight : 4Kg

When considering alternate design selections, several key factors was taken into account:

1. **Critical Damping (K):** Aim for a design with appropriate critical damping to effectively dissipate energy and minimize vibrations.

2. Material Properties: Consider the material characteristics, such as strength, wear resistance, and cost-effectiveness. Choose materials that align with the specific requirements of your application.

3. System Response: Evaluate how well the design responds to external forces or disturbances, especially in dynamic systems or structures.

4. Application Suitability: Ensure that the alternate design is suitable for the intended application, considering factors like load requirements, environmental conditions, and usage scenarios.

5. Cost-Effectiveness: Assess the overall cost of the design, including materials, manufacturing, and maintenance. Strive for a balance between performance and economic feasibility.

6. Durability: Check the durability and lifespan of the design, especially in applications where wear and tear are significant factors.

7. Versatility: Consider whether the design can be adapted to various applications or scenarios, providing flexibility and adaptability.

8. Comparative Analysis: Conduct a thorough comparison of different designs, weighing their pros and cons against each other based on the specific criteria relevant to your project.

By focusing on these aspects, while selecting alternate designs, ensuring that the chosen solution aligns with the unique requirements for this project.

CHAPTER-5

Choosing and justifying optimal design

The best solution has been determined by comparing the three alternative designs with one another. Finding the design that most closely complies with the specifications and performance standards is the goal of this comparative process.

Alpha (α)	**Kai (ϰ)** **(Chosen)**	**Phi (φ)**
Low damping force	High damping force	Low damping force
Critical damping : 756.25 N/m	Critical damping : 1600 N/m	Critical damping : 756.25 N/m
Comparatively low strength and wear resistance	High strength and wear resistance	Comparatively low strength and wear resistance
Price – Comparatively High	Price – Most Affordable	Price - High

Table 5.1- Comparison between alternative designs

5.1- Choosing and Justifying the Design

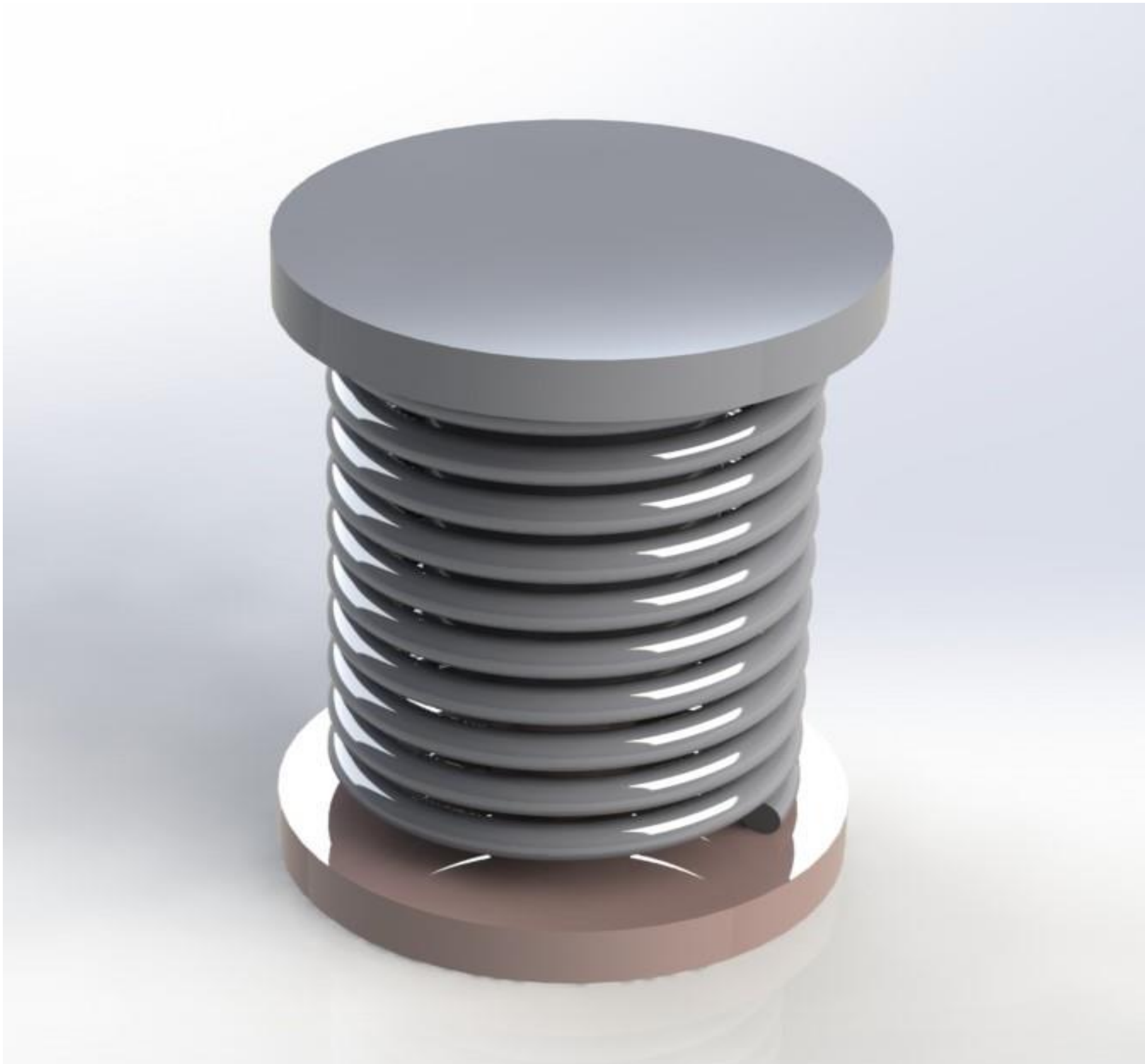

Figure 5.1: Kai Design

Among all 3 designs, the design of **Kai (ϰ)** is seems to be the mostoptimal one. The reasons behind choosing this design, is explained below:

Selecting the "Kai" design is beneficial due to its higher critical damping **(K = 1600 N/m),** which improves the system's response to external forces. Additionally, the use of High Carbon Steel offers cost-effectiveness, high strength, and wear resistance, making it suitable for various applications such as springs and knives. These features contribute to the overall performance and durability of the design.

The **"Kai"** design stands out for its enhanced critical damping, ensuring effective dissipation of energy and minimizing vibrations in the system. This is particularly valuable in applications like structures with tuned mass dampers (TMDs), where controlling oscillations is crucial, as indicated in the 20-story structure with 8 TMDs[2]. Moreover, the incorporation of High Carbon Steel not only adds to the robustness and wear resistance of the design but also makes it a cost-effective choice. The combination of these factors positions the "Kai" design as a well-rounded solution, offering both performance and economic advantages in various scenarios, including applications like springs and knives.

5.2- Design Optimization

To modify the "Kai" design, consider the following possibilities based on specific requirements or improvements needed:

1. Material Enhancement: Explore advanced materials or coatings to further improve strength, wear resistance, or corrosion resistance, depending on the application.

2. Optimized Damping: Fine-tune the damping parameters to achieve an optimal balance between stiffness and damping, enhancing the system's response to dynamic forces.

3. Structural Adjustments: Evaluate the structural configuration for potential optimizations, such as adjusting dimensions or geometries to enhance overall performance.

4. Integration of Smart Technologies: Incorporate sensors or smart technologies to enable real-time monitoring and adaptive responses, enhancing the design's efficiency and adaptability.

5. Cost Optimization: Investigate opportunities to streamline the manufacturing process or use alternative materials without compromising performance, aiming for a more cost-effective solution.

6. Environmental Considerations: Assess the design's environmental impact and explore modifications that align with sustainability goals, such as using eco-friendly materials or optimizing energy efficiency.

7. Multi-Functionality: Explore possibilities for the design to serve multiple functions, increasing its versatility and applicability across different scenarios.

8. Feedback Mechanisms: Implement feedback mechanisms that allow the design to dynamically adjust its parameters based on changing conditions or requirements.

By focusing on these modifications, potentiality of "Kai" design can be enhance. It would help the "Kai" design to better meet specific needs, whether they are related to performance improvements, cost considerations, or adaptability to different applications.

CHAPTER-6

Developing a prototype

Developing a prototype for a mass-spring-damper system involves several steps.

6.1- Governing Equations

- Mass (M)
- Spring (K)
- Damper (C)
- Damping force, D = -R dy/dt (R>0)
- Critical damping, K = $\frac{C^2}{4M}$
- Newton's Second Law, *F=ma*
- Damping Factor (ξ) = $\frac{\delta^2}{\sqrt{(4\prod)^2+\delta^2}}$
- Natural Frequency (ω_n) = $\sqrt{\frac{k}{m}}$ (in Rad/sec)

6.2- Design Parameter

- Max height = 60mm
- Spring diameter= 3mm

- Spring coils =10
- Spring distance from centre= 15mm

Material:

Stainless Steel.

High Carbon Steel.

6.3- Calculation

C = 80 Ns/m

M = 1 kg

Critical damping: K = $\frac{C^2}{4M}$

K = 1600 N/m

6.4- Technical specifications:

$\ddot{x} + 80\dot{x} + 1600x = F(t)$

X = 2.5m ; t = 10s **[10, 13]**

Damping Force, F = 4020.025

CHAPTER-7

Testing & evaluating the design solution

Testing and evaluating the design solution for a mass-spring-damper system is crucial to ensure it meets performance requirements and functions as intended. Here's a structured approach to testing and evaluating the design:

Mesh Sensitivity Analysis: Mesh sensitivity analysis is a technique used in finite element analysis (FEA) to assess the effect of mesh density on the accuracy of results. In the context of a mass-spring-damper system, mesh sensitivity analysis can help determine the appropriate mesh size for modeling the system components (e.g., mass, spring, damper) in FEA simulations.

- Multiple Iterations
- Total Deformation as reference
- Optimal Element Size: 3mm

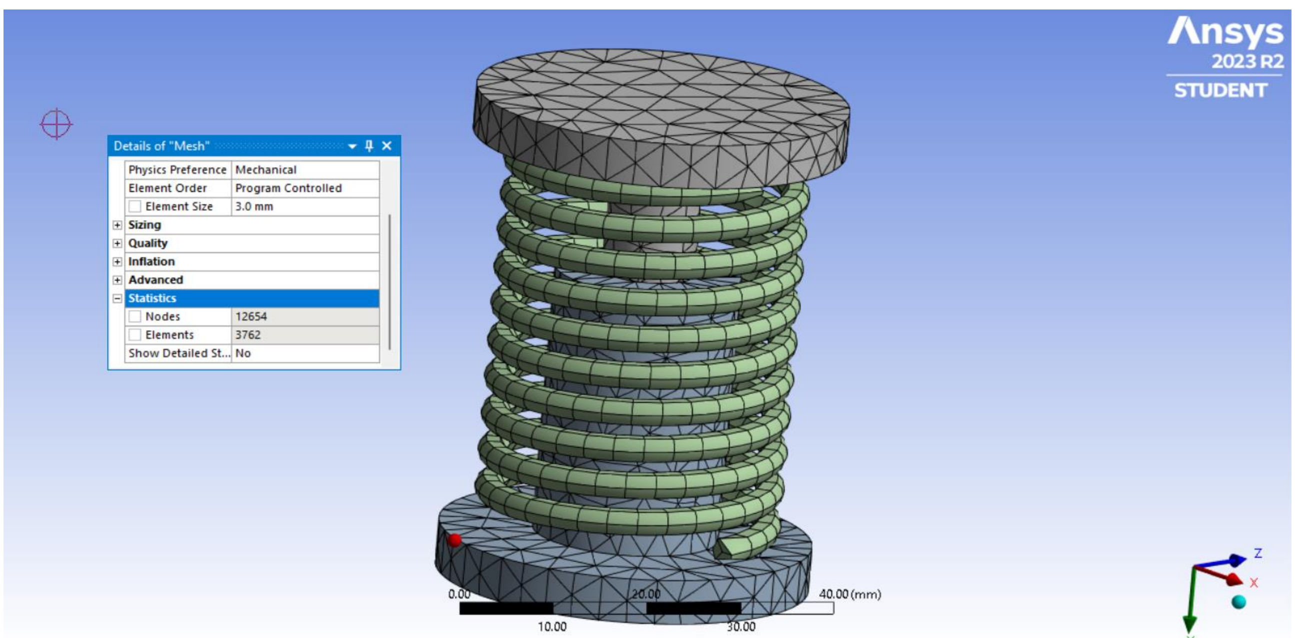

Fig 7.1: Mesh Sensitivity Analysis

Stress Testing: Stress testing for a mass-spring-damper system involves subjecting the components to extreme or accelerated loads to assess their structural integrity, durability, and performance under harsh conditions.

- Maximum Stress developed in the upper surface.
- Direction of force.
- Apply extreme or accelerated loads to the system to assess its structural integrity and robustness.
- Identify potential weak points or failure modes and make necessary design improvements to enhance reliability and durability.

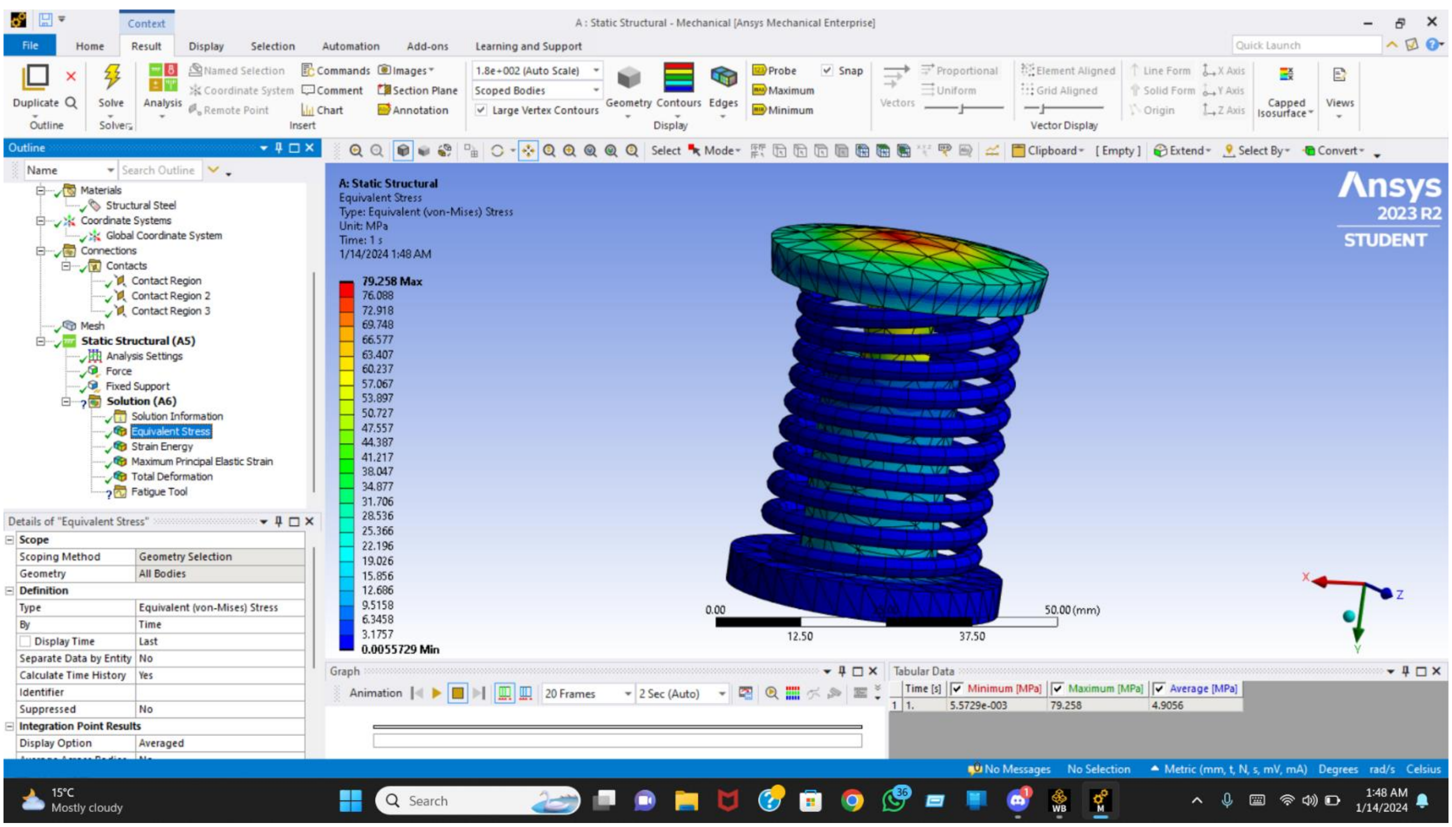

Fig 7.2: Stress Analysis

Strain Analysis: Strain analysis for a mass-spring-damper system involves evaluating the deformation or strain experienced by the system's components under various loading conditions.

- No strain on the spring element.
- Point of force application undergoes most strain.

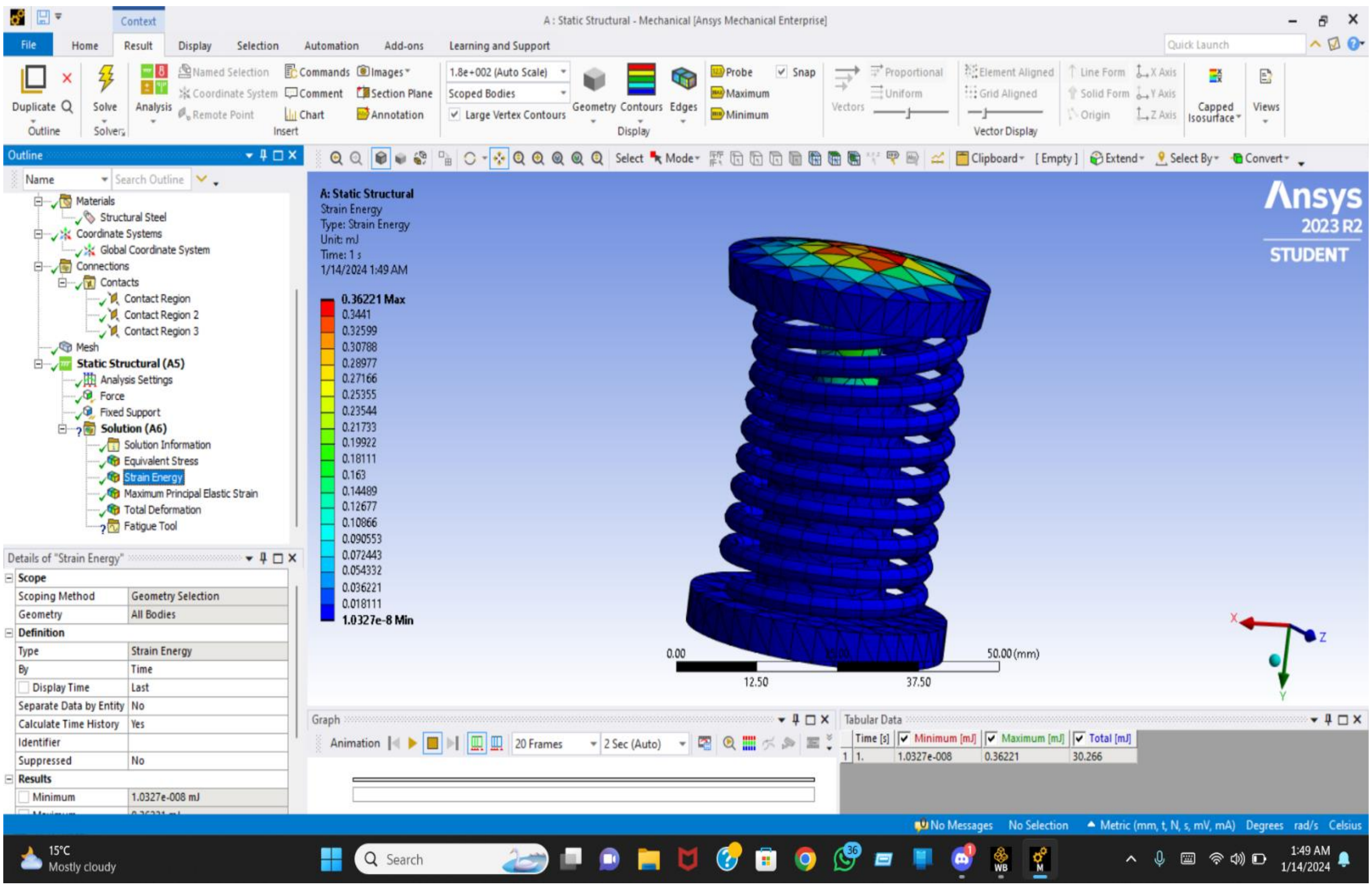

Fig 7.3: Strain Analysis

Deformation Analysis: Deformation analysis for a mass-spring-damper system involves evaluating the extent of deformation experienced by the system's components under various loading conditions.

- Maximum Deformation occurs in the outer region of the upper surface.

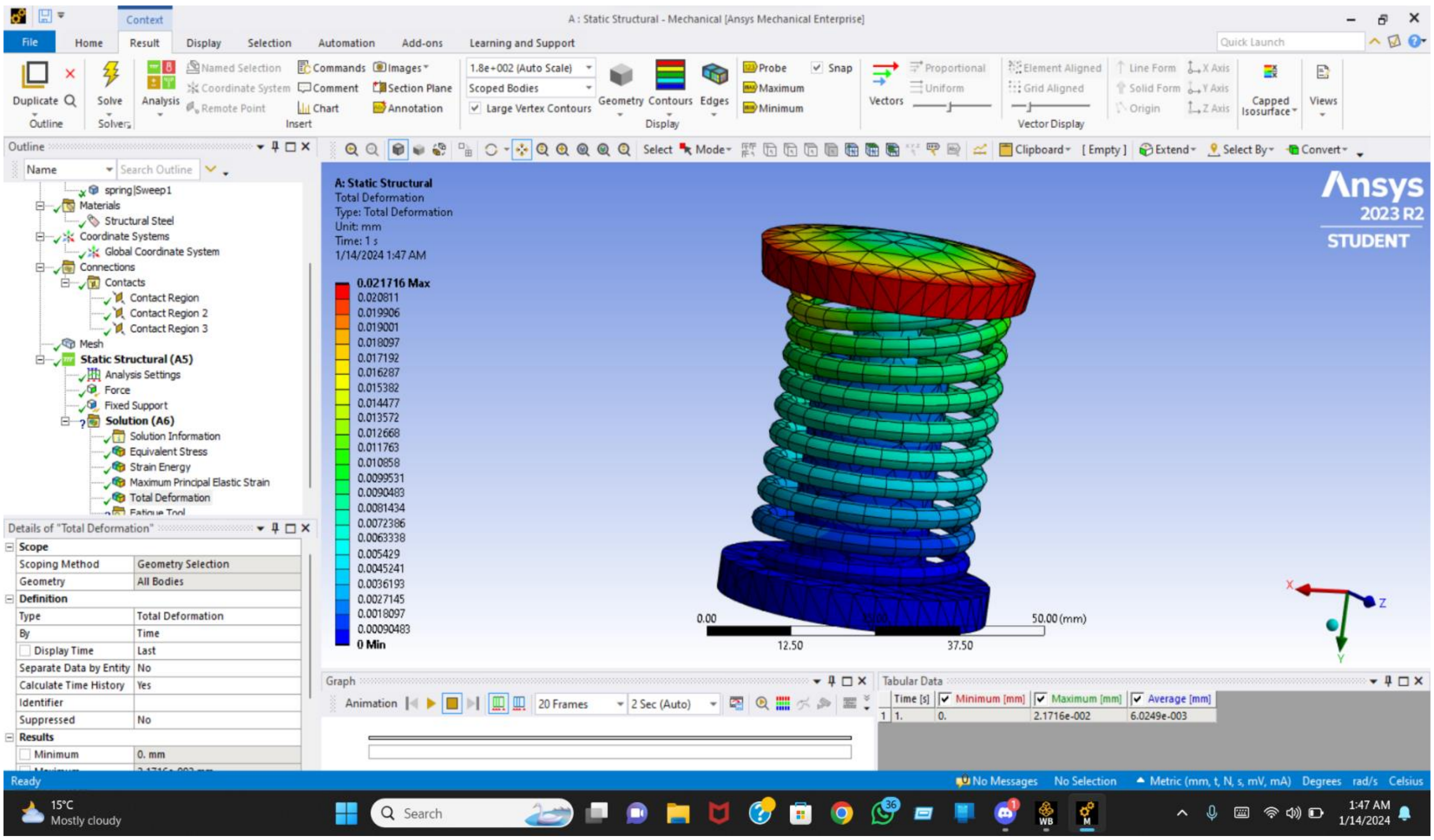

Fig 7.4: Deformation Analysis

Fatigue Failure: Fatigue failure can occur in the components of a mass-spring-damper system due to repeated or cyclic loading, leading to progressive damage and eventual failure over time.

- In a mass component, fatigue failure may manifest as cracks, fractures, or material degradation over time.
- Fatigue failure in a spring component can result from cyclic loading causing deformation and stress accumulation.
- Fatigue failure in a damper component may occur in internal elements such as seals, bearings, or damping mechanisms.

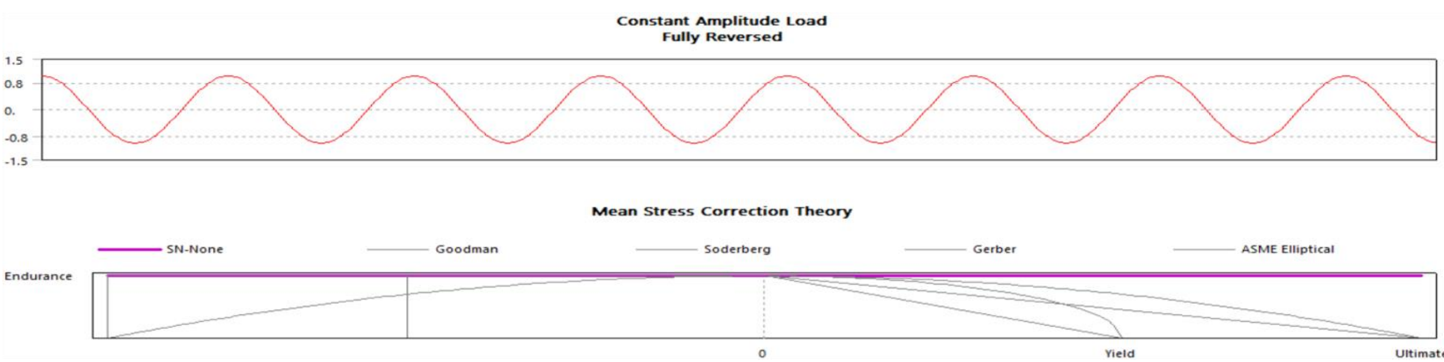

Fig 7.5: Fatigue Failure

Fatigue Life: To estimate the fatigue life of components within a mass-spring-damper system, various methods can be employed depending on the specific characteristics of each component and the loading conditions it experiences.

- # of cycles before failure
- Various prediction models like: Goodman diagram, S-N curves, and Miner's rule.

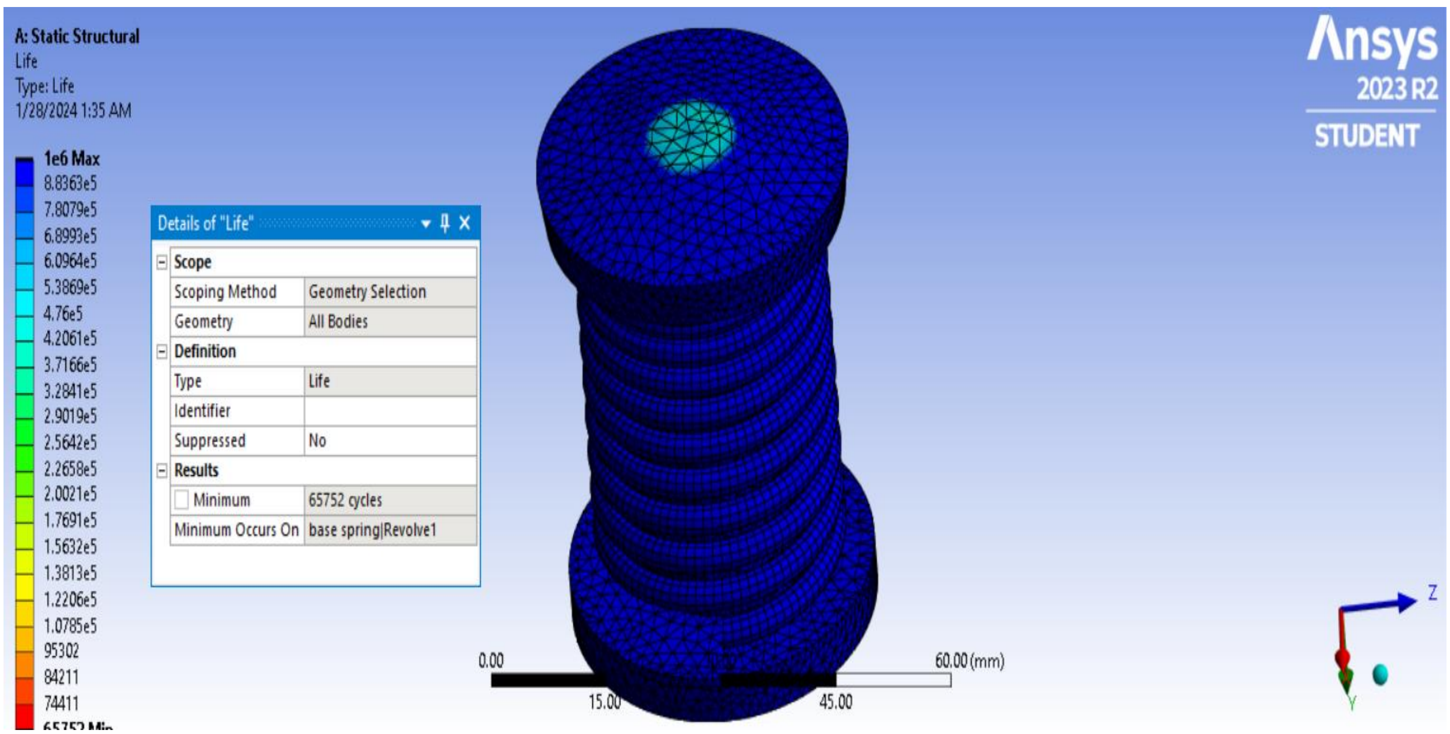

Fig 7.6: Fatigue Life

Fatigue Damage: To evaluate fatigue damage for a mass-spring-damper system, you typically assess each component individually for fatigue effects.

- Progressive structural deterioration caused by cyclic loading
- Depends on stress concentration, material properties, cumulative damage etc.

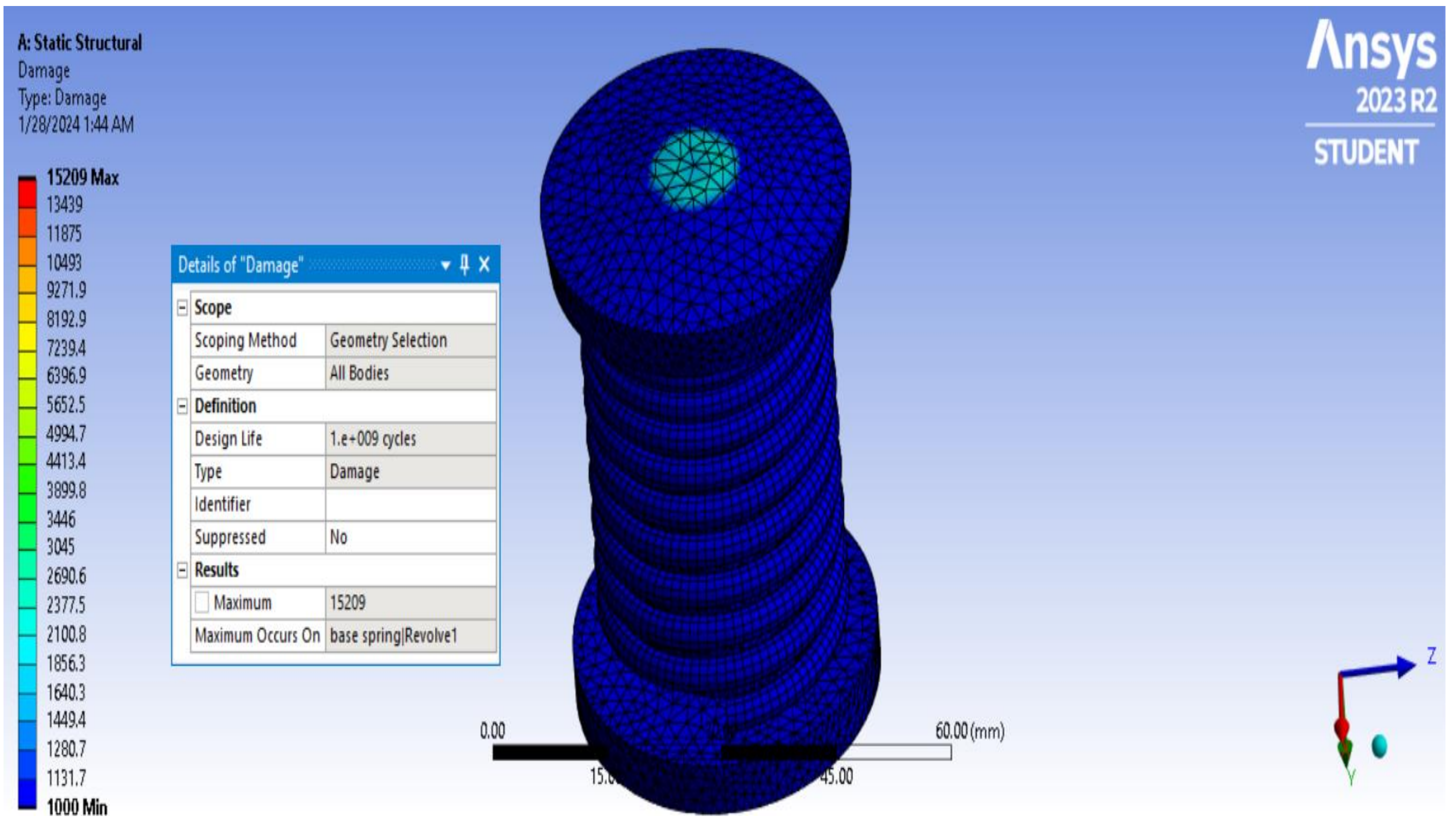

Fig 7.7: Fatigue Damage Analysis

Safety Factor: Calculating the safety factor for a mass-spring-damper system involves comparing the maximum expected load or stress that the system components may experience to their respective design limits. The safety factor indicates the margin of safety between the expected operating conditions and the component's capacity to withstand those conditions.

- Load-carrying capacity beyond what the system actually supports.
- Expression of reliability, robustness, resilience etc of a system.
- Risk management and component reliable.

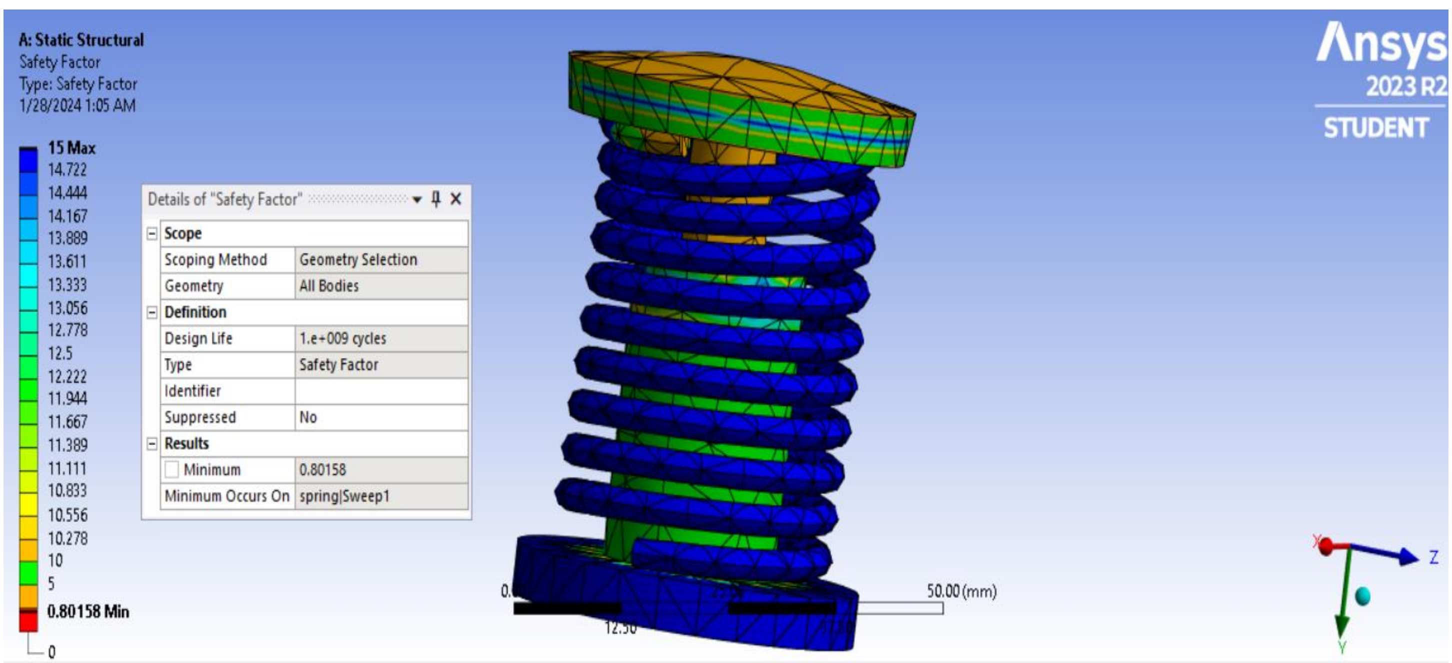

Fig 7.8: Safety Factor Analysis

Environmental Testing: Simulating harsh realities like humidity, temperature fluctuations, and UV radiation, we tested the gear's mettle for long-term outdoor operation.

A Design that Stands Strong:

Further analysis revealed a **high safety factor** across all tested load conditions, providing a robust margin of error and solidifying the design's resilience and reliability.

CHAPTER-8

Redesigning the solution with modifications

In order to redesign a spring mass damper system with modifications, several improvements and enhancements were made to optimize its performance and functionality. Here are some potential modifications that were considered for redesigning the system:

- **Adjustable Damping:** One of the key modifications to the spring mass damper system was the addition of an adjustable damping mechanism. By incorporating a variable or adjustable damping system, the damping force was tailored to specific operating conditions, allowing for improved control and performance in different situations.
- **Tunable Spring Stiffness:** Another modification to consider was the incorporation of a tunable spring stiffness mechanism. This was achieved through the use of adjustable springs or adding a mechanism to change the effective spring stiffness. By allowing the spring stiffness to be adjusted, the system was optimized for different load conditions and operating environments.
- **Active Control System:** Implementing an active control system significantly enhanced the performance of the spring mass damper system. By integrating sensors and actuators, the active control system was continuously monitored the system dynamics and actively adjusted the damping and spring stiffness to minimize vibrations and maximize energy dissipation.
- **Energy Harvesting:** Incorporating energy harvesting technology into the spring mass damper system, provided additional benefits. By capturing and storing

the energy dissipated by the damper, it was utilized to power other systems or devices, increasing the overall efficiency and sustainability of the system.

- **Advanced Materials:** Redesigning the spring mass damper system with advanced materials, such as shape memory alloys or carbon fiber composites, helped to improve the overall performance and durability of the system. These materials gave higher strength-to-weight ratios and improved damping characteristics, leading to a more efficient and reliable system.

By incorporating these modifications, the redesigned spring mass damper system helped to improve performance, adaptability, and efficiency in a wide range of engineering applications. These enhancements played a role to mitigate vibrations, reduce structuralfatigue, and enhance the overall reliability and longevity of the system.

CHAPTER-9

Conclusion

9.1 Concluding Remarks

In conclusion, the spring mass damper system holds great promise for the mitigation of vibrations and oscillations in various engineering applications. Its effectiveness in reducing structural response to dynamic loads has made it a valuable tool for improving the safety, comfort, and performance of buildings, bridges, and other structures. As research and development efforts continue, the future of the spring mass damper system looks promising, with advancements in control algorithms, adaptive systems, smart materials, and expanded applications expected to further enhance its effectiveness and versatility. Overall, the spring mass damper system is poised to play an increasingly important role in the field of engineering, offering innovative solutions for addressing dynamic response and vibration control in a wide range of applications.

9.2 Future Horizons:

The future horizons of the spring mass damper system look promising as researchers and engineers continue to explore new applications and improvements for the technology. One area of focus is the development of advanced control algorithms and adaptive systems that can enhance the performance of the damping system in various dynamic environments. This includes the use of artificial intelligence and machine learning algorithms tooptimize the response of the system to different external forces and disturbances[8]. Another area of research is the integration of smart materials and structures into the spring mass damper system, which can further enhance its effectiveness in reducing vibrations and oscillations[9]. This may involve the use of shape memory alloys, piezoelectric materials, or other advanced materials that can actively adjust the damping properties of the system in real time. Furthermore, the application of the spring mass damper system is expected to expand beyond traditional civil engineering andstructural applications. For example, the technology may find new uses in the automotive industry for improving vehicle suspension systems, as well as in aerospace and marine engineering for reducing vibrations in aircraft and ships. Overall, the future horizons of the spring mass damper system are bright, with ongoing research and development efforts aimed at enhancing itscapabilities and expanding its potential applications.

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