Department of Electronic and Telecommunication Engineering University of Moratuwa

EN2160- Electronic Design Realization

Design Methodology Document

Vibration Damping System for Machine Tools

Group K (29)

210204R Hansindu K.A.A.

210341H Liyanaarachchi L.A.S.

Contents

1 Introduction

The Design Methodology Document for the Vibration Damping System for Machine Tools was created following the Cambridge EDC Inclusive Design Methodology. This document provides a comprehensive overview of the project's development, focusing on designing a data acquisition system for vibrational data and a spring and damper system to enhance the performance and reliability of machine tools. The primary objectives of this project are to minimize vibrations that can affect the precision and longevity of machine tools and to provide a robust data acquisition framework for continuous monitoring and analysis.

The methodology employed ensures that the design process is thorough, inclusive, and user-centered, incorporating feedback from a wide range of stakeholders including engineers, developers, manufacturers, and end-users. This approach not only improves the design's functionality but also ensures its practical applicability in real-world scenarios.

Key aspects of the design process include:

- **Review of Existing Solutions**: Analyzing current industry practices and academic research to understand the state-of-the-art in vibration damping systems.
- **Stakeholder Engagement**: Identifying and involving key stakeholders to gather requirements and ensure the design meets their needs.
- **User Observation and Feedback**: Studying how different users interact with machine tools and identifying their needs and pain points.
- **Concept Development**: Generating multiple design concepts and evaluating them against established criteria to select the most effective solution.
- **Detailed Design and Prototyping**: Creating detailed schematics and prototypes, followed by rigorous testing to validate the design.

The document is structured to provide a clear and detailed account of each phase of the project, ensuring transparency and facilitating future enhancements. This systematic and inclusive approach ensures the development of a reliable, efficient, and user-friendly vibration damping system that can significantly improve the operational efficiency and precision of machine tools.

2 Review Progress

A thorough analysis of the current advancements in vibration-damping systems for machine tools was conducted, drawing insights from industry practices, academic research, and existing commercial solutions. This review provided a solid foundation for our project's objectives and methodology.

2.1 Academic Research

Research papers highlight the importance of accurately identifying the natural frequencies of machine tools to design effective damping systems. Techniques using accelerometers and signal processing algorithms have been widely studied.

2.1.1 Analysis of Vibration Damping in Machine Tools

Description: This study provides a detailed analysis of energy dissipation mechanisms in machine tools, incorporating frictional forces, control loops, and modal damping into numerical models.

Key Findings: Highlights the significance of integrating these mechanisms for accurate dynamic behavior prediction, crucial for optimizing material removal and minimizing oscillations.

Reference: Bianchi, G. et al., 2014. "Analysis of Vibration Damping in Machine Tools," Procedia CIRP.

Link: Analysis of Vibration Damping in Machine Tools

2.1.2 Vibration Damping Control of Robot Arm Intended for Service Application in Human Environment

Description: This study investigates the vibration-damping control of an anthropomorphic robot arm designed for service applications, focusing on improving safety and performance during physical interactions with humans and the environment.

Key Findings: The research demonstrates that by using torque measurement in each joint and tactile area recognition, the proposed vibration damping control significantly reduces oscillations in heavily loaded joints. This is achieved through acceleration signal feedback and a lead controller, enhancing the robot's smooth continuous motion and ensuring safer interactions with humans.

Reference: Tsetserukou, D., Kawakami, N., & Tachi, S. (2008). "Vibration Damping Control of Robot Arm Intended for Service Application in Human Environment," 2008 8th IEEE-RAS International Conference on Humanoid Robots (Humanoids 2008). DOI: 10.1109/ICHR.2008.4756002

Link: Vibration damping control of robot arm intended for service application in the human environment

2.1.3 Active Vibration Control for a CNC Milling Machine

Description: Explores adaptive vibration control methods for CNC milling machines, focusing on improving surface finish, reducing tool wear, and compensating for structural vibrations under high-speed machining conditions.

Key Findings: The active vibration control system uses sensors and adaptive controllers to measure and mitigate vibrations, resulting in improved machining accuracy and surface quality. The study demonstrated significant vibration reduction and enhanced stability in CNC milling operations.

Reference: Ford, D.G., Myers, A., Haase, F., Lockwood, S., & Longstaff, A.P. (2013). "Active Vibration Control for a CNC Milling Machine," Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science. DOI: 10.1177/0954406213484224

Link: Active vibration control for a CNC milling machine

2.1.4 Active Vibration Damping with Magnetic Actuators

Description: Explores the use of magnetic actuators for active damping of machine tools, focusing on reducing chatter and improving machining stability.

Key Findings: Effective in suppressing vibrations, enhancing tool performance, increasing dynamic stiffness, and significantly improving chatter-free material removal rates.

Reference: Chen, F., Hanifzadegan, M., Altintas, Y., & Lu, X. (2015). "Active Damping of Boring Bar Vibration With a Magnetic Actuator," IEEE/ASME Transactions on Mechatronics, 20(6), 1-12. DOI:

Link: Active Damping of Boring Bar Vibration With a Magnetic Actuator

2.1.5 Hybrid Damper with Tunable Particle Impact Damping and Coulomb Friction

Description: This study examines a hybrid damper combining a particle impact damper (PID) and a Coulomb friction damper (FD). It highlights the advantages of both damping technologies, aiming to improve the damping capacity of the PID and FD. The damper is theoretically modeled and experimentally tested on a single-degree-of-freedom (SDOF) structure.

Key Findings: The proposed hybrid damper effectively reduces the maximum vibration amplitude by 66% and 43% compared to using the FD and PID only, respectively. It is also effective over a wide range of excitation frequencies and does not require an optimally tuned natural frequency and damping, unlike traditional tuned mass dampers (TMDs).

Reference: Akbar, M.A., Wong, W.-O., & Rustighi, E. (2023). "A Hybrid Damper with Tunable Particle Impact Damping and Coulomb Friction," Machines, 11(5), 545. DOI: 10.3390/machines11050545

Link: Hybrid Damper with Tunable Particle Impact Damping and Coulomb Friction

2.2 Industry Developments

Industry advancements in vibration-damping systems for machine tools have led to the development of both active and passive solutions designed to enhance machining precision and tool life. These products demonstrate significant advancements in reducing vibrations, thereby enhancing machining performance and tool longevity.

2.2.1 Sandvik Coromant - Silent Tools™ Turning Adapters

Description: The Silent Tools™ turning adapters by Sandvik Coromant feature an advanced internal damping mechanism designed to reduce vibrations during machining operations with long overhangs. The damping unit consists of a heavy mass supported by rubber spring elements and an oil-filled cavity, which enhances the damping effect.

Key Features: Enhanced damping mechanism, improved surface finish, increased tool life, and efficient performance in long overhang operations.

Applications: Ideal for internal turning operations with extended tool lengths.

Link: Silent Tools™ for turning

Figure 1: Silent Tools™ cylindrical turning adaptors

2.2.2 Big Daishowa - Smart Damper

Description: The Smart Damper by Big Daishowa integrates a damping mechanism close to the cutting edge, which significantly reduces vibrations in deep boring applications. The system is designed for both fine and rough boring operations.

Key Features: High efficiency in deep hole finish boring, improved surface finish, and extended tool life.

Applications: Ideal for boring operations requiring high precision and minimal vibration.

Link: Damping Tools

Figure 2: Smart Damper Basic Holders for Mills HSK-A

2.2.3 Seco Tools - Steadyline® Vibration Damping System

Description: The Steadyline® system by Seco Tools is designed for high rigidity and stability during extreme cutting conditions. It employs a dynamic passive damping system within the holder body, where a damping mass counteracts flexural vibrations.

Key Features: Available in various bar sizes (6xD, 8xD, 10xD), features coolant supply channels, and quick mounting and setting procedures.

Applications: Suitable for roughing and finishing operations with long overhang tools, providing high metal-removal rates and smooth surface finishes.

Link: Seco expands Steadyline® vibration damping system with boring bars

Figure 3: Seco expands Steadyline® vibration damping system with boring bars

2.2.4 Makino - ADVANTiGE Active Damping System

Description: The ADVANTiGE system by Makino adjusts frictional forces based on low-frequency vibration sensing to avoid chatter and cutter damage in real-time. This active damping system significantly enhances machining performance by enabling deeper cuts and higher metal-removal rates.

Key Features: Real-time vibration suppression, reduced tool wear, and improved machining accuracy.

Applications: Particularly effective in titanium machining and other high-stress cutting operations.

Link: Makino - ADVANTiGE Active Damping System

2.3 Summary of Findings

- **Real-Time Adaptability:** Active systems using sensors and control algorithms are highly effective in dynamically adjusting to vibrations, offering significant improvements in machining accuracy and tool longevity.
- **Hybrid Solutions:** Combining different damping mechanisms (e.g., particle impact and spring-damper systems) provides a versatile solution that can address a broader frequency range.
- **Cost-Effectiveness:** While active systems offer precise control, passive systems are more cost-effective and easier to implement, making them suitable for smaller workshops with budget constraints.

2.4 Progress

Upon receiving approval for the project, we began by planning the architecture of the Vibration Damping System (VDS) for machine tools, which features two primary components: the damping mechanism and the control module. The damping mechanism is designed to reduce vibrations passively. The control module serves as the command center, monitoring vibration levels.

The initial stage of the project focuses on designing and simulating the circuit schematics and mechanical layouts to ensure the VDS will achieve its targeted goals. Significant progress has been made in drafting the schematics for both the damping mechanism and control module circuits. While the design of the control module is advancing smoothly, we have encountered challenges with the damping mechanism due to the need for precise tuning and component selection to maximize efficiency and minimize space requirements.

To overcome these obstacles, we are continuously reviewing and refining our designs. This involves experimenting with various strategies, such as exploring alternative components, adjusting layout configurations, and employing advanced signal processing algorithms for vibration detection and control. We are also integrating feedback from experts and conducting peer reviews to address potential issues proactively.

Throughout the design phase, we regularly review our progress to ensure alignment with project timelines and goals. This iterative process allows us to make necessary adjustments and improvements to the schematics. Once the circuit designs are complete and validated through rigorous testing, we will transition to implementing the circuits on prototype boards. These prototypes will undergo comprehensive laboratory testing to ensure they meet performance, safety, and reliability standards.

Successful validation of the prototypes will pave the way for developing printed circuit boards (PCBs) using surface-mounted electronic components, enhancing the compactness and suitability of the system for industrial applications. Our ongoing review process includes testing various use-case scenarios and monitoring the interaction between the VDS components to ensure optimal performance.

As we finalize the PCB designs, our focus will shift to designing and manufacturing an enclosure that meets industry standards and provides adequate protection for the VDS hardware. Additionally, we aim to develop a user-friendly interface that allows operators to monitor and control the system easily. This interface will provide real-time data on vibration levels and system performance, enabling proactive maintenance and adjustment of the damping mechanism.

By continuously refining our approach and incorporating user feedback, we strive to deliver a top-tier, reliable, and efficient vibration-damping system for machine tools, enhancing machining precision and tool longevity.

3 Identification Of Stake Holders

Creating a stakeholder map for the Vibration Damping System for Machine Tools involves identifying and categorizing the various stakeholders involved in the development, implementation, and use of the system. This categorization helps in understanding their roles, interests, and influence on the project, ensuring effective engagement and management strategies are in place to optimize project outcomes.

3.1 Stakeholders Identified

3.1.1 Engineers and Developers

- **Description:** Responsible for designing and developing the vibration-damping system. This includes mechanical engineers, electrical engineers, and software developers.
- **Interest/Influence:** High interest, high influence.

3.1.2 Manufacturers of Machine Tools

- **Description:** Companies involved in producing machine tools that could benefit from vibration-damping technology. Their input is crucial for integration and compatibility.
- **Interest/Influence:** High interest, high influence.

3.1.3 End Users

- **Description:** Operators who will use the machine tools equipped with the vibration damping technology. Their feedback on usability and effectiveness is valuable.
- **Interest/Influence:** High interest, medium influence.

3.1.4 Maintenance Technicians

- **Description:** Individuals responsible for maintaining and servicing the vibration-damping system and the machine tools it's integrated with.
- **Interest/Influence:** Medium interest, medium influence.

3.1.5 Quality Control Managers

- **Description:** Personnel ensuring that the vibration-damping system meets quality standards and performance expectations.
- **Interest/Influence:** Medium interest, medium influence.

3.1.6 Safety Regulators

- **Description:** Government agencies or industry organizations responsible for ensuring the safety standards of industrial machinery, including vibration-damping systems.
- **Interest/Influence:** High interest, high influence.

3.1.7 Investors

- **Description:** Individuals or entities financially invested in the development and success of the vibration-damping system project.
- **Interest/Influence:** High interest, high influence.

3.1.8 Suppliers

- **Description:** Companies providing components or materials necessary for the production of the vibration-damping system.
- **Interest/Influence:** Medium interest, medium influence.

3.1.9 Training Instructors

- **Description:** Personnel responsible for training end-users on operating and maintaining the vibration-damping system effectively.
- **Interest/Influence:** Medium interest, low influence.

3.1.10 Competitors

- **Description:** Other companies developing similar vibration-damping technologies or alternative solutions.
- **Interest/Influence:** High interest, high influence.

3.1.11 Industry Associations

- **Description:** Groups representing the interests of manufacturers, engineers, or users within the machine tool industry.
- **Interest/Influence:** Medium interest, medium influence.

3.1.12 Research Institutions

- **Description:** Universities or research centers conducting studies on vibration-damping technology and its applications.
- **Interest/Influence:** High interest, medium influence.

3.2 Stakeholder Map

The stakeholder map diagram visually represents the various stakeholders involved in the Vibration Damping System for Machine Tools project. It categorizes stakeholders based on their levels of interest and influence, facilitating effective engagement and management strategies.

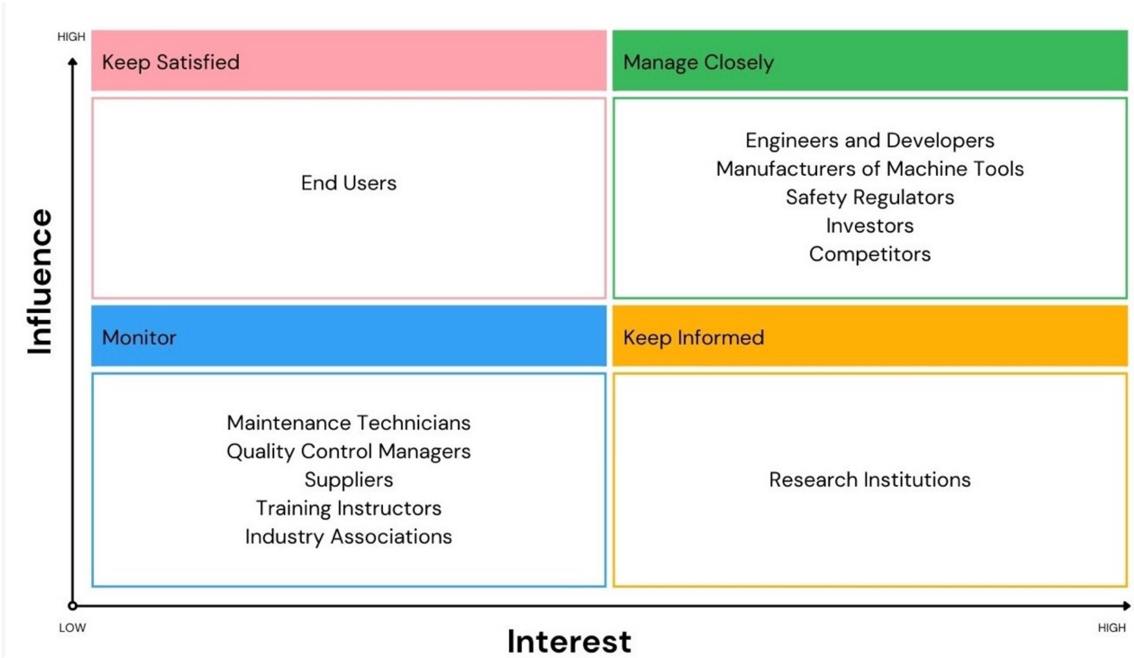


Figure 4: Stakeholder Map

This systematic classification ensures thorough engagement with key stakeholders and maintains regular communication channels with those deemed most critical. By aligning stakeholder engagement strategies with their respective levels of interest and influence, project stakeholders can be effectively managed to optimize project outcomes.

Competitors Examples

- Sandvik Coromant
- Seco Tools
- BIG Daishowa

By incorporating these stakeholder management strategies, we aim to ensure that all relevant parties are engaged appropriately throughout the project life cycle, thereby maximizing the potential for successful outcomes.

4 Observe Users

The objective of this section is to identify how different types of users interact with the Vibration Damping System (VDS) for machine tools, ascertain their needs and challenges, and evaluate the system's performance in meeting these requirements. This information is vital for guiding design enhancements that cater to a diverse range of user scenarios and needs.

4.1 User Profiles

Observing various categories of users and their specific interaction with the VDS provides insights into how the system can be optimized to meet their needs:

4.1.1 Machine Tool Operators

Operators who work directly with machine tools equipped with Vibration Damping Systems. Their primary focus is on achieving precise machining outcomes, minimizing tool wear, and ensuring smooth operations.

- How operators adjust the VDS settings during different machining operations, ease of use, and their feedback on vibration reduction effectiveness.

4.1.2 Maintenance Technicians

Individuals are responsible for the upkeep and maintenance of the machine tools and the VDS. They need the system to be reliable and easy to troubleshoot.

- Frequency of maintenance required, common issues faced, and effectiveness of the VDS in reducing wear and tear.

4.1.3 Quality Control Managers

Personnel ensure that the VDS meets quality standards and enhances the machining process. They focus on the consistency and reliability of the vibration damping.

- Impact of the VDS on product quality, ease of monitoring system performance, and integration with quality control processes.

4.1.4 Production Managers

Managers overseeing the overall production process, who are interested in the efficiency and productivity gains provided by the VDS.

- Improvements in production speed and output, reduction in downtime due to machine vibrations, and overall cost savings.

4.2 User Needs and Requirements

Through observation, the following user needs and requirements should be identified and analyzed:

4.2.1 Scalability

The VDS should be adaptable to various machine types and operational scales. This includes the ability to handle different levels of vibration and integrate with a wide range of machine tools.

- Flexibility in system configuration, ease of scaling the solution up or down, and adaptability to different operational conditions.

4.2.2 Safety and Reliability

Users across all sectors prioritize a system that provides robust safety features and consistent reliability. This includes protection against system failures and ensuring operational safety.

- Frequency of system failures, effectiveness of safety features, and user confidence in the system's reliability.

4.2.3 Monitoring and Reporting

The VDS should provide real-time monitoring of key metrics such as vibration levels, system status, and performance data. It should offer users easy access to this data, possibly through user-friendly interfaces and data visualization tools.

- User interactions with monitoring tools, ease of accessing and interpreting data, and the usefulness of the provided information in decision-making.

4.2.4 Ease of Use

The user experience with the VDS should be intuitive and straightforward. This involves examining the system's installation, configuration, and daily operation for different types of users.

- Complexity of system setup and configuration, user training requirements, and overall user satisfaction with the interface.

4.3 User Feedback and Pain Points

Gathering user feedback and identifying pain points is crucial to improving the Vibration Damping System.

4.3.1 Complexity

Observing users' ability to understand and operate the VDS, focusing on whether they find the system complex and if any particular areas require simplification.

- Specific components or processes users struggle with, suggestions for simplifying operations, and overall user comfort with the system.

4.3.2 Integration

Evaluate the VDS's compatibility and ease of integration with other systems, such as machine control systems, quality control tools, and data management systems.

- Challenges in integrating the VDS with existing systems, compatibility issues, and user satisfaction with the integration process.

4.3.3 Support and Documentation

Investigate the level of support provided, including documentation quality and customer service responsiveness. Proper support and comprehensive documentation play a significant role in the user's experience.

- Availability and usefulness of support resources, quality of documentation, and user satisfaction with customer service.

4.4 Real-World Use Cases

Analyzing real-world applications and use cases provides practical insights.

4.4.1 Application in High-Precision Machining

Assess the VDS's performance and adaptability in maintaining precision during high-speed machining operations.

- Improvements in precision, reduction in tool wear, and overall system stability during complex machining tasks.

4.4.2 Application in Heavy-Duty Industrial Settings

Evaluate how the VDS handles the specific requirements of heavy-duty industrial applications, including the ability to manage high levels of vibration.

- Effectiveness in reducing vibrations in heavy-duty operations, impact on machine longevity, and improvements in operational safety.

4.4.3 Application in Small-Scale Workshops

Examine how the VDS meets the needs of smaller workshops, ensuring ease of use and affordability while maintaining performance and safety.

- User satisfaction in small-scale settings, cost-benefit analysis, and any specific challenges faced by smaller operations.

By systematically observing users across these various categories and their interactions with the VDS, the design team can derive actionable insights for enhancing the system's functionality, ease of use, and reliability across a broad range of applications. This will enable the creation of a robust and versatile VDS that meets the diverse needs of its users.

5 Need List

To ensure the Vibration Damping System (VDS) for machine tools meets user needs effectively, the following user requirements have been identified. These requirements are derived from observations and interactions with various user groups, including machine operators, maintenance technicians, quality control managers, and production managers.

5.1 Ease of Installation

- **User Requirement:** The VDS should be designed with a focus on user accessibility, featuring a streamlined installation process that demands minimal technical expertise or specialized tools.

- **Implementation:** Comprehensive installation guides should provide clear step-by-step instructions, helping users navigate the setup process efficiently and accurately, reducing the chance of installation errors and ensuring a successful initial configuration.

5.2 User-Friendly Operation

- **User Requirement:** The VDS should offer a highly intuitive interface with user-centric controls, allowing operators to navigate the system effortlessly and efficiently.

- **Implementation:** A centralized monitoring system should provide real-time access to essential metrics, such as vibration levels, system status, and performance data, empowering users to make informed decisions and maintain optimal system performance.

5.3 Extensive System Visibility

- **User Requirement:** The VDS should offer in-depth visibility into system status and performance, granting users access to detailed data and analytics regarding the health and condition of the machine tools.

- **Implementation:** Such comprehensive insight facilitates strategic decision-making, enabling users to manage system performance, forecast maintenance needs, and optimize overall operational strategies.

5.4 Reduced Maintenance Requirements

- **User Requirement :** Routine maintenance tasks, such as firmware updates and system diagnostics, should be straightforward and manageable even for users with limited technical expertise.

- **Implementation:** The VDS should include self-diagnostic capabilities that enable continuous monitoring and analysis of system performance, proactively identifying and addressing potential issues to ensure smooth, uninterrupted operation.

5.5 Streamlined System Management

- **User Requirement:** The VDS should integrate advanced functionalities that simplify system management, such as adaptive damping algorithms and efficient vibration control methods, to promote the longevity and sustained performance of the machine tools.

- **Implementation:** Its intelligent features should contribute to enhanced machine efficiency, reducing wear and extending the machine's usable life, which in turn supports overall productivity goals.

5.6 Proactive Issue Resolution

- **User Requirement:** The VDS should incorporate sophisticated monitoring and diagnostic tools that proactively identify potential issues and anomalies within the machine tools.

- **Implementation:** By addressing issues before they become critical, the VDS should minimize system downtime, increase safety, and enhance operational efficiency, leading to greater overall reliability and user satisfaction.

By addressing these user requirements, the VDS for machine tools can be optimized to meet the diverse needs of its users, ensuring a robust and user-friendly system that enhances overall productivity and reliability.

6 Stimulate Ideas

To develop innovative solutions for the Vibration Damping System (VDS) for machine tools, we employed several idea stimulation techniques. These methods foster creativity, collaboration, and thorough exploration of potential solutions.

6.1 Idea Stimulation Techniques Used

6.1.1 Research and Benchmarking

- **Approach:** Conducting extensive research on existing vibration damping technologies and benchmarking against industry standards.
- **Benefits:** Identifies current best practices, uncovers gaps in the market, and provides a foundation for developing advanced solutions.

6.1.2 Peer Discussion

- **Approach:** Engaging in regular discussions with peers and experts to share knowledge, experiences, and insights related to vibration damping technology.
- **Benefits:** Promotes knowledge exchange, sparks new ideas, and offers diverse perspectives on potential solutions.

6.1.3 Mind Mapping

- **Approach:** Utilizing mind mapping tools to visually organize thoughts and ideas related to the VDS project.
- **Benefits:** Helps in identifying connections between different concepts, encourages structured thinking, and facilitates brainstorming sessions.

6.1.4 Brainstorming

- **Approach:** Conducting structured brainstorming sessions to generate a wide range of ideas and solutions for the Vibration Damping System.
- **Benefits:** Encourages free thinking, allows for the rapid generation of ideas, and promotes team collaboration. Rules such as "no idea is a bad idea" and "build on others' ideas" are followed.

6.1.5 Conceptual Design Creation

- **Approach:** Developing multiple conceptual designs to explore various approaches to vibration damping.
- **Benefits:** Visualizes potential solutions, allows for comparison of different designs, and facilitates the evaluation of their feasibility and effectiveness.

6.2 Process Overview

6.2.1 Conduct Comprehensive Research

Gather information on existing technologies, materials, and methodologies related to vibration damping.

6.2.2 Initiate Discussions

Regularly scheduled meetings with team members and experts to discuss the project and share insights.

6.2.3 Create Mind Maps

Use mind mapping to organize ideas, identify key concepts, and establish relationships between different elements of the Vibration Damping System project.

6.2.4 Brainstorm Sessions

Host brainstorming sessions where all team members contribute ideas without criticism. Document all suggestions for further analysis.

6.2.5 Develop Conceptual Designs

Translate the most promising ideas into conceptual designs. Create sketches and models to visualize each concept.

6.2.6 Evaluate Designs

Assess each conceptual design for feasibility, cost, effectiveness, and potential impact. Select the best ideas for further development.

By integrating these techniques, we can ensure a thorough exploration of potential solutions, leading to innovative and effective designs for the VDS.

7 Conceptual Design

In the course of our collaborative efforts, both within our core team and with our wider project stakeholders, we have developed several conceptual designs for our product. These designs meticulously detail both the aesthetic exterior and the internal functional architecture, showcasing how each component interacts within the system. We have developed four design sketches accompanied by functional block diagrams to illustrate our proposed concepts.

7.1 Concept - 1

7.1.1 Overview

Concept 1 presents a portable DAQ device with a Wi-Fi connection, USB charging, and an OLED display, eliminating the need for a wired connection and enabling easy data transfer for vibration analysis over WIFI using a Wi-Fi-compatible MCU.

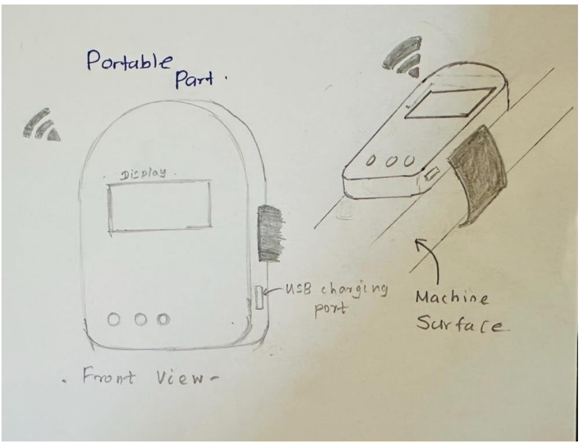


Figure 5: Conceptual Design 1

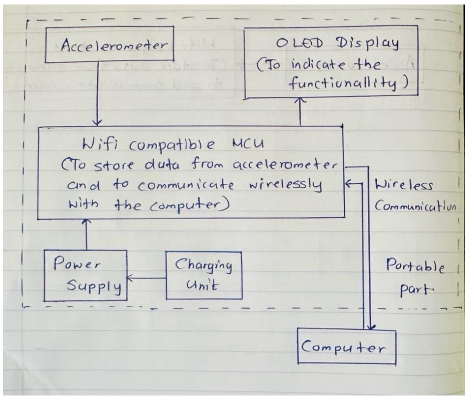


Figure 6: Functional Block Diagram 1

7.1.2 Key Features

- **Portable and Compact:** The device is designed to be easily attached to machine surfaces and carried around as needed.
- **Wireless Communication:** Equipped with a Wi-Fi-compatible microcontroller unit (MCU), the device communicates wirelessly with a computer, facilitating real-time data transfer and analysis.
- **Display and Interface:** An OLED display provides real-time feedback and operational status, enhancing user interaction.
- **Power Supply:** The device includes a rechargeable battery with a USB charging port, ensuring continuous operation without the need for frequent battery replacements.

7.1.3 Benefits

- **Ease of Use:** The portable nature and wireless communication eliminate the hassle of dealing with cables, making it user-friendly and easy to deploy in various settings.
- **Real-Time Monitoring:** Allows for real-time data acquisition and analysis, enabling prompt responses to vibration issues.
- **Versatility:** Suitable for a wide range of machine tools and environments due to its compact and flexible design.

7.2 Concept - 2

7.2.1 Overview

Concept 2 integrates a wired connection with separate sections for data acquisition and display, incorporating a dedicated power supply. This design favors a direct cabled power source and computational division, foregoing Wi-Fi connectivity and USB charging for potentially enhanced stability and processing power.

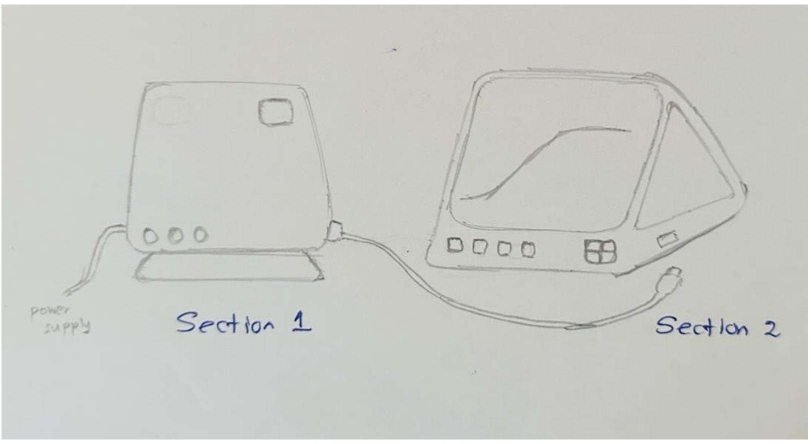


Figure 7: Conceptual Design 2

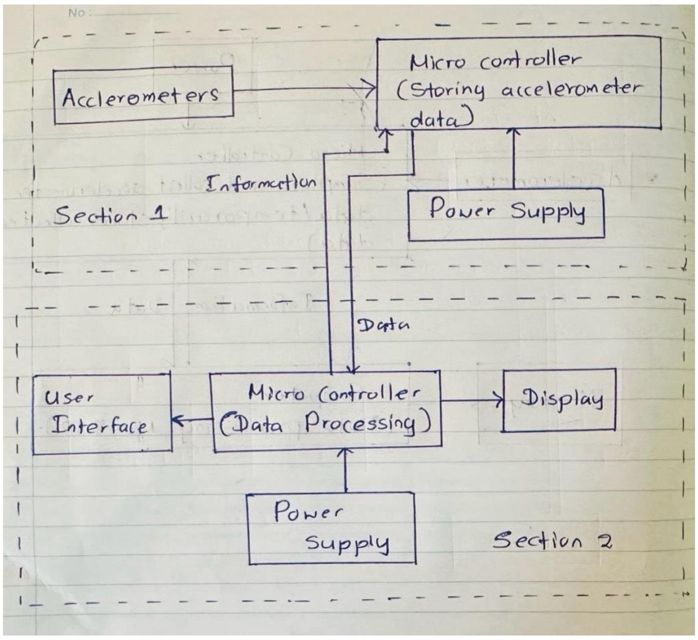


Figure 8: Functional Block Diagram 2

7.2.2 Key Features

- **Sectional Design:** The system is divided into two sections - one for data acquisition and another for data processing and display.
- **Wired Communication:** Ensures stable and reliable data transfer between sections.
- **Dedicated Power Supply:** Provides continuous and consistent power to both sections, reducing the risk of power interruptions.

7.2.3 Benefits

- **Enhanced Stability:** Wired connections provide more stable and reliable data transfer compared to wireless systems.
- **Robust Design:** Suitable for environments where wireless communication might be unreliable or undesirable.

7.3 Concept - 3

7.3.1 Overview

This design utilizes a wired accelerometer and omits the digital display, focusing on direct data acquisition and processing through a lightweight cable connection to a computer. The emphasis is on a simple, robust system that prioritizes data accuracy and processing efficiency.

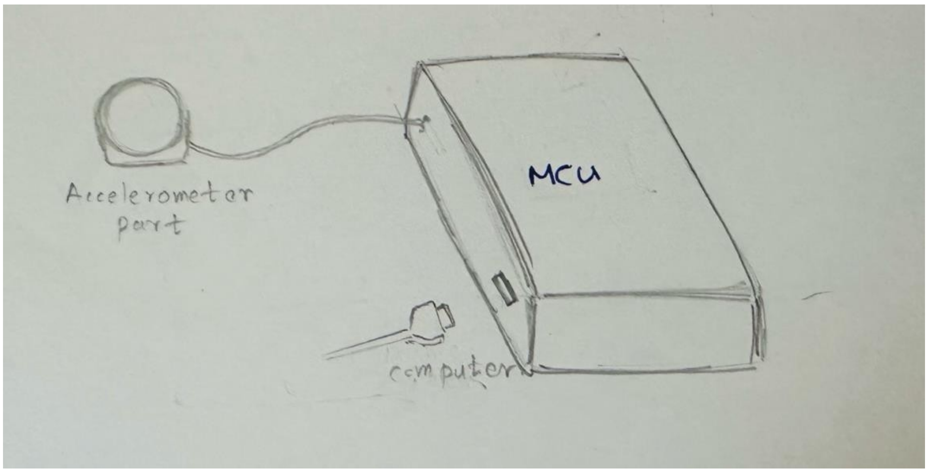


Figure 9: Conceptual Design 3

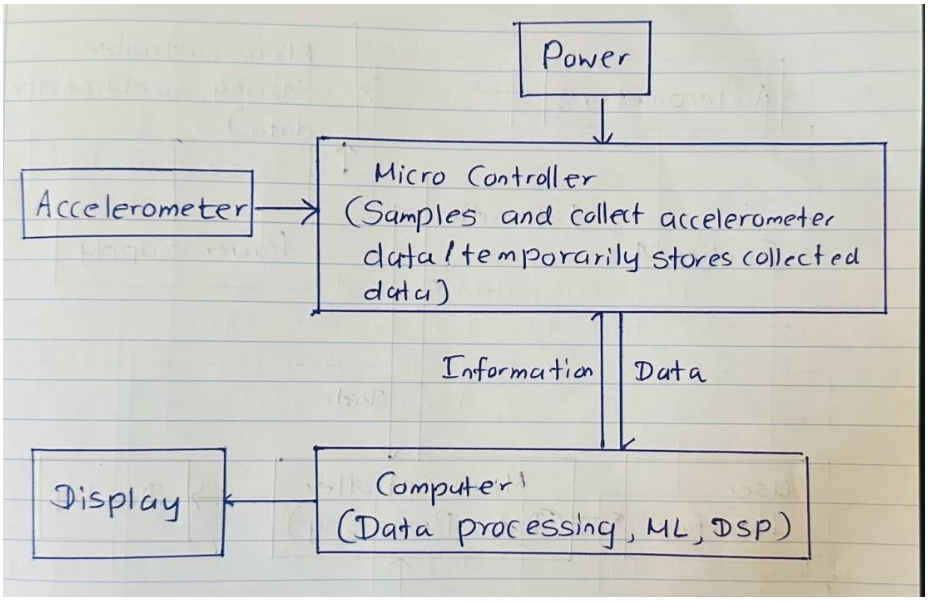


Figure 10: Functional Block Diagram 3

7.3.2 Key Features

- **Wired Accelerometer Connection:** Ensures reliable and consistent data transfer from the accelerometer to the microcontroller.
- **Direct Data Processing:** Data is directly sent to a computer for processing, leveraging advanced algorithms for analysis.
- **Simplified Design:** By omitting a digital display, the system reduces complexity and potential points of failure.

7.3.3 Benefits

- **Enhanced Data Accuracy:** The wired connection minimizes data loss and latency, ensuring high-precision vibration measurement.
- **Increased Processing Power:** Offloading data processing to a computer allows for more sophisticated analysis using machine learning and digital signal processing (DSP) techniques.
- **Robust and Reliable:** Simplified hardware design enhances reliability and ease of maintenance.

7.4 Concept - 4

7.4.1 Overview

Concept 4 introduces multiple portable DAQ units with Wi-Fi capability, eliminating wired constraints for a scalable, precise vibration signal acquisition system communicating wirelessly with a central computer.

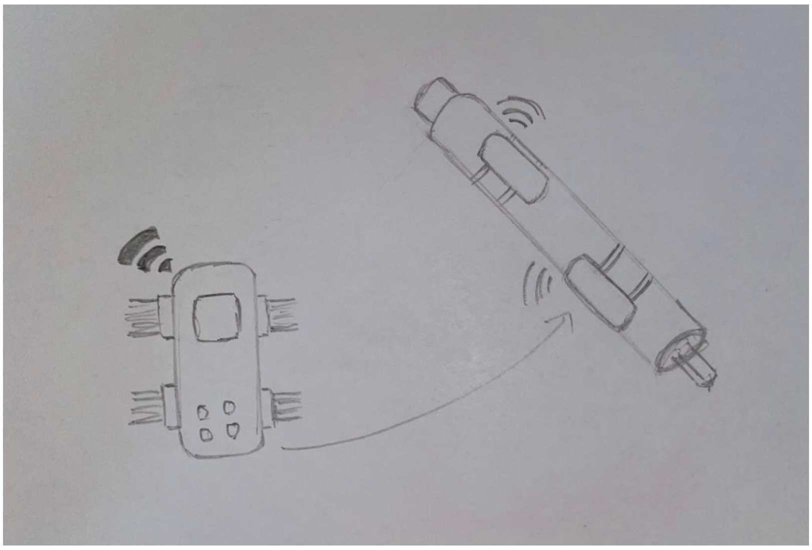


Figure 11: Conceptual Design 4

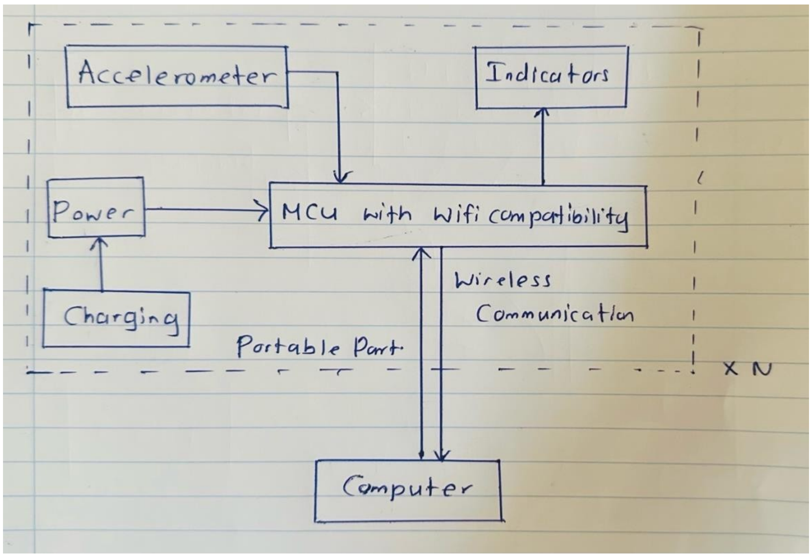


Figure 12: Functional Block Diagram 4

7.4.2 Key Features

- **Multiple Portable Units:** Each unit can be attached to different parts of the machine to gather comprehensive vibration data.
- **Wi-Fi Communication:** Equipped with Wi-Fi-compatible microcontroller units (MCUs), the devices communicate wirelessly with a central computer, allowing for real-time data transfer and analysis.
- **Indicators:** Each unit features indicators to provide visual feedback on operational status.
- **Power Supply and Charging:** Includes an integrated power supply with charging capabilities, ensuring continuous operation.

7.4.3 Benefits

- **Scalability:** The system can easily scale by adding more units, allowing for detailed vibration monitoring across large or complex machinery.
- **Flexibility:** Wireless communication eliminates the need for extensive cabling, simplifying installation and setup.
- **Precision:** Multiple units provide a comprehensive view of vibration patterns, enhancing the accuracy of the analysis.

7.5 Mechanical Damper System

7.5.1 Overview

This design features a mechanical damper system utilizing a spring and damper mechanism. The design is intended to absorb and dissipate vibrations through mechanical means, enhancing the stability and precision of machine tools.

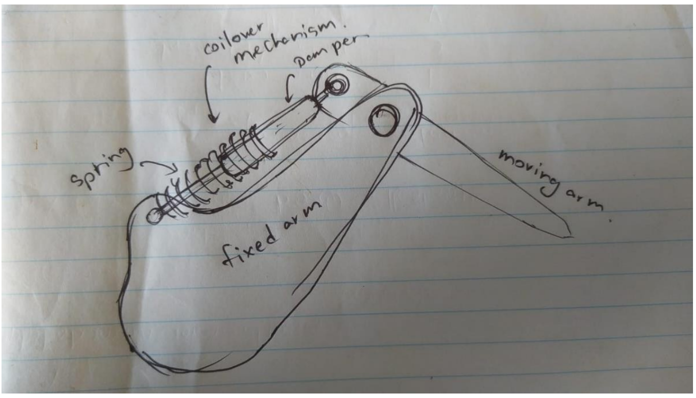


Figure 13: Damper

7.5.2 Key Features

- **Spring and Damper Mechanism:** Utilizes a coilover mechanism that includes a spring and a damper to reduce vibrations effectively.
- **Fixed and Moving Arms:** The system comprises a fixed arm and a moving arm, allowing for dynamic absorption of vibrations during machine operation.
- **Mechanical Design:** Focuses on a purely mechanical approach, eliminating the need for electronic components.

7.5.3 Benefits

- **Simplicity and Reliability:** The mechanical nature of the system ensures durability and requires minimal maintenance.
- **Effective Vibration Reduction:** The spring and damper combination provides a robust solution for damping vibrations, improving the overall performance of machine tools.
- **Cost-Effective:** Without the need for electronic components, the system is economical to produce and maintain.

7.6 Conclusion

By developing and comparing these conceptual designs, we aim to identify the most effective and feasible solution for implementing a Vibration Damping System that meets the diverse needs of our users and stakeholders. Each design offers unique advantages and caters to different operational requirements, ensuring a comprehensive approach to vibration management in machine tools. The next steps involve detailed evaluation and prototyping to determine the optimal design for practical application.

8 Evaluation of Conceptual Design

To determine the most effective and feasible solution for implementing the Vibration Damping System (VDS), we evaluated each conceptual design based on two primary criteria: Enclosure Design Criteria and Functional Block Diagram Criteria. This evaluation helps ensure that the selected design meets both the practical requirements and the functional needs of the system.

8.1 Evaluation Criteria

8.1.1 Enclosure Design Criteria:

1. Functionality: How well does the design support the main functionalities?
2. Aesthetics: How much eye-catching and overall appeal of the user?
3. Precision: How accurate is the gathered data?
4. Assembly and Serviceability: How easily is the assembly and disassembly done?
5. Simplicity
6. Durability: How well does the design withstand impacts and environmental conditions?

8.1.2 Functional Block Diagram Criteria:

1. Functionality: How well does the circuit design meet functional requirements?
2. User Experience: How intuitive and user-friendly is the interaction?
3. Manufacturing Feasibility: Evaluate the feasibility of manufacturing the design.
4. Cost: Evaluate the overall cost-effectiveness of the provided functionality.
5. Performance: Evaluate the signal quality, resolution, and bandwidth range.
6. Power Efficiency: How effectively does the device manage power consumption?

8.2 Complete Comparison

		Conceptual design 1	Conceptual design 2	Conceptual design 3	Conceptual design 4
Newly added features		WIFI connection USB charging port OLED Display Portable	Power supply with cables Wired connection Separate device for computations and display	Wired accelerometer part	WIFI compatibility Multiple portable parts
Removed features		Wired connection	WIFI connection USB charging port	Digital display	Wired connection
Enclosure design criteria comparison	Functionality	8	6	8	8
	Aesthetics	9	5	7	8
	precision	7	7	8	8
	Assembly and serviceability	7	5	9	6
	Simplicity	8	5	9	7
	Durability	8	6	7	7
Functional block design criteria comparison	Functionality	8	7	8	8
	User experience	9	6	8	8
	Manufacturing feasibility	7	5	8	6
	Cost	8	4	9	6
	Performance	7	6	7	8
	Power	7	7	9	7
Total		93	69	99	87

8.3 Selected Conceptual Design

In our product, we prioritize computational power due to our use of MATLAB for data processing. While developing an interactive user-friendly interface is desirable, it has been deemed lower priority compared to ensuring core functionality. Additionally, the decision to use a wired connection over Wi-Fi is influenced by concerns about Wi-Fi's error rates, which could affect the precision of the vibration data collected.

Our selected design is Conceptual Design 3, which utilizes a wired accelerometer system, emphasizing direct data acquisition and processing through a lightweight cable connection to a computer. This design is cost-effective, easy to use, and meets our need for high computational power and precision.

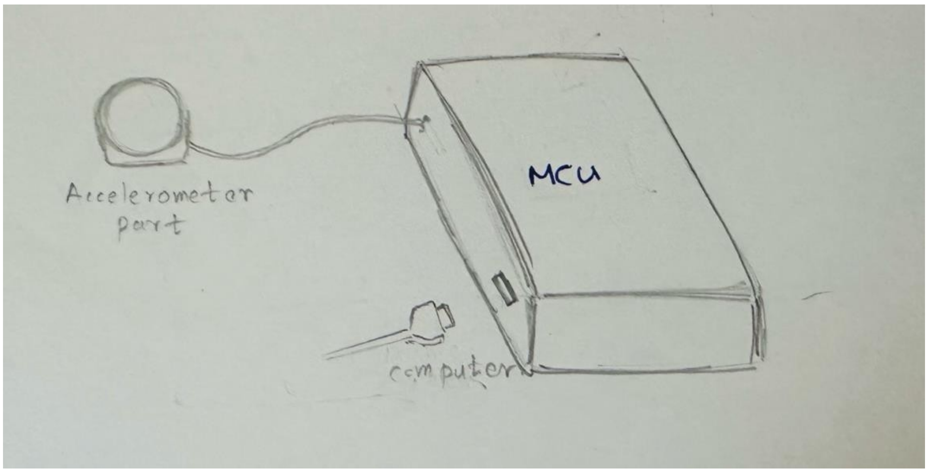


Figure 14: Conceptual Design 3

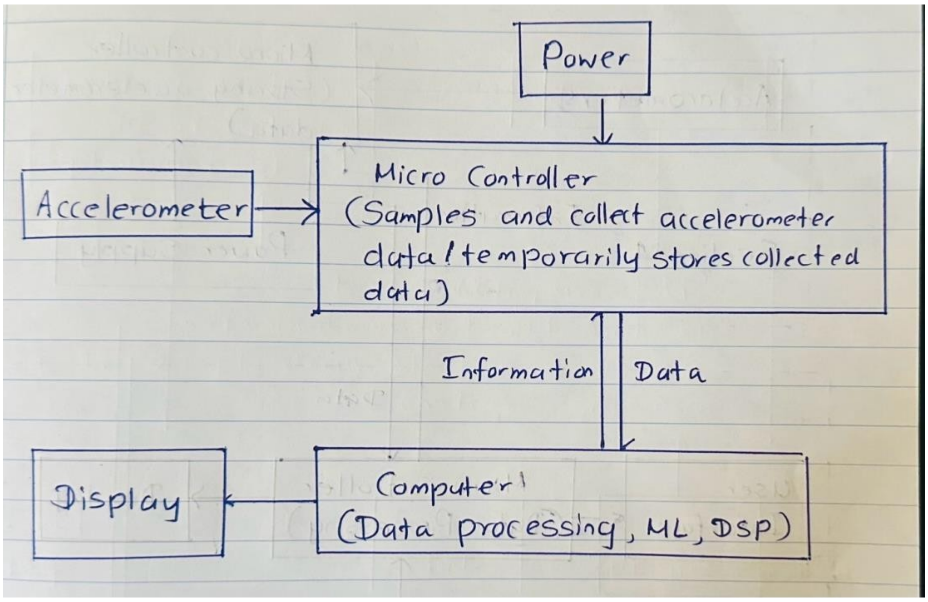


Figure 15: Functional Block Diagram 3

Conceptual Design 3 is selected as the **final design** for several compelling reasons:

- **Computational Power:** This design provides enhanced computational power necessary for processing vibration data using MATLAB. The direct connection to a computer allows leveraging advanced data processing algorithms, machine learning, and digital signal processing (DSP) techniques, which are crucial for accurate and sophisticated vibration analysis.

- **Data Accuracy and Precision:** The wired accelerometer connection ensures reliable and consistent data transfer, minimizing data loss and latency. This is critical for achieving high-precision vibration measurement, essential for diagnosing and mitigating vibration issues in machine tools.

- **Cost-Effectiveness:** The simplified hardware design of Design 3 is economical to produce and maintain. By omitting the digital display and focusing on core functionality, the design reduces production costs without compromising performance.

- **Ease of Use:** The straightforward design and direct data processing reduce the complexity of the system, making it user-friendly. Maintenance and troubleshooting are simpler due to fewer components and connections.

- **Stability and Reliability:** The wired connection provides a stable and robust solution, reducing the risk of data transmission errors that can occur with wireless systems. This enhances the overall reliability of the system, ensuring consistent performance in industrial environments.

Overall, Conceptual Design 3 stands out as the optimal choice for a Vibration Damping System for machine tools due to its combination of computational power, data accuracy, cost-effectiveness, ease of use, stability, and flexibility. Its robust design makes it well-suited for various industrial applications, ensuring precise vibration measurement and analysis, ultimately contributing to improved productivity and operational efficiency.

9 Schematic Design

Designing electronic circuits is essential to ensure the seamless operation of our data acquisition (DAQ) system. The schematic design of our Vibration Damping System (VDS) is meticulously crafted to ensure proper functionality and integration of various components. The schematics provide a detailed view of the connections between different electronic elements such as resistors, capacitors, transistors, and integrated circuits. This section will highlight the key components and their configurations.

9.1 Key Components and Their Configurations

9.1.1 Sensor Input Circuit

The sensor input circuit is designed to interface with accelerometers, capturing vibration data. The main components are:

- **Accelerometer:** Captures vibration data and sends it to the microcontroller.

This circuit is crucial for accurate data acquisition, providing the raw input needed for analysis.

9.1.2 Microcontroller Circuit (ATmega328P)

The microcontroller circuit, built around the ATmega328P, serves as the central unit for data processing and communication. Key features include:

- **ATmega328P Microcontroller:** Handles data acquisition, processing, and communication tasks.
- **Crystal Oscillator:** Provides the clock signal for the microcontroller, ensuring precise timing operations.
- **Decoupling Capacitors:** Placed close to the IC to filter out noise and provide a stable power supply to the microcontroller.

This setup is designed for efficient data handling and communication, forming the core of the DAQ system.

9.1.3 USB Port Circuit (CH340C)

The USB port circuit incorporates the CH340C IC, facilitating communication between the DAQ system and a computer. This circuit includes:

- **CH340C USB-to-Serial Converter:** Enables seamless data transfer via USB.
- **Capacitors:** Two 0.1µF capacitors for noise filtering.

- **LED Indicators:** Provide visual feedback on the status of the data transfer.

This circuit ensures easy and reliable communication with external devices, enhancing the system's usability.

9.1.4 Power Supply Circuit (LM7805)

The power supply circuit features the LM7805 linear voltage regulator, providing a stable 5V supply essential for our microcontroller and other components. The design includes:

- **LM7805 Voltage Regulator:** Ensures a steady 5V output.
- **Capacitors:** Two 10µF capacitors are used for input and output filtering to stabilize the voltage and reduce noise.

This configuration offers a reliable power source, crucial for maintaining consistent performance across the DAQ system.

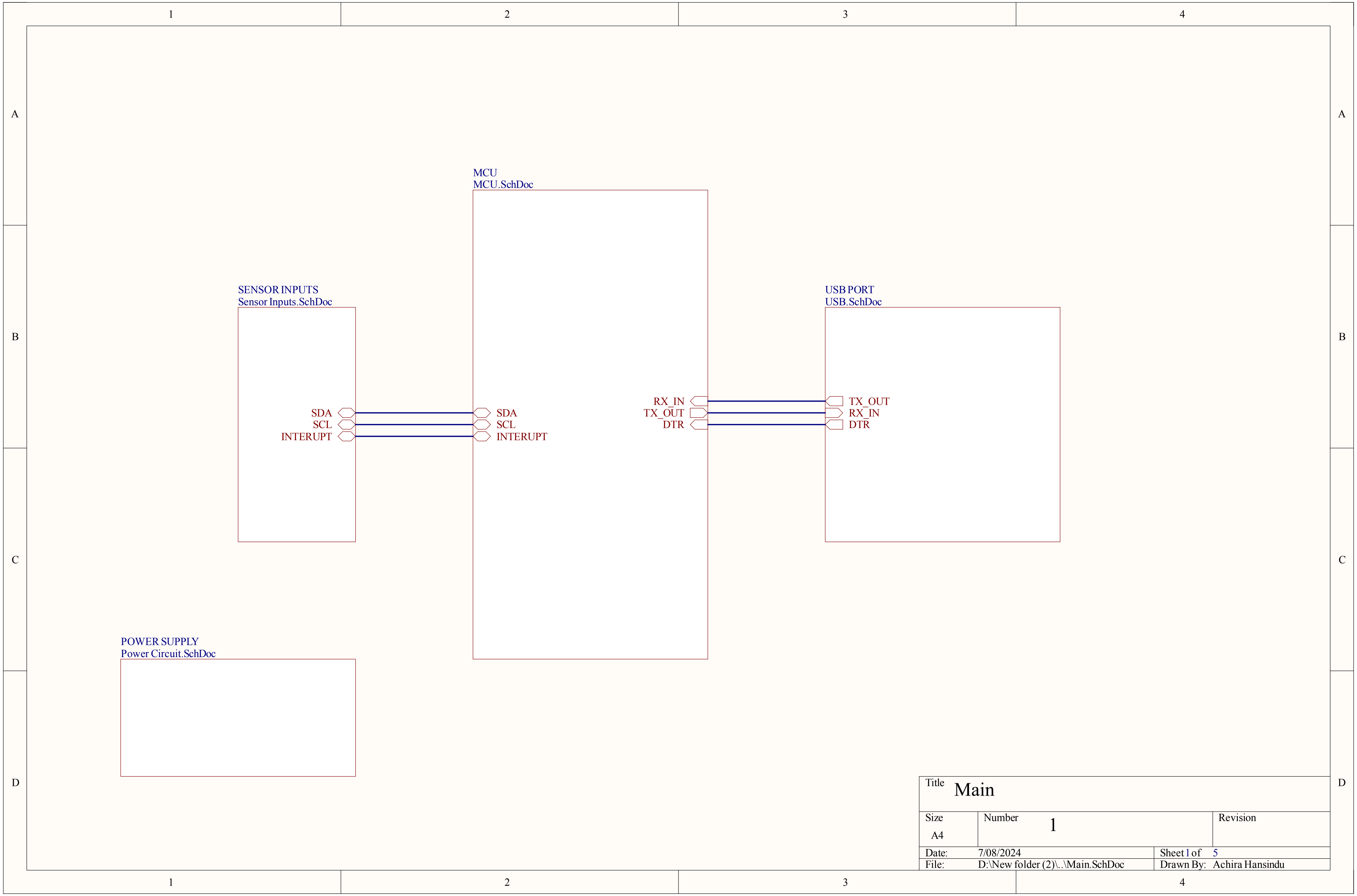
9.2 Component List

The major components required for the circuit design are:

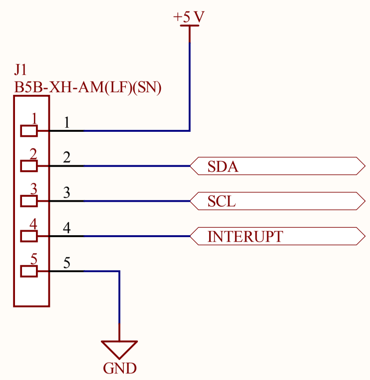
- ATmega328P Microcontroller
- LM7805 Voltage Regulator
- CH340C USB-to-Serial Converter
- Capacitors (10µF, 0.1µF)
- Crystal Oscillator (e.g., 16MHz)
- LEDs (for status indication)
- External Power Source (e.g., 12V DC)
- Resistors
- Programming Header
- Pin Connectors (for sensor connections)

These components collectively ensure the robust operation of the DAQ system, enabling precise vibration data acquisition and reliable communication with external devices.

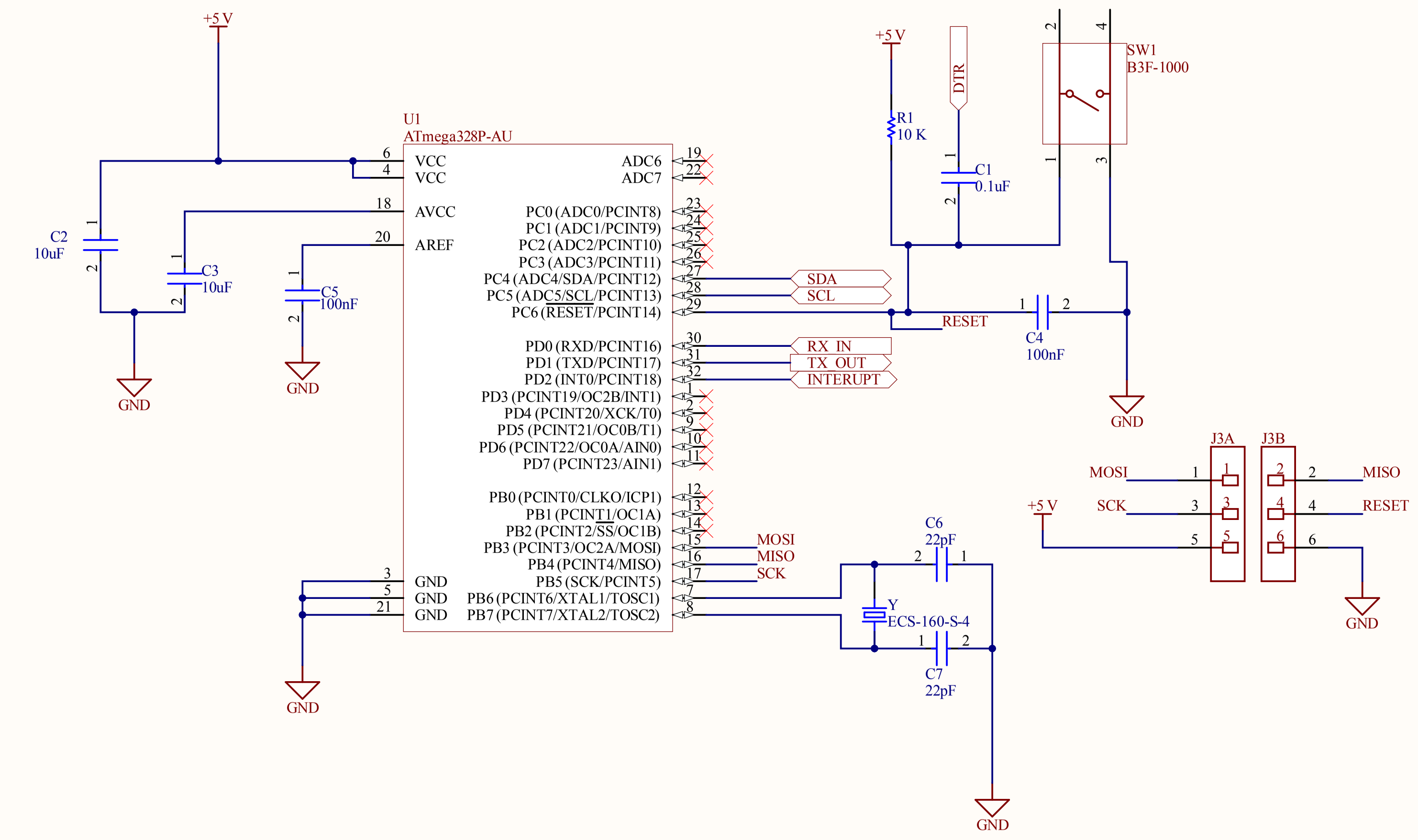
9.3 Schematic Diagram



MCU
MCU.SchDoc
SENSOR INPUTS
Sensor Inputs.SchDoc
USB PORT
USB.SchDoc
POWER SUPPLY
Power Circuit.SchDoc
SDA
SCL
INTERUPT
SDA
SCL
INTERUPT
RX_IN
TX_OUT
DTR
TX_OUT
RX_IN
DTR
Title Main
Size A4
Number 1
Revision
Date: 7/08/2024
Sheet 1 of 5
File: D:\New folder (2)\..\Main.SchDoc
Drawn By: Achira Hansindu

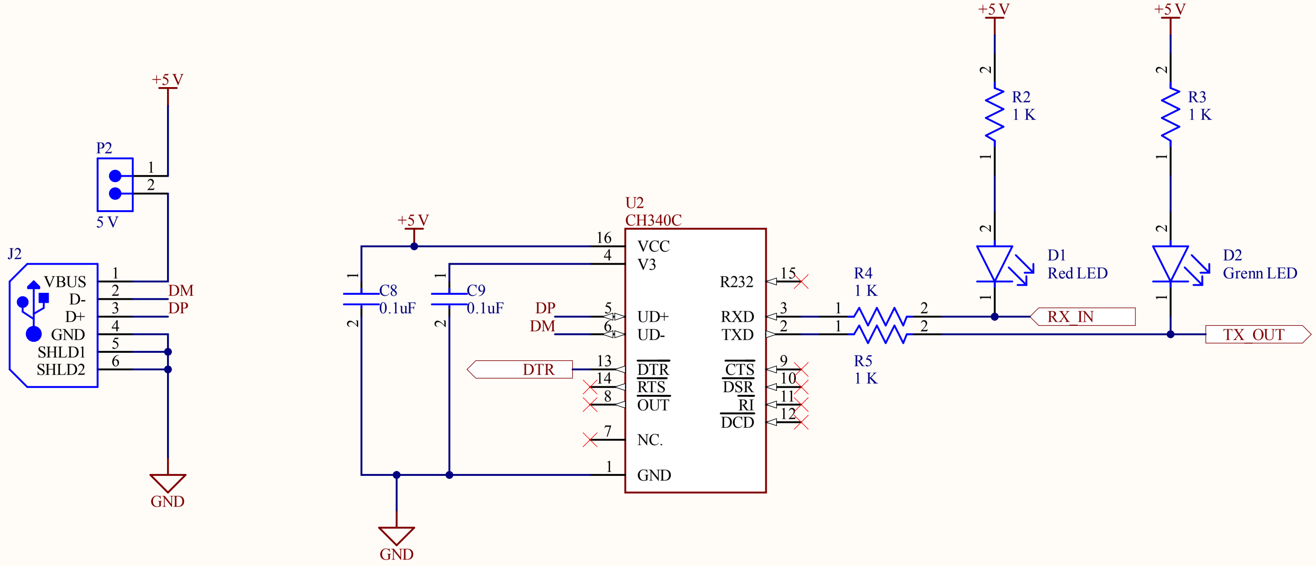


Title	Sensor Inputs		
Size	Number		Revision
A4	2		
Date:	7/08/2024	Sheet 2 of 5	
File:	D:\New folder (2)\..\Sensor Inputs.SchDoc	Drawn By:	Achira Hansindu

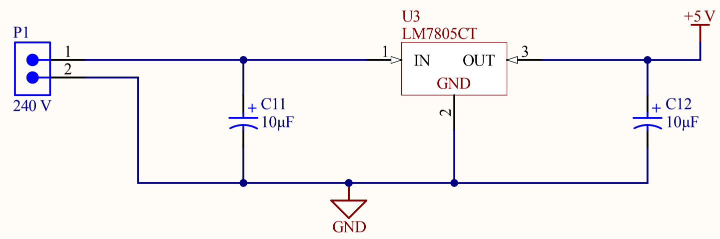


Decoupling capacitors(C2, C3, C5) should be as much as close to the IC

Title	Microcontroller		
Size: A4	Number: 3		Revision
Date:	7/08/2024	Sheet 3 of 5	
File:	D:\New folder (2)\..\MCU.SchDoc	Drawn By:	Achira Hansindu



Title	USB Port		
Size	Number		Revision
A4	4		
Date:	7/08/2024	Sheet 4 of 5	
File:	D:\New folder (2)\..\USB.SchDoc	Drawn By:	Achira Hansindu



Title	Power Supply		
Size A4	Number 5		Revision
Date:	7/08/2024	Sheet 5 of 5	
File:	D:\New folder (2)\..\Power Circuit.SchDoc	Drawn By:	Achira Hansindu

10 PCB Design

The PCB layout integrates all schematic designs onto a single board, ensuring optimal component placement and efficient signal routing. Our design process prioritizes robustness, reliability, and ease of integration. The PCB layout has been meticulously crafted to meet the high standards required for effective vibration damping systems.

10.1 Key Considerations

10.1.1 Traces

Adequate width traces are used for power paths to minimize voltage drop and support the current requirements of the components.

Signal traces are routed to minimize interference and maintain signal integrity, ensuring reliable communication between components.

10.1.2 Component Placement

Components are positioned strategically to minimize trace lengths and optimize signal paths.

Critical components such as the microcontroller and ICs are placed centrally to enhance stability and performance.

10.1.3 Thermal Management

Heat dissipation for components such as the LM7805 voltage regulator and the microcontroller is managed through proper placement and the addition of heat sinks where necessary.

This ensures components operate within safe temperature ranges, enhancing reliability and lifespan.

10.2 PCB Layout Details

10.2.1 2D View

The 2D view of the PCB provides a detailed layout of component placement and trace routing, showcasing the systematic organization of all elements. It highlights the efficient use of board space and the logical arrangement of components to support functional and mechanical requirements.

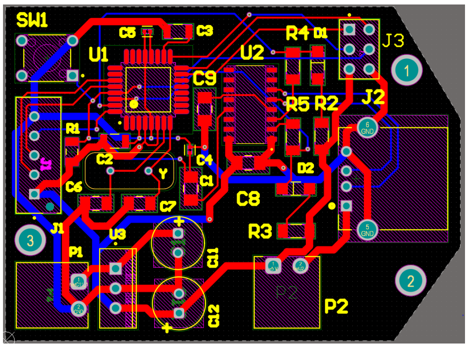


Figure 16: 2D View

10.2.2 3D View

The 3D view offers a comprehensive visualization of the assembled PCB, including component heights and spatial relationships. This perspective aids in ensuring that all components fit within the designated enclosure and meet the design specifications for physical integration.

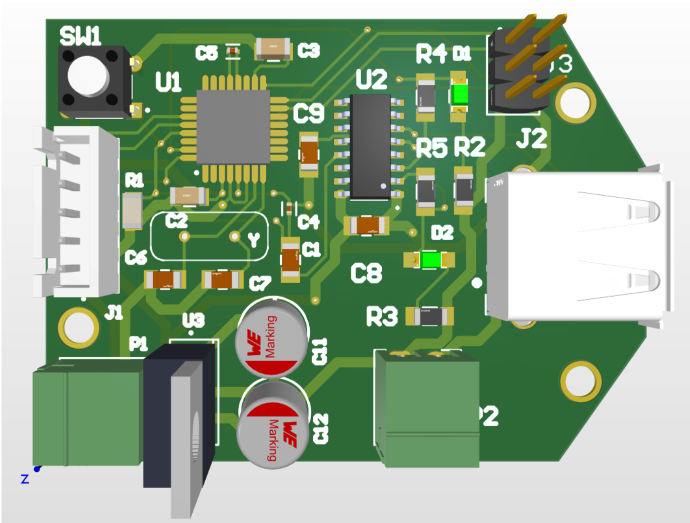


Figure 17: 3D View

10.3 Conclusion

The final PCB design encapsulates the critical aspects of our schematics into a cohesive, reliable, and efficient layout. By adhering to best practices in PCB design, we ensure that the vibration-damping system meets its performance objectives while maintaining ease of manufacturing and assembly. This comprehensive design approach facilitates seamless integration into machine tools, offering a robust solution for vibration damping.

By focusing on these design principles, we have developed a PCB layout that is not only effective in its functionality but also optimized for production and operational reliability.

11 SolidWorks Design

Our SolidWorks design consists of two primary components: the Main Controller Unit and the Accelerometer Holding Part. Both designs are moldable and have been meticulously created to ensure functionality and ease of manufacturing. Below are the details and design trees for both components:

11.1 Main Controller Unit

The Main Controller Unit part is designed to house the main microcontroller and associated electronic components. The design includes a base and a lid, both moldable for efficient manufacturing.

11.1.1 Main Controller Unit Base

- The base is designed to hold the microcontroller securely.
- It includes mounting points for the PCB and provisions for connectors and other components.
- Features like cable entry points are incorporated for optimal functionality.

11.1.2 Main Controller Unit Lid

- The lid is designed to enclose the Main Controller Unit securely.
- It includes features for easy attachment to the base, such as screw holes.
- The lid design ensures that all components are protected while allowing access for maintenance.

11.1.3 Assembly

- The assembly of the Main Controller Unit involves aligning the base and the lid and securing them together.
- The design ensures that the assembly process is straightforward, with clear alignment features to avoid any misfits.

11.1.4 Figures

Design Tree

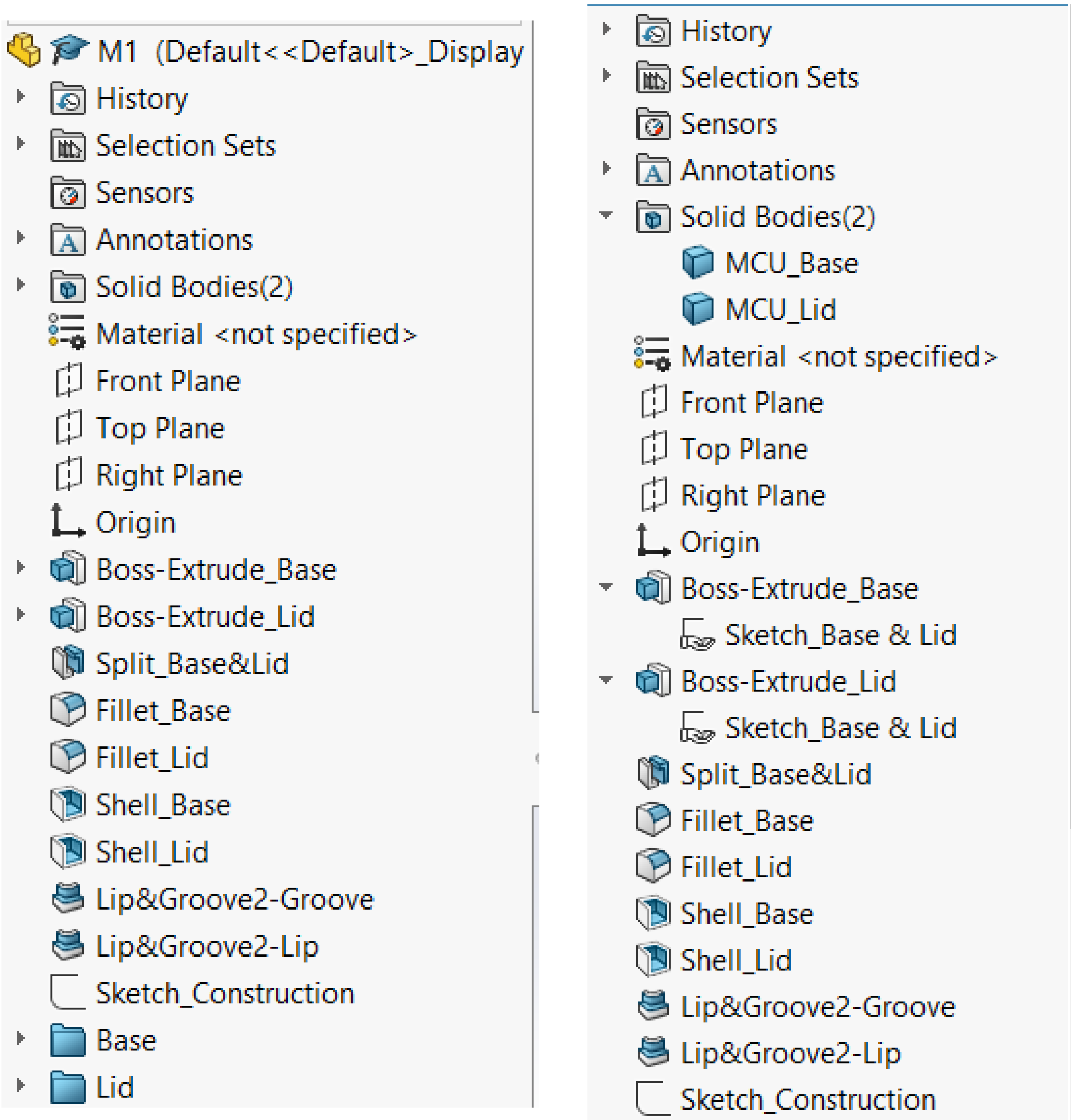


Figure 18: Design Tree of Main Controller Unit

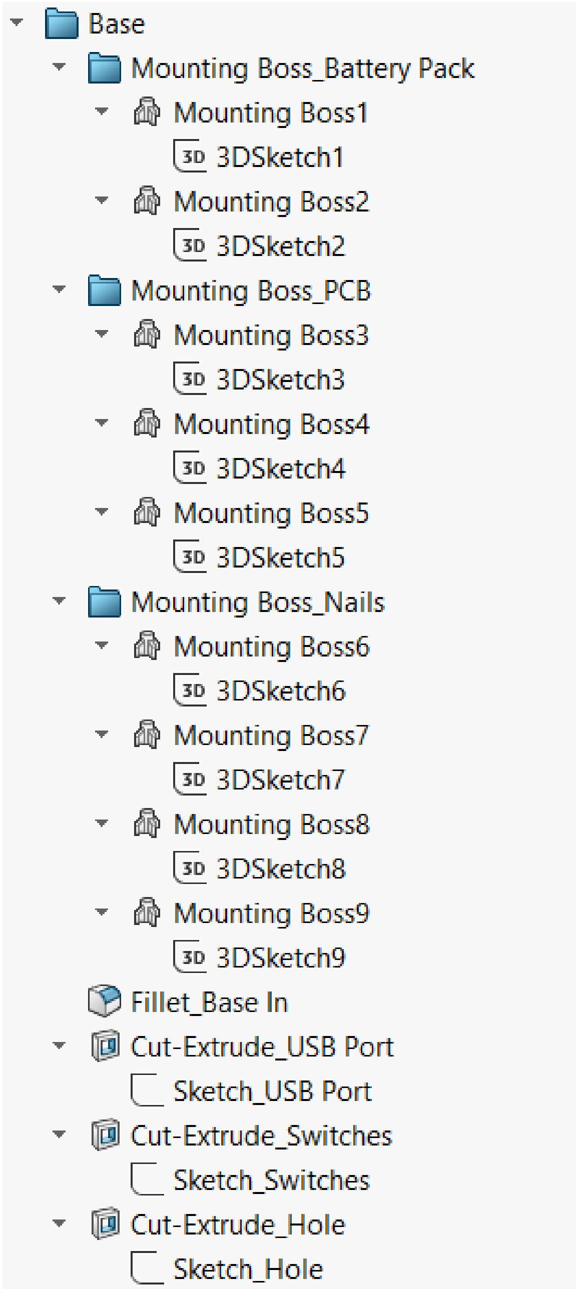


Figure 19: Design Tree of Main Controller Unit Base

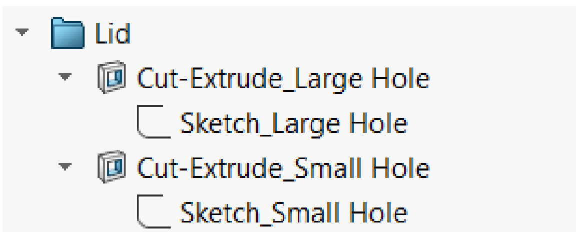


Figure 20: Design Tree of Main Controller Unit Lid

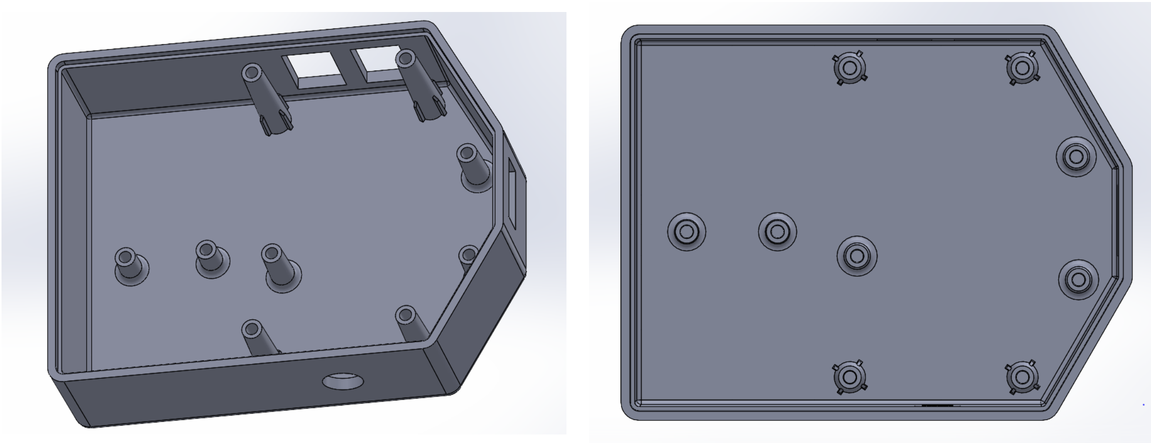


Figure 21: Main controller Unit Base

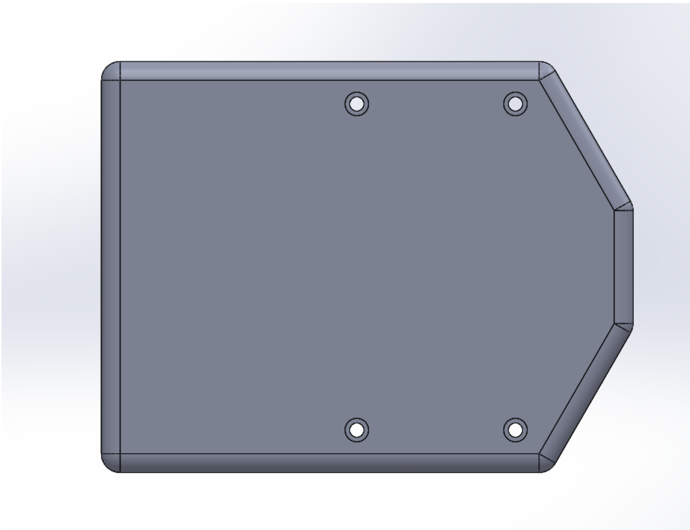


Figure 22: Main Controller Unit Lid

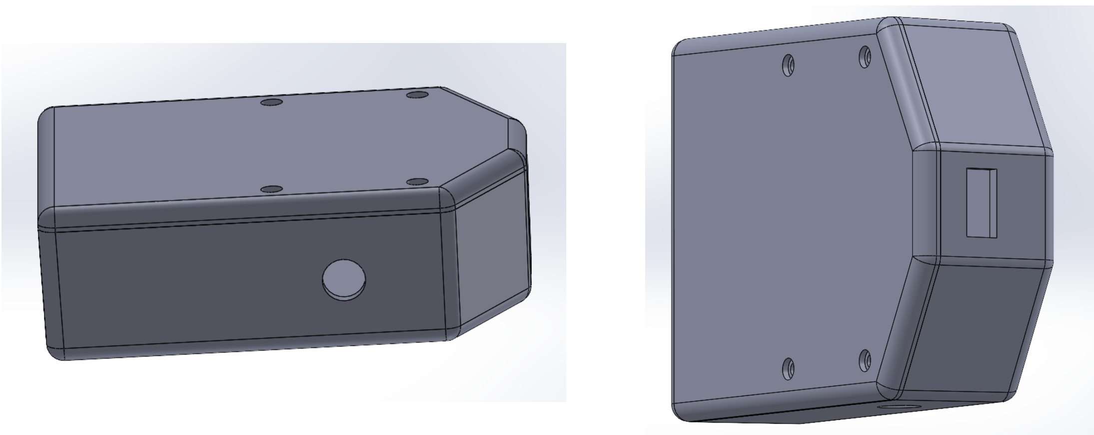


Figure 23: Main Controller Unit Assembly

11.2 Accelerometer Holding Part

The Accelerometer Holding Part is designed to securely hold the accelerometer in place while allowing for precise measurements. Like the Main Controller Unit, it consists of a base and a lid.

11.2.1 Accelerometer Base

- The base is designed to provide a stable platform for the accelerometer.
- It includes features for mounting the accelerometer securely and provisions for cable management.

11.2.2 Accelerometer Lid

- The lid is designed to protect the accelerometer while allowing it to perform measurements accurately.
- It includes features for securing the lid to the base, such as screw holes.

11.2.3 Assembly

- The assembly involves securing the accelerometer within the base and attaching the lid.
- The design ensures easy access to the accelerometer for maintenance while providing robust protection.

11.2.4 Figures

Design Tree

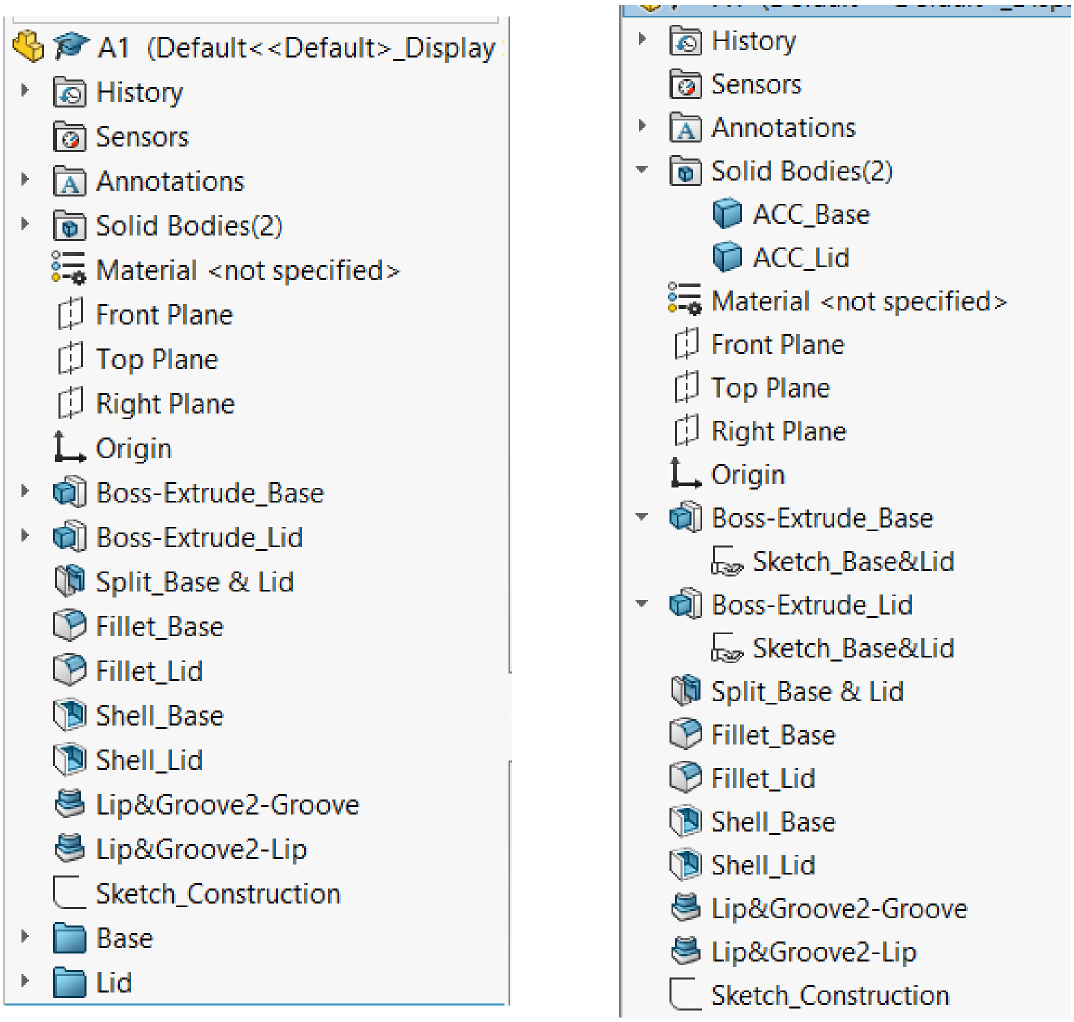


Figure 24: Design Tree of Accelerometer

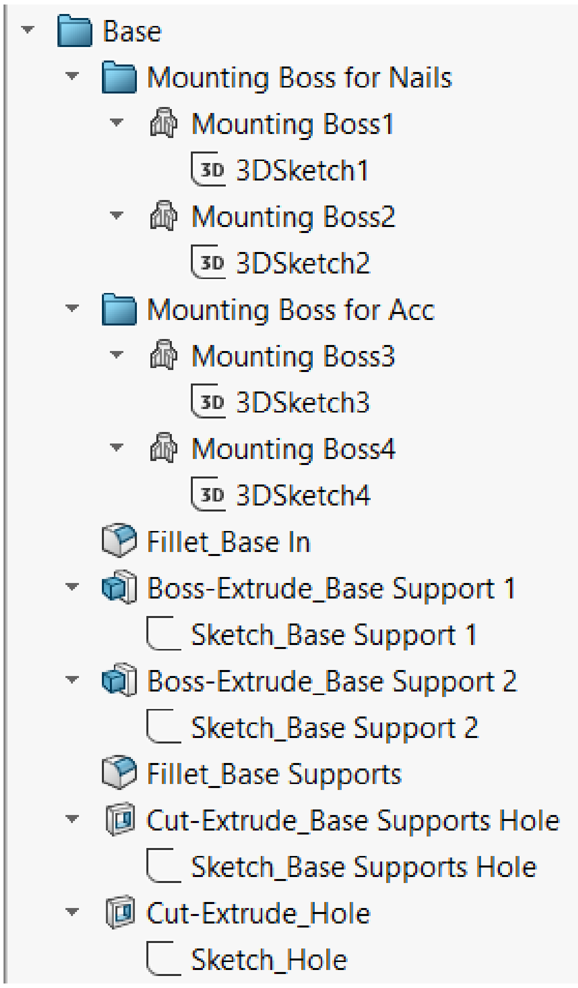


Figure 25: Design Tree of Accelerometer Base

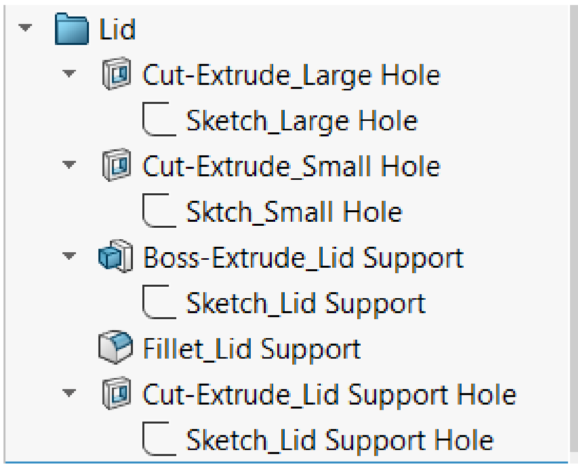


Figure 26: Design Tree of Accelerometer Lid

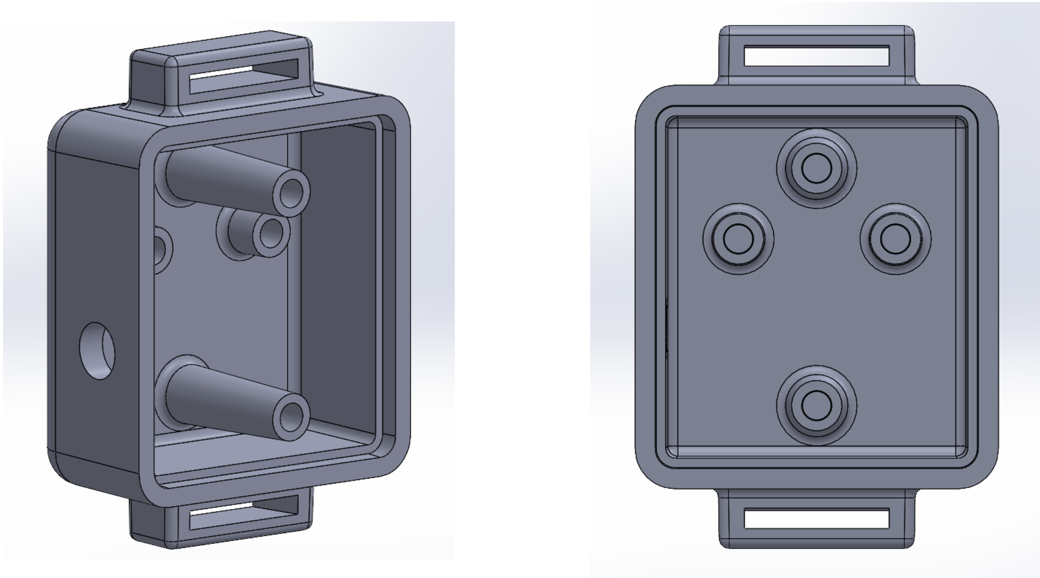


Figure 27: Accelerometer Holding Part Base

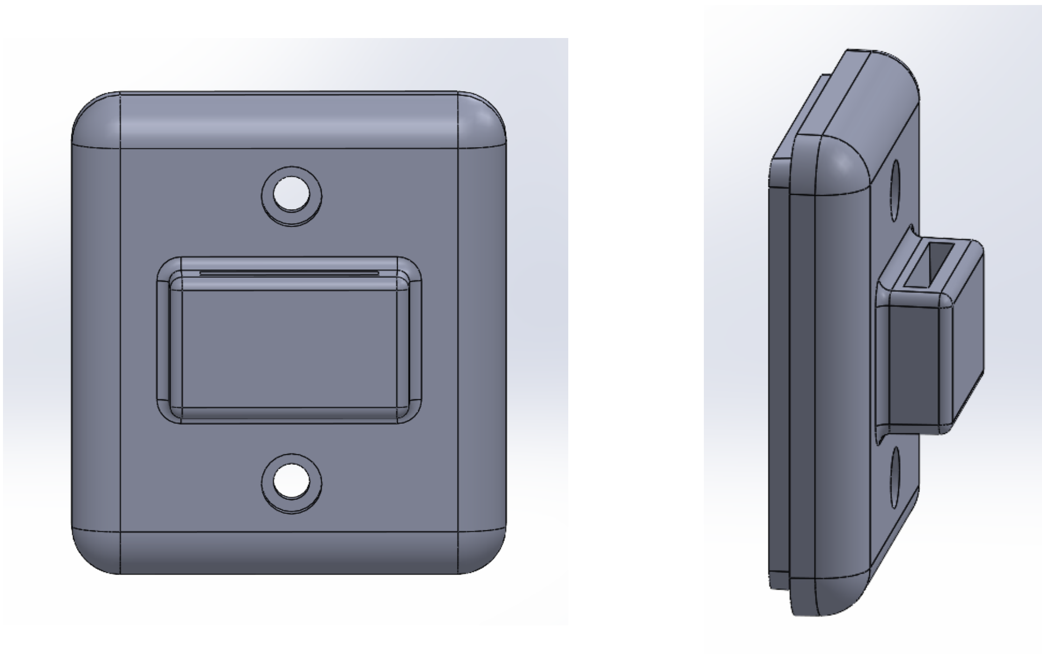


Figure 28: Accelerometer Holding Part Lid

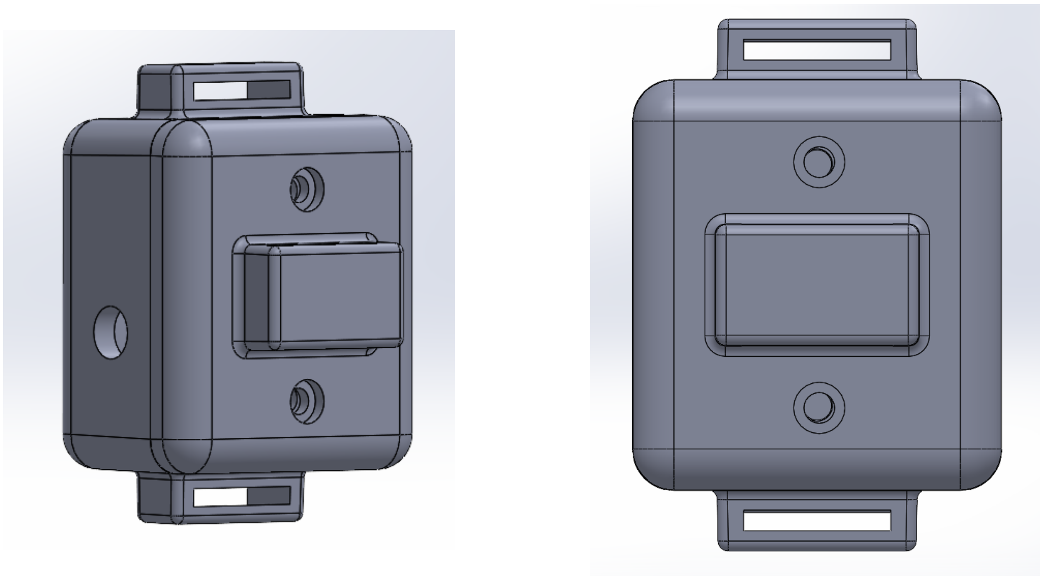


Figure 29: Accelerometer Holding Part Assembly

11.3 Conclusion

Both designs ensure that the components are securely housed and protected while allowing for efficient assembly and maintenance. The moldable design of these parts facilitates cost-effective manufacturing and ensures durability and reliability in their application.

References

[1] icrochip Technology, 8-bit AVR Microcontroller with 32K Bytes In-System Programmable Flash. Version 7810D–AVR–01/15. Available at: https://ww1.microchip.com/downloads/en/DeviceDoc/Atmel-7810-Automotive-Microcontrollers-ATmega328P_Datasheet.pdf

[2] anjing Qinheng Microelectronics, USB to Serial Port Chip. Sheet version 2C. Available at: https://www.mpja.com/download/35227cpdata.pdf

[3] DK InvenSense, MPU-6050 Six-Axis (Gyro + Accelerometer) MEMS MotionTracking™ Device. Available at: https://invensense.tdk.com/wp-content/uploads/2015/02/MPU-6000-Datasheet1.pdf

[4] ianchi, G. et al., 2014. "Analysis of Vibration Damping in Machine Tools," Procedia CIRP. Available at: https://www.researchgate.net/publication/275230904_Analysis_of_Vibration_Damping_in_Machine_Tools

[5] setserukou, D., Kawakami, N., & Tachi, S. (2008). "Vibration Damping Control of Robot Arm Intended for Service Application in Human Environment," 2008 8th IEEE-RAS International Conference on Humanoid Robots (Humanoids 2008). DOI: 10.1109/ICHR.2008.4756002. Available at: https://www.researchgate.net/publication/224373517_Vibration_damping_control_of_robot_arm_intended_for_service_application_in_human_environment

[6] ord, D.G., Myers, A., Haase, F., Lockwood, S., & Longstaff, A.P. (2013). "Active Vibration Control for a CNC Milling Machine," Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science. DOI: 10.1177/0954406213484224. Available at: https://www.academia.edu/56290445/Active_vibration_control_for_a_CNC_milling_machine

[7] hen, F., Hanifzadegan, M., Altintas, Y., & Lu, X. (2015). "Active Damping of Boring Bar Vibration With a Magnetic Actuator," IEEE/ASME Transactions on Mechatronics, 20(6), 1-12. DOI: Available at: https://www.researchgate.net/publication/276383735_Active_Damping_of_Boring_Bar_Vibration_With_a_Magnetic_Actuator

[8] kbar, M.A., Wong, W.-O., & Rustighi, E. (2023). "A Hybrid Damper with Tunable Particle Impact Damping and Coulomb Friction," Machines, 11(5), 545. DOI: 10.3390/machines11050545. Available at: https://www.mdpi.com/2075-1702/11/5/545

[9] andvik Coromant - Silent Tools™ Turning Adapters: https://www.sandvik.coromant.com/en-us/tools/turning-tools/internal-turning-tools/silent-tools-turning

[10] ig Daishowa - Smart Damper: https://www.bigkaiser.eu/en/products/damping-tools.html

[11] eco Tools - Steadyline® Vibration Damping System: https://www.secotools.com/article/20850