Design Document

Movable Impact Testing Platform

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Contents

1 Introduction

1.1 Problem Statement

Impact loading is widely used in structural engineering research to evaluate the dynamic response of structural specimens such as beams, plates, and other components. However, many existing impact testing methods rely either on large fixed laboratory equipment or on simple drop-weight devices. These approaches often have important limitations in practical use. Large testing systems are usually difficult to move and require dedicated space, while simple impact devices often provide limited control over impact conditions.

In addition, conventional testing approaches may suffer from insufficient flexibility, limited adjustability of impact parameters, and poor repeatability between tests. For experimental studies that require controlled and repeated impact loading, these limitations can reduce testing efficiency and affect the quality of measured structural response data.

Therefore, this project aims to develop a movable, repeatable, and adjustable impact testing platform for structural dynamic response experiments. The proposed system is intended to provide controllable impact excitation for structural specimens and to support future testing scenarios involving a small movable cart as the impacted object.

1.2 Proposed Solution

To address the problem described above, this project proposes a movable impact testing platform based on a hydraulic actuation system. The system uses a motor-driven pump, an oil tank, a control valve, and a hydraulic cylinder to generate controlled vertical motion of an impact head. The impact head will eventually strike a small cart during testing, allowing the team to study the dynamic behavior of the target structure or object under repeated impact conditions.

The platform is designed to be movable so that it can be positioned near different experimental setups. In addition, the system is intended to support adjustable impact conditions, including impact frequency and overall impact intensity. Hydraulic actuation is selected because it can provide relatively large output force in a compact structure and allows convenient adjustment of impact motion through pressure and flow control. This makes it suitable for repeated laboratory impact testing where controllability and repeatability are important.

At the current prototype stage, the hydraulic control component is planned as a proportional directional valve. This choice is used as the reference solution for the present design and cost analysis, while alternative valve options may still be revisited in future optimization if necessary.

Overall, the proposed design provides a practical and flexible testing solution that combines mobility, controllability, and repeatability in a single platform.

1.3 Visual Aid

Figure 1 presents the conceptual framework of the proposed movable impact testing platform. The figure shows the major functional components of the hydraulic system, including the motor, pump, oil box, relief valve, control valve, and hydraulic cylinder. It illustrates how hydraulic power is generated, regulated, and transmitted to produce the motion of the impact head. This conceptual figure is intended to provide a clear overview of the operating principle of the proposed system rather than its detailed physical layout.

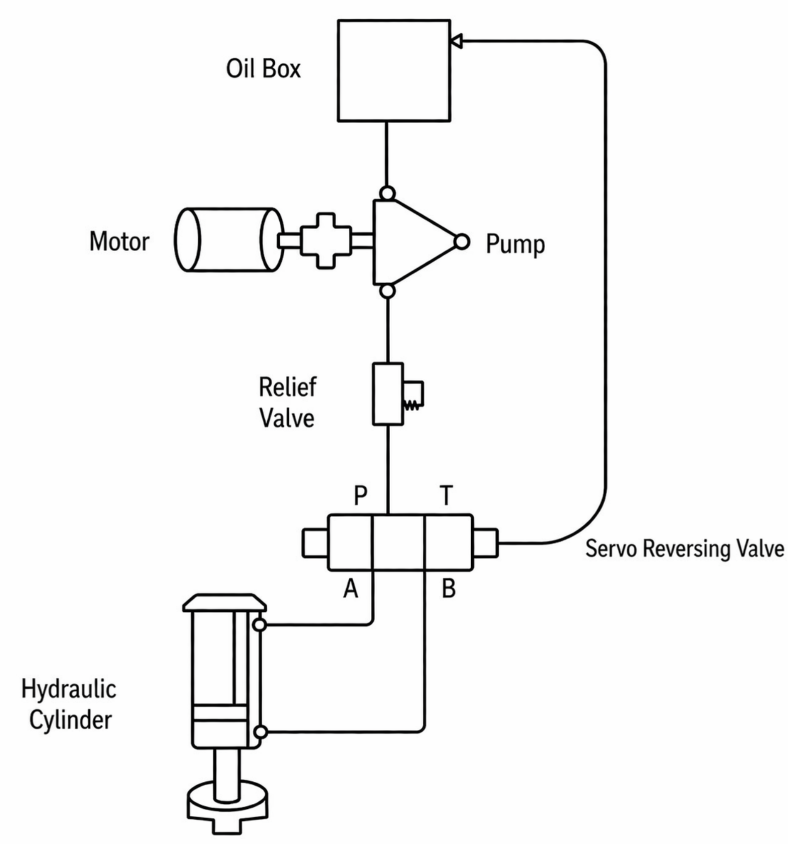

Figure 1: Conceptual framework of the movable impact testing platform.

1.4 High-Level Requirements

The overall system is expected to satisfy the following high-level requirements:

1. **Mobility requirement:** The platform shall be movable by two users and fit through a standard laboratory doorway so that it can be used in different experimental locations.
2. **Impact performance requirement:** The platform shall generate repeatable impact loads with adjustable impact frequency and adjustable impact intensity within a practical operating range for laboratory testing.
3. **Safety and stability requirement:** The platform shall remain mechanically stable during operation and include basic safety protection to reduce the risk of accidental contact with moving hydraulic and impact components.

2 Overall Design

2.1 System Overview

The movable impact testing platform is designed as an integrated hydraulic impact system for controlled laboratory testing. At a high level, the system consists of a power and hydraulic supply section, a control valve section, an actuation section, a structural support section, and a physical platform for mounting and operation. These subsystems work together to generate and transmit hydraulic power, control the motion of the actuator, and finally produce a vertical impact on the target object.

During operation, the motor drives the pump to deliver hydraulic fluid from the oil tank into the hydraulic circuit. The pressurized fluid is then regulated through the relief valve and directed by the control valve to the hydraulic cylinder. By switching the flow direction, the control valve drives the cylinder to extend or retract, thereby producing the required motion of the impact head. In the current design stage, the team is still determining whether the control valve will be implemented using a servo valve or an electromagnetic reversing valve. The hydraulic cylinder is mounted beneath the platform structure so that its output motion can be used to create the desired impact action on the test target. In the final testing scenario, the impact head will strike a small cart positioned below the platform.

Overall, the design emphasizes controllability, repeatability, and modularity. The hydraulic components are grouped according to function, while the physical structure provides support for installation, alignment, and future integration of additional sensing and safety features.

2.2 Block Diagram

Figure 2 shows the overall block diagram of the proposed impact testing platform. The system is divided into four main functional modules: the power module, the hydraulic supply module, the control valve module, and the actuation module. The power module includes the motor and pump, which generate the hydraulic power required by the system. The hydraulic supply module includes the oil tank and relief valve, which provide fluid storage and pressure protection. The control valve module determines the flow direction and controls the motion of the actuator. The actuation module consists of the hydraulic cylinder, which converts hydraulic energy into vertical mechanical motion.

The lines between modules indicate the major paths of hydraulic flow in the system. The pressure or supply line delivers hydraulic energy from the pump to the control and actuation components, while the return line carries fluid back to the oil tank. This block diagram is intended to highlight the functional relationships among the major subsystems and to show how energy and hydraulic flow move through the platform during operation.

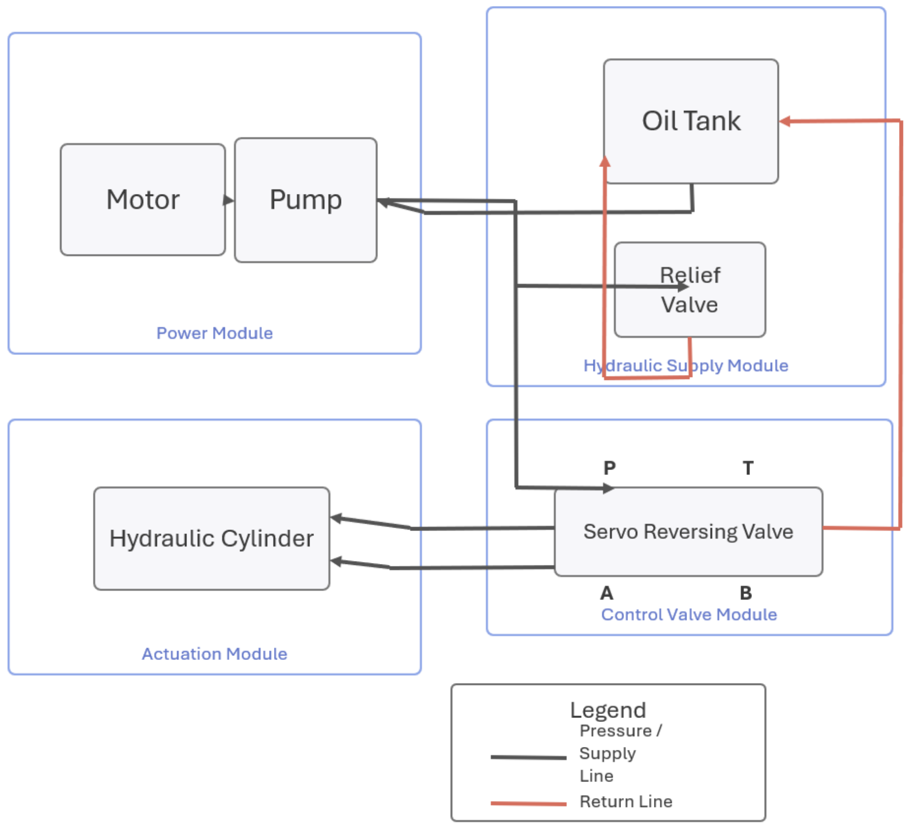

Figure 2: Overall block diagram of the movable impact testing platform.

2.3 Physical Design Overview

Figure 3 presents the current physical design concept of the system. The design includes a flat base platform that supports the hydraulic components and provides the main installation surface. The oil tank, motor-pump assembly, and control components are mounted above the platform, while the hydraulic cylinder is arranged below the platform so that the impact head can move vertically through an opening in the base plate. This layout allows the actuation mechanism to remain compact while keeping the impact path aligned with the test target.

The physical arrangement is intended to support convenient assembly, operation, and future mobility. The base platform serves as the main structural support, while the surrounding frame can be further developed to include additional support members, protective covers, and possible wheel-and-locking structures for movement and positioning. The final design is also expected to include a control box and safety protection features to improve usability and reduce operational risk. At this stage, Figure 3 is used to illustrate the approximate spatial arrangement of the major components rather than the final fully detailed mechanical design.

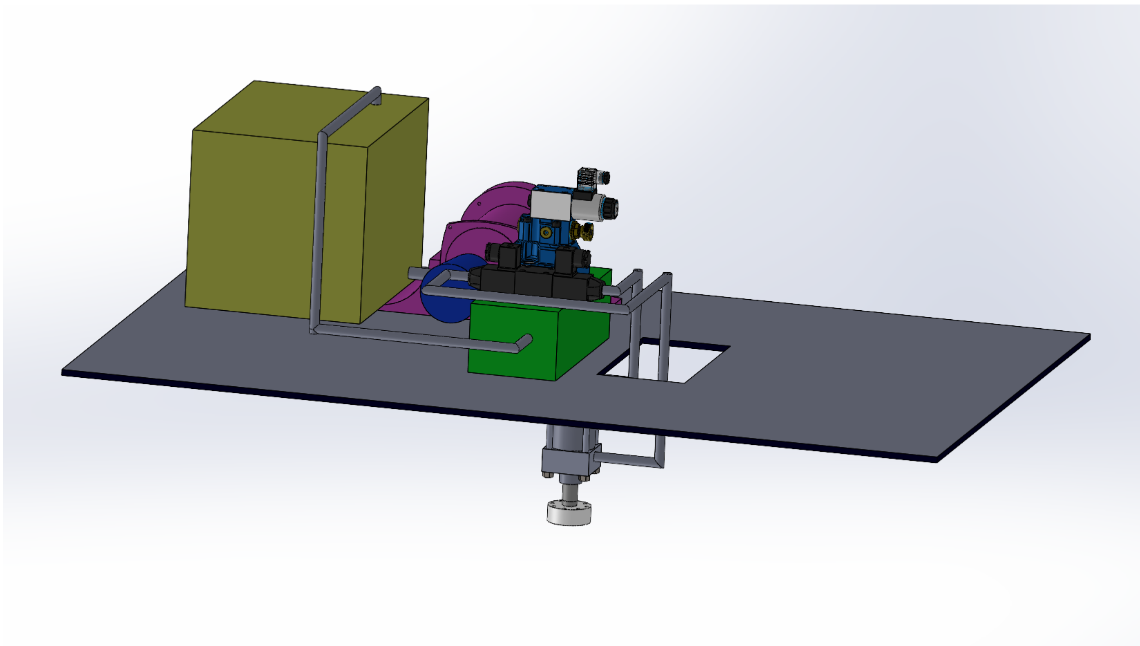

Figure 3: Physical design overview of the movable impact testing platform.

3 Subsystem Design

This section describes the major subsystems of the movable impact testing platform. For each subsystem, the design document provides a functional description, subsystem-level requirements, verification methods, and supporting material. The subsystem requirements are written for the student-designed system rather than only for off-the-shelf components, and the verification methods are intended to provide clear test procedures and success criteria.

3.1 Power Module

3.1.1 Description

The Power Module provides the primary energy input for the entire impact testing platform. It mainly consists of the electric motor, the hydraulic pump, and the coupling structure between them. During operation, the motor converts electrical power into rotational mechanical power, and the pump converts that mechanical power into hydraulic energy for the downstream hydraulic circuit.

This module directly interacts with the Hydraulic Supply Module by delivering pressurized hydraulic fluid into the system. Stable operation of the Power Module is essential because fluctuations in speed, torque transmission, or pump output can affect the performance of the control valve, the hydraulic cylinder, and ultimately the repeatability of the impact process.

3.1.2 Requirements and Verification

Table 1: Requirements and verification for the Power Module

Requirements	**Verification**
1. The Power Module shall provide sufficient and continuous hydraulic power to support repeated operation of the impact system for at least 10 minutes without unplanned shutdown.	1. Run the system continuously for 10 minutes under normal operating conditions. The module passes if no shutdown, severe overheating, or abnormal interruption occurs.
2. The motor-pump connection shall transmit motion reliably without visible slipping, severe vibration, or mechanical loosening during operation.	2. Operate the motor-pump assembly at the intended working condition and inspect the coupling connection visually and mechanically. The module passes if no slipping, loosening, or abnormal vibration is observed.
3. The pump output shall remain sufficiently stable so that the measured supply pressure variation stays within $\pm 10\%$ of the average steady operating value during repeated testing.	3. Measure the hydraulic supply pressure over multiple repeated cycles. The module passes if the pressure remains within $\pm 10\%$ of the average steady operating value.

3.1.3 Supporting Material

The overall block diagram can be used as supporting material for this module because it shows the functional relationship between the motor, pump, and the downstream hydraulic circuit. In addition, a future close-up drawing of the motor-pump assembly may be included to explain the coupling structure and installation arrangement in greater detail.

3.2 Hydraulic Supply Module

3.2.1 Description

The Hydraulic Supply Module is responsible for storing, delivering, and protecting the hydraulic fluid used by the system. It includes the oil tank, hydraulic lines, and the relief valve. The oil tank stores the working fluid and receives return flow from the circuit, while the hydraulic lines route the pressure and return flow between subsystems. The relief valve provides basic pressure protection by limiting excessive hydraulic pressure.

This module interacts with the Power Module, the Control Module, and the Actuation and Impact Module. It receives hydraulic energy from the pump, supplies fluid to the control valve, and supports stable system operation by maintaining a safe and continuous hydraulic flow path.

3.2.2 Requirements and Verification

Table 2: Requirements and verification for the Hydraulic Supply Module

Requirements	**Verification**
1. The Hydraulic Supply Module shall provide a complete pressure and return flow path that supports continuous repeated operation without visible fluid leakage.	1. Fill the system with hydraulic oil and run repeated operating cycles. The module passes if no visible leakage is found at the tank, line connections, or valve interfaces.
2. The oil tank capacity shall be sufficient to support at least 10 minutes of repeated testing without causing unstable suction or interruption of hydraulic supply.	2. Operate the system continuously for 10 minutes and observe the oil level and fluid supply condition. The module passes if no unstable suction, cavitation-like behavior, or flow interruption is observed.
3. The relief valve shall provide overpressure protection by opening at a pressure not more than 10% above the selected design operating pressure.	3. Increase system pressure under controlled conditions and record the pressure at which the relief valve activates. The module passes if the valve opens at or below 1.1 times the design operating pressure.

3.2.3 Supporting Material

The hydraulic system framework and the block diagram both serve as useful supporting material for this module because they show the pressure line, the return line, the oil tank, and the relief valve. A future annotated hydraulic flow figure may also be added to communicate the supply and return paths more clearly.

3.3 Control Module

3.3.1 Description

The Control Module manages both actuator control and force-signal acquisition in the current prototype. At the current design stage, the team plans to use a combined PLC-and-PCB control architecture. The PLC will serve as the main controller for system start, stop, interlock logic, and valve actuation. It is responsible for the switching and sequencing functions required for hydraulic operation. In parallel, a dedicated PCB-based acquisition board will be used for the load cell mounted at the impact target.

Under this architecture, the PLC and PCB perform different but complementary tasks. The PLC focuses on discrete control and actuator-side logic, while the PCB focuses on the low-level analog signal chain required to capture the impact force waveform. This division is necessary because the load cell produces a low-level bridge output signal that is not suitable for direct high-quality dynamic measurement through ordinary switching logic alone. The PLC-based control architecture is developed based on general programmable controller design principles and hardware considerations [1].

This module interacts directly with the hydraulic control valve through the PLC control path and with the load cell through the PCB-based sensing path. It also interacts indirectly with the actuation subsystem by determining when the hydraulic cylinder moves and by recording the force response generated during impact. Stable control and acquisition performance are both important for safe operation and for consistent impact testing.

3.3.2 Requirements and Verification

Table 3: Requirements and verification for the Control Module

Requirements	**Verification**
1. The PLC-based control system shall execute start, stop, interlock, and valve switching commands reliably for 100 consecutive command cycles without loss of control.	1. Run 100 consecutive start/stop and valve switching operations. The module passes if all commanded actions are executed correctly and no control failure occurs.
2. The PCB-based acquisition board shall provide stable excitation and signal acquisition for the load cell during repeated impact tests, with no loss of measurement function or obvious waveform interruption.	2. Connect the load cell to the PCB and record the force signal during repeated impact operation. The module passes if the signal can be recorded continuously throughout the test and no obvious interruption or acquisition failure is observed.
3. The response time between a PLC output command and the observable valve actuation shall be less than 0.2 seconds in repeated trials, and the PCB acquisition chain shall record the corresponding impact signal without obvious clipping or saturation.	3. Measure the time delay between the PLC output signal and the observed valve actuation over multiple trials, and inspect the recorded force waveform. The module passes if the delay remains below 0.2 seconds for all trials and no obvious clipping or saturation is observed in the acquired signal.

3.3.3 Supporting Material

The block diagram is useful supporting material for this module because it shows the functional position of the control valve and the sensing path within the overall system. In a later revision, an additional control-and-acquisition architecture figure may be included to show the relationship among the PLC, the valve-driving circuit, the PCB-based load cell acquisition board, and the external data-recording interface.

3.4 Actuation and Impact Module

3.4.1 Description

The Actuation and Impact Module converts hydraulic energy into vertical mechanical motion and ultimately generates the impact applied to the test target. It includes the control valve, the hydraulic cylinder, and the impact head or impact rod. The control valve determines the flow direction in the hydraulic circuit, and the hydraulic cylinder uses that flow to extend or retract. The vertical cylinder motion is then transmitted to the impact head, which will strike a small cart during testing.At the current stage, the hydraulic control element is planned as a proportional directional valve [2].

At the current stage, the team is still deciding whether the control valve should be implemented as a servo valve or as an electromagnetic reversing valve. Regardless of the final choice, this subsystem is responsible for producing controllable, repeatable, and properly aligned impact motion. It interacts directly with the Hydraulic Supply Module for fluid delivery and with the Structural Support and Platform Module for mounting and alignment.

3.4.2 Requirements and Verification

Table 4: Requirements and verification for the Actuation and Impact Module

Requirements	**Verification**
1. The hydraulic cylinder and impact head shall provide a repeatable vertical impact stroke with a cycle-to-cycle displacement variation of no more than ±5% under the same operating condition.	1. Measure the impact stroke over at least 10 repeated cycles at the same setting. The module passes if the measured displacement variation remains within ±5%.
2. The valve-actuator combination shall respond reliably to repeated switching commands for at least 100 consecutive actuation cycles without stalling or missed motion.	2. Perform 100 consecutive actuation cycles and observe the cylinder response. The module passes if no missed motion, stalling, or incomplete actuation occurs.
3. The impact output measured at the target through the load cell shall remain repeatable, with the peak measured load varying by no more than ±10% over 10 repeated impacts at the same setting.	3. Use the load cell at the target to record 10 repeated impacts under the same operating condition. The module passes if the peak measured load remains within ±10% of the average peak value.

3.4.3 Supporting Material

The hydraulic framework figure and the physical layout figure are both useful for this module. The hydraulic figure explains how the valve and cylinder are connected in the flow circuit, while the physical layout figure shows how the cylinder and impact head are arranged on the platform. A future local CAD detail of the impact head path may further improve the explanation of the motion and alignment.

3.5 Structural Support and Platform Module

3.5.1 Description

The Structural Support and Platform Module provides the physical foundation for the entire system. It includes the base plate, mounting structure, and supporting frame used to hold the hydraulic and control components in their intended positions. This module ensures that the major components remain properly aligned and that the vertical impact path is maintained during operation. It also provides the basic structure needed for future mobility and safety features, such as wheels, locking devices, and protective covers.

This module interacts with all other subsystems because it physically supports and positions them. In particular, it is important for the Actuation and Impact Module because structural misalignment or insufficient stiffness can reduce impact accuracy and repeatability.

3.5.2 Requirements and Verification

Table 5: Requirements and verification for the Structural Support and Platform Module

Requirements	**Verification**
1. The platform structure shall support the full installed system without permanent deformation or loosening during repeated operation.	1. Assemble the full system on the platform and run repeated operating cycles. The module passes if no permanent deformation, structural loosening, or mounting failure is observed.
2. The support structure shall maintain the alignment of the hydraulic cylinder and impact path such that the lateral offset at the impact point does not exceed 5 mm.	2. Measure the alignment of the cylinder axis and the impact point before and after repeated operation. The module passes if the lateral offset remains within 5 mm.
3. The platform shall remain stable during operation, with no visible sliding, tipping tendency, or excessive vibration that interferes with normal testing.	3. Operate the system under repeated impact conditions and observe the base behavior. The module passes if no visible sliding, tipping tendency, or excessive vibration is observed.

3.5.3 Supporting Material

The physical layout figure is the main supporting material for this module because it shows the base platform, the mounting arrangement, and the spatial positions of the major components. In a later version of the design document, an additional structural drawing may be included to show the support frame, the mounting points, and the future wheel-locking arrangement more clearly.

4 Tolerance Analysis

A critical function of the movable impact testing platform is to generate a reasonably repeatable impact on the target object. For the current design, this function mainly depends on the hydraulic cylinder output. Therefore, a simplified tolerance analysis is performed for the Actuation and Impact Module.The hydraulic cylinder selection and force-output discussion are supported by standard industrial hydraulic cylinder documentation [3].

The output force of the hydraulic cylinder can be approximated by

$$F = PA \tag{1}$$

where P is the hydraulic pressure and A is the piston area. For a piston diameter D,

$$A = \frac{\pi D^2}{4} \tag{2}$$

Thus, the impact energy over an effective stroke s can be estimated as

$$E = Fs = P\frac{\pi D^2}{4}s \tag{3}$$

Based on this relation, the relative variation of impact energy can be approximated by

$$\frac{\Delta E}{E} \approx \frac{\Delta P}{P} + 2\frac{\Delta D}{D} + \frac{\Delta s}{s} \tag{4}$$

Table 6 shows a preliminary design case used for this estimate.

Table 6: Preliminary values for tolerance analysis

Parameter	**Nominal Value**	**Tolerance**
Hydraulic pressure P	2.0 MPa	$\pm 5\%$
Cylinder diameter D	40 mm	± 0.5 mm
Effective stroke s	20 mm	± 2 mm

Using these values,

$$2\frac{\Delta D}{D} = 2\left(\frac{0.5}{40}\right) = 2.5\% \tag{5}$$

and

$$\frac{\Delta s}{s} = \frac{2}{20} = 10\% \tag{6}$$

Therefore, the estimated worst-case variation of impact energy is

$$\frac{\Delta E}{E} \approx 5\% + 2.5\% + 10\% = 17.5\% \tag{7}$$

This result shows that the stroke variation is the dominant factor affecting impact repeatability. Even with relatively loose prototype-level tolerances, the system is still expected to provide a controllable and reasonably repeatable impact output for preliminary laboratory testing. The analysis therefore supports the feasibility of the current hydraulic actuation design at the prototype stage.

5 Cost Analysis

Table 7 summarizes the current estimated cost of the movable impact testing platform. Some components have already been purchased, while several remaining components are still estimated based on the current design plan. At the current stage, the valve type is planned as a proportional directional valve.

Table 7: Preliminary cost analysis of the movable impact testing platform

Item	**Qty.**	**Unit Cost (CNY)**	**Total (CNY)**	**Status**
Hydraulic oil tank	1	187.10	187.10	Purchased
Hydraulic pump	1	410.00	410.00	Purchased
Load cell sensor	1	198.00	198.00	Purchased
Motor controller	1	946.51	946.51	Purchased
Motor	1	1970.00	1970.00	Purchased
Battery pack	1	5998.05	5998.05	Purchased
Proportional directional valve	1	7100.00	7100.00	Quoted
Cooling system	1	600.00	600.00	Quoted
Relief valve	1	1200.00	1200.00	Quoted
Valve block (non-standard custom)	1	2100.00	2100.00	Quoted
Hydraulic cylinder	1	350.00	350.00	Estimated
PLC controller	1	500.00	500.00	Estimated
PCB board	1	150.00	150.00	Estimated
Hydraulic hoses and fittings	1 set	300.00	300.00	Estimated
Base plate and support frame materials	1 set	600.00	600.00	Estimated
Wheels and locking mechanism	1 set	250.00	250.00	Estimated
Fasteners, wiring, and miscellaneous parts	1 set	200.00	200.00	Estimated
		Purchased Subtotal	**9709.66**	
		Quoted / Estimated Remaining Cost	**13350.00**	
		Total Estimated Cost	**23059.66**	

The purchased subtotal is based on the components that have already been ordered at the time of writing. The remaining items are preliminary estimates and may change as the final design is refined. In particular, the cost of the proportional directional valve, the PLC controller, the PCB-based acquisition board, the structural frame, and the hydraulic cylinder may vary depending on the final specifications.

6 Schedule and Division of Labor

Table 8 shows the preliminary project schedule from March 30, 2026 to May 18, 2026. The schedule is organized by week, with one primary task assigned to each team member in each week.

Table 8: Project schedule and division of labor

Week	**Shangyu Wang**	**Yihang Shen**	**Feiyu Tang**	**Bingkun Fu**
Mar. 30–Apr. 5	Draft project introduction and design document outline	Develop initial mechanical layout and platform concept	Define the combined PLC-and-PCB control architecture, including PLC I/O planning and load-cell acquisition requirements	Organize hydraulic component list and support initial system integration plan
Apr. 6–Apr. 12	Write Introduction and Overall Design sections	Refine structural platform design and impact mechanism arrangement	Select PLC-related components and develop the preliminary PCB-based load-cell acquisition plan	Assist with hydraulic circuit planning and component matching
Apr. 13–Apr. 19	Write subsystem descriptions and prepare document figures	Complete detailed mechanical design of base, support frame, and mounting positions	Design PLC wiring for valve control and prepare the PCB schematic for load-cell signal acquisition	Coordinate hydraulic assembly plan and check pump, tank, and valve connections
Apr. 20–Apr. 26	Write subsystem requirements and verification draft	Support fabrication drawing preparation and assembly layout checking	Begin PLC programming and PCB layout/testing preparation	Prepare purchased components and support hardware assembly
Apr. 27–May 3	Update design document based on hardware progress and record design decisions	Assemble mechanical structure and align impact path	Implement PLC control for start/stop and valve actuation, and integrate the PCB-based acquisition board	Assist with hydraulic assembly, tubing connections, and troubleshooting
May 4–May 10	Record experimental procedures and organize testing notes	Adjust mechanical alignment and improve structural stability	Debug the PLC control sequence and verify the PCB-based force-signal acquisition	Support system integration and basic functional testing
May 11–May 17	Write testing results, cost analysis, and final report revisions	Support repeated impact tests and mechanical issue correction	Verify control response and support sensor-related testing and data acquisition validation	Assist with final hydraulic debugging and overall system reliability check
May 18	Finalize experiment records and submit final written materials	Perform final mechanical inspection	Perform final PLC and PCB system check	Perform final system inspection and integration support

7 Ethics and Safety

The movable impact testing platform involves several safety and ethical considerations because it combines electrical power, hydraulic actuation, and repeated mechanical impact. The main safety risks of the project include high-current electrical components, hydraulic pressure, moving mechanical parts, and the impact applied to the target object. If these risks are not properly controlled, they may lead to equipment damage or personal injury during testing.

From the electrical side, the motor, controller, battery pack, PLC, and PCB interface require careful wiring and insulation. Improper connections may cause overheating, short circuits, or unexpected system behavior. From the hydraulic side, pressurized fluid may create leakage or sudden force output if hoses, fittings, or valves are not properly installed. In addition, the hydraulic cylinder and impact head introduce mechanical hazards such as pinch points, moving parts, and unintended impact during operation.

To reduce these risks, the design will include several basic protection measures. First, all electrical wiring will be insulated and secured, and the power system will be checked before operation. Second, hydraulic connections will be inspected for leakage before each test, and the relief valve will be used to prevent excessive pressure in the system. Third, the impact area will be kept clear during operation, and only authorized team members will be allowed near the device while testing is in progress. Fourth, the structural platform will be designed to remain stable during repeated operation, and wheel-locking or equivalent fixing methods will be used if mobility is added in the final version. Finally, the system will include controlled start and stop procedures through the PLC so that the operator can reduce the risk of unintended motion.

This project also involves ethical responsibilities. The team must report design limitations, experimental observations, and test results honestly. Performance data should not be altered to make the prototype appear more successful than it actually is. In addition, the team must operate the device in a way that protects other students and shared laboratory equipment. Any abnormal behavior, including leakage, unstable motion, or electrical faults, must be recorded and addressed before further testing.

The project will follow general engineering ethics and laboratory safety principles. In particular, the team will follow the spirit of professional engineering responsibility by prioritizing safety, honest reporting, and responsible testing. The design will also follow relevant laboratory safety rules and general machine and electrical safety practices, including safe operation around moving components, proper handling of pressurized systems, and controlled use of electrical power.

Overall, safety and ethics are treated as integral parts of the design rather than as secondary concerns. The selected hydraulic layout, PLC-based actuator control approach, PCB-based sensing and data-acquisition approach, structural support design, and testing procedures are all intended to reduce operational risk while supporting reliable and responsible experimentation.

References

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[3] Parker Hannifin Corporation, *Heavy Duty Hydraulic Cylinders*, catalog HY08-1314-2/NA. [Online]. Available: https://www.parker.com/content/dam/Parker-com/Literature/Industrial-Cylinder/cylinder/cat/english/GenII_HY08-1314_2H_3H_Family.pdf