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Design and Fabrication of an Automated Discharge Collection Unit for the Synthetic Hydro-experimental Machine.

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INTERIM REPORT

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Declaration

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Abstract

The synthetic hydro experimental machine used for fluid mechanics experiments in the fluids lab at JKUAT employs an older technology in the measurement of fluid properties. The machine is wholly mechanical as most of the parameter manipulations are done by hand. In experiments to determine the coefficient of discharge by using the Venture and the Orifice, flow rate control is achieved by hand by opening the ball valve in small steps which can be inconsistent. Besides, one has to measure the temperature and time of discharge simultaneously. As a result, with these discrepancies and lack of synchronism, the findings might frequently be outside of the acceptable range due to human error.

This project intends to design and fabricate an automated discharge collection process to minimize human error while maintaining the credibility of the experiment. This design will be a modular system comprised of two major units; the discharge flow control unit and the discharge collection unit. Through the use of a graphical user interface, the user will be prompted to input the time to perform the experiment and the number of steps. Based on the provided information and the pipe circumference, the system automatically determines the number of steps required. The system will automatically initiate the pump to force water into the pipe system for a specified amount of time to attain steady flow after which the ball valve closes. A servo motor attached to the valve shaft is used to open the valve in small and precise steps. A flap system diverts the discharge either into the collection tank or into the water reservoir. The collected discharge is weighed and at the same time, its temperature is measured, recorded, and displayed on the user interface after which the discharge is released into the reservoir through a solenoid valve to allow for the next step.

This automation reduces the oftenly huge error margins in fluid flow experiments due to human errors.

Contents

List of Figures

List of Tables

1 Introduction

1.1 Background

Fluid flow measurement involves the measurement of the properties of a smooth and uninterrupted stream of flowing particles that conform to a pipe. These flow properties include the coefficient of discharge, mass flow rate, fluid velocity, differential pressure, and conductivity coefficients [8]. They are altered and measured by flow measuring devices such as the Venturi, the Orifice, turbine flow meters and rotameters [9]. These measurements are finally related to the flow using the Bernoulli's equation.

The Synthetic Hydro-Experimental machine, currently installed in JKUAT, is a configurable machine with these flow meters. This machine is used to conduct experiments to establish relationships between the fluid flow properties and the behavior of the flow. It has a lift pump, gate valves, alcohol manometers, pressure gauges, a Pelton turbine, a Venturi, an orifice, and water reservoirs. During experiments, the lift pump is turned on, and the discharge valve is fully opened to establish a steady flow. The discharge valve is then closed. The valve is opened in small steps depending on the number of steps required. For each step, the discharge is collected, and its temperature is measured within a specific time interval. Finally, the weight of the collected discharge is also measured.

1.2 Problem statement

In fluid flow experiments utilizing the Venturi and the orifice to establish the coefficient of discharge, the discharge steps must be precisely opened, and time and temperature measurements must be made concurrently with discharge collection so as to achieve values that are within a reasonable range.The Synthetic Hydro-Experimental machine now in use at JKUAT to establish this relationship, however, is entirely mechanical, making it impossible for a human to do some of the simultaneous measurements. A ball valve regulates the flow rate in small intervals using human intuition, which can be imprecise.

As a result, with these discrepancies, the findings might frequently be outside of the acceptable range. Automating the discharge collection process can minimize the error in the results and still preserve the credibility of the experiment.

1.3 Objectives

1.3.1 Main objective

To automate the discharge collection process for the Synthetic Hydro-Experimental machine.

1.3.2 Specific objectives

1. To design an automated discharge flow control unit that can precisely discharge in steps.
2. To design and fabricate a discharge collection unit with automated weight, time and temperature measurements.
3. To design a user interface and the control algorithm.

1.3.3 Expected outcomes

The following are what are expected of the specific objectives mentioned

1. **Discharge flow control unit**
   A discharge flow control mechanism that can turn the ball valve in precise steps. The steps obtained from the division of the circumference of a full turn by the number of steps should be precise to the nearest whole number.

2. **Discharge collection unit**

   A discharge collection unit that can precisely collect the discharge within the specified time interval while taking its temperature and weight simultaneously. This can be expected if the expectations of the following sub-units are met :

   (a) **Flow diversion sub-unit**

   A precisely sized diversion sub-unit, correctly positioned to collect or divert the discharge with minimal splashes the whole stream. This will improve on the accuracy of the weight of the discharge and hence that of the whole experiment experiment in general.

   (b) **Discharge collection tank**

   A discharge collection tank whose shape can allow for accurate weight measurement. The collection tank should allow for motivated discharge into the reservoir and it should also be positioned in such a way that flow into this tank utilizes gravity to eliminate the need for an extra pump.

   (c) **Discharge weight and temperature measurements**

   It is expected these units measuring devices can measure to the smallest resolution.

3. **Control and Display**

   The control module that can handle intense computations such as error approximation, immediate rendering of results and communicating with the sensors and transducers that will be used in the system. The user interface should also be slick and ergonomic.

1.4 Justification

This automation will streamline the discharge collecting process while also ensuring the consistency and quality of the data collected in each phase of the fluid flow tests performed on the system. In contrast to the existing condition, such automation allows a single person to perform the experiment without significant effort. Furthermore, the automated system will also be modular, allowing it to be readily attached and detached from the main machine with few modifications.

2 Literature Review

2.1 Introduction

Fluid flow experiments involve collecting the discharge within specific time intervals. This is usually done simultaneously with the temperature measurement of the discharge in order to minimize the environmental effect on this reading. The weight of the discharge is finally measured for the computation of the mass flow rate property of the flow.

2.2 Existing Technologies

Some advanced and even rudimentary technologies have been used in place of the Synthetic Hydro-Experimental machine for the determination of fluid flow properties. The technologies include :

2.2.1 Computational Fluid Dynamics

CFD! (**CFD!**) is a powerful modelling and analysis technique that utilizes finite difference techniques to solve highly non-linear differential equation of pressure, energy, relative humidity, air temperature and velocity [10]. It can be used to model fluid flow in flow measurement devices.

Tukimin et al [1] in their study conducted a CFD analysis using an **SKE!** (**SKE!**) turbulence model to determine the coefficient of discharge of a Venturi tube, and finally compared the results to those obtained from a physical experimental setup. The test loop shown in figure 2.1 was used both in a physical setup and a CFD model.

They designed a CFD model using the ANSYS Design Modeller software. The model consists of a Venturi tube, designed according to the standards ISO 5167:2003 [11], and a liquid and gas system. They did a physical experiment using the same test matrix used

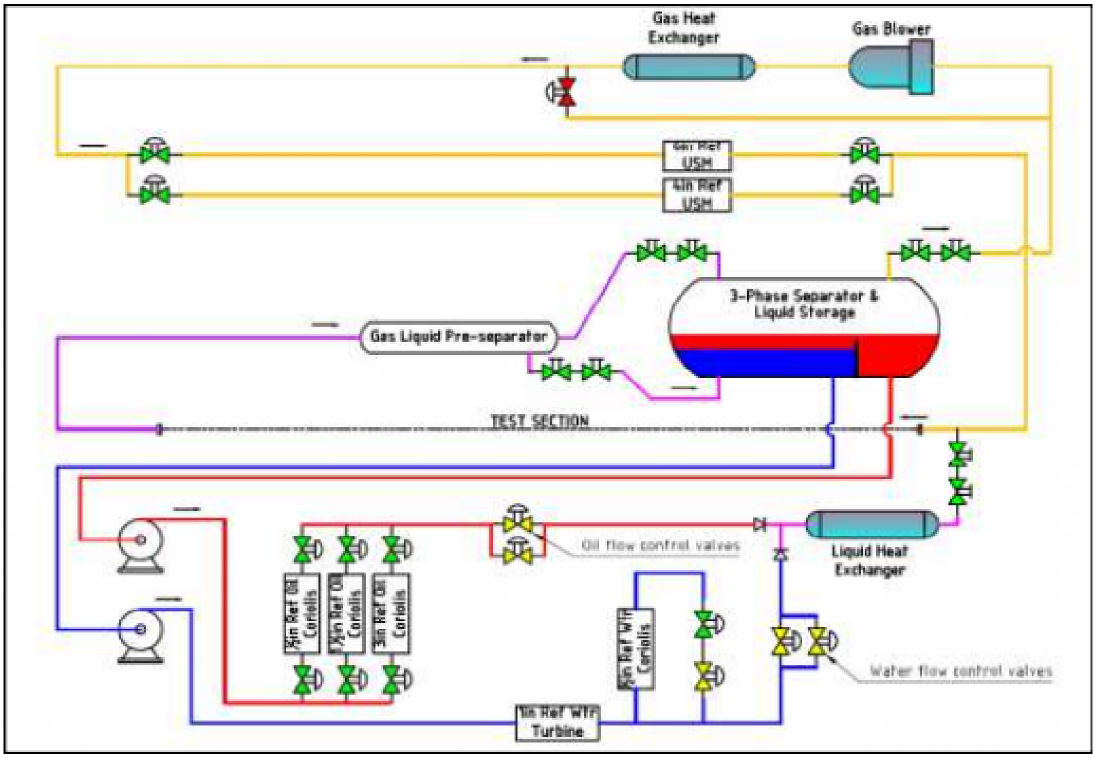


Figure 2.1: Test loop schematic [1]

Table 2.1: Calculated C_d

Venturi under Test	Average Discharge Coefficient	Average Discharge Coefficient
	From experiment	From CFD post
Venturi 1	0.99366	0.984347

in the numerical simulation model. Finally, they computed the coefficient of discharge of the venturi using equationt 3.2.

$$Cd = \frac{4m\sqrt{1-\beta^4}}{\pi \varepsilon d^2 \sqrt{200000 D p_1 \rho_1}} \tag{2.1}$$

The results obtained in 2.1 showed a difference of less than 1% between the C_d obtained from the two setups.

Table 2.2: Results

Reading No.	Experiment	CFD analysis
1	0.9724	0.9619
2	0.9592	0.9689
3	0.9779	0.9692

Tamhankar et al [2] also did a similar experiment using a CFD model designed in ANSYS Fluent 13.0 utilizing a Realizable k-ϵ turbulence model which is superior to a Standard k-ϵ turbulence model and compared the results to those obtained from an experimental setup show in figure 2.2.

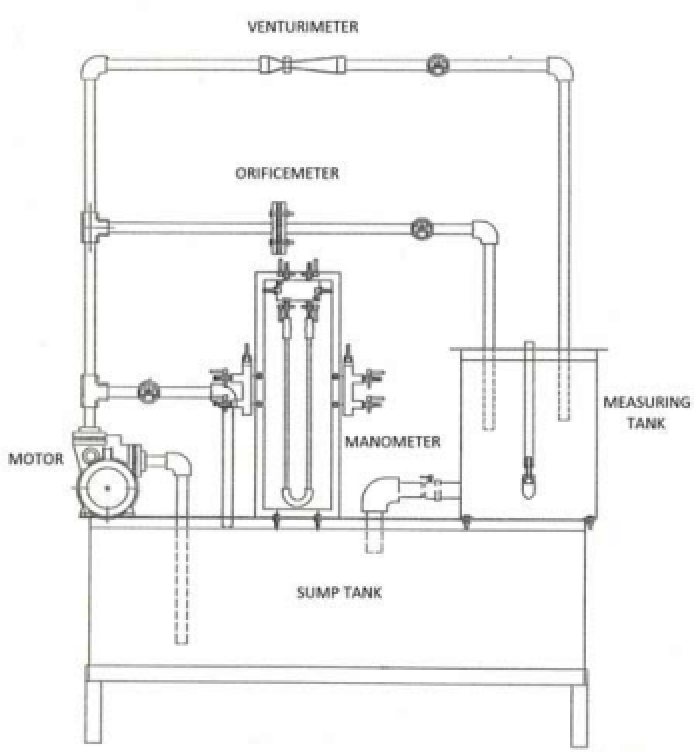


Figure 2.2: Experimental setup [2]

Table 2.2 shows the results obtained from the study

The study concluded that difference in values of the coefficient of discharge obtained from

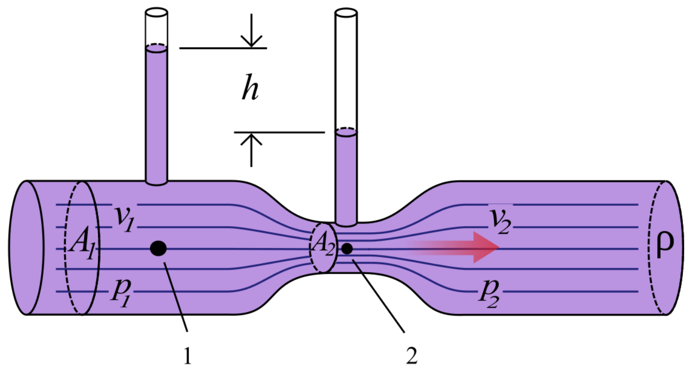


Figure 2.3: Venturi meter

the model and those obtained from the experimental setup was less than 5% .

2.2.2 Analytical Predictions

This technique utilizes the Bernoulli's equation to establish an analytical correlation between the fluid flow and the coefficient of discharge of the Venturi meter.

Figure 2.3 shows the Venturi meter. Assuming the flow is ideal and applying the Bernoulli's equation before and after the contraction,

$$\begin{aligned}
&\frac{p_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + z_2 \\
&\text{But } Z_1 = Z_2, \\
&\frac{(p_1 - p_2)}{\rho} = \frac{(v_2^2 - v_1^2)}{2} \\
&\frac{(p_1 - p_2)}{\rho} = \frac{v_2^2}{2}\left(1 - \frac{A_2^2}{A_1^2}\right) \\
&\frac{\Delta p}{\rho} = \frac{v_2^2}{2}\left(1 - \beta^4\right) \\
&v_2 = \frac{1}{\sqrt{1-\beta^4}}\sqrt{\frac{2\Delta p}{\rho}}
\end{aligned} \tag{2.2}$$

Applying the continuity equation to the result of the derivation in 2.2,

$$\begin{aligned} Q_{th} &= A_1 v_1 = A_2 v_2 \\ Q_{th} &= A_2 v_2 = \frac{1}{\sqrt{1-\beta^4}} \frac{\pi d^2}{4} \sqrt{\frac{2\Delta p}{\rho}} \end{aligned} \tag{2.3}$$

Equation 2.3 of theoretical flow rate is based on the assumption that the flow is steady, incompressible, inviscid, irrotational, no losses and the velocities V_1 and V_2 are constant across the cross section [12].

$$\mathrm{Q_{act}} = \frac{\mathrm{C_{d_{std}}}}{\sqrt{1-\beta^4}} \frac{\pi \mathrm{d}^2}{4} \sqrt{\frac{2\Delta \mathrm{p}}{\rho}} \tag{2.4}$$

The frictional and viscous losses in a laminar flow can be estimated by the Darcy's law

$$\mathrm{H_L} = \frac{(\Delta \mathrm{p})_{\mathrm{viscous}}}{\rho \mathrm{g}} = \mathrm{f} \frac{\mathrm{v}^2}{2\ \mathrm{g}} \frac{\mathrm{D}}{\mathrm{D}} \tag{2.5}$$

where 'f' is the friction factor.

Coefficient of discharge equation 2.7 where for laminar flow, 'f' is given by equation 2.6 . This equation is derived from both the Darcy's law equation and the theoretical flow rate equation 2.3.

$$f = \frac{64}{R_{ed}} \tag{2.6}$$

$$C_{\mathrm{d}} = 0.995 \sqrt{\frac{1}{(1+3f)}} \tag{2.7}$$

Arun et al [12] did a comparision of the C_d obtained by this method and that obtained from a CFD simulation. The study concluded that the results from the two methods had an uncertainty of 0.9%.

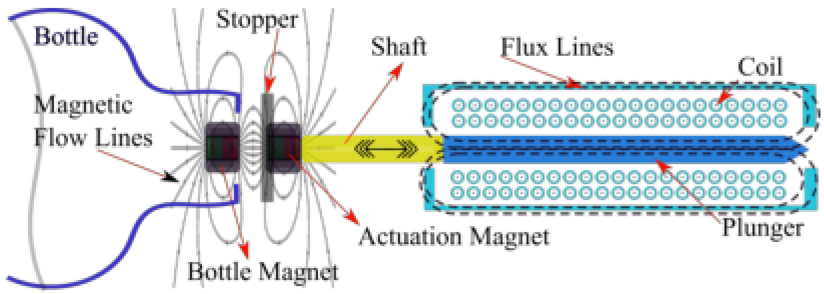


Figure 2.4: Sampler actuation mechanism [3]

2.3 Related Works

Discharge collection techniques have been developed for various applications. Some of these applications are related to the discharge collection unit used in the Synthetic Hydro-Experimental machine.

2.3.1 Electromagnetic activation

Angelo et al [3] implemented this technique in the design and testing of an Modular **MAWS!** (**MAWS!**). They designed MAWS and mount them on **UMV!** (**UMV!**) with the aim of collecting water samples for scientific campaigns in front of polar tidewater glaciers. Their main design considerations was the response time of the stopper since the MAWS were operated under water and at the risk of damage by glaciers. The actuation unit of the sampler is shown in figure 2.4.

When the coil in the solenoid is crossed by a current a strong magnetic field is generated that attracts the ferromagnetic plunger connected to the sealing stopper and opens the bottle allowing water to flow into the bottle's neck. As the current stops the two permanent magnets attract each other and the stopper seals the bottle [3].

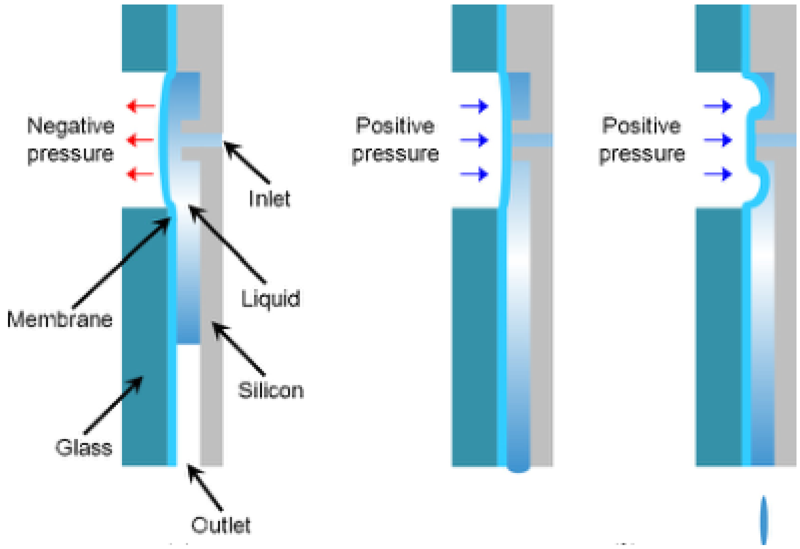


Figure 2.5: Dispensing mechanism [4]

2.3.2 Pneumatic Control

Pneumatic actuators utilizes the power of compressed air to impart motion on objects. Sangmin, and Joonwon [4] did a design of cartridge-type pneumatic dispenser with a back flow stopper. The system used a membrane covering a discharge hole. The membrane was opened and closed using negative and positive pneumatic pressure respectively as shown in figure 2.5.

The application was able to do precise dispensation of 100nL to 400nL droplets.

2.4 Summary

Every fluid flow experiment done on the Synthetic Hydro-Experimental machine involves the collection of discharge and the measurement of its properties. The most common experiment is the determination of the coefficient of discharge of the Venturi and the Orifice. In this literature, other techniques such as CFD and analytical methods have been found to be effective as alternatives to this machine. These techniques have been proven to produce results with a difference of less than 1% from the experimental results obtained from a physical setup. Such results can also be obtained from the fluids rig currently used in JKUAT by automating the discharge collection unit. With regard to this, the literature has also covered discharge collection techniques that have proven to be effective in other applications and can be adapted for this automation. This techniques include the application of pneumatics and electromagnetism.

2.5 Gap analysis

1. The use of the CFD method or the analytical method undermines the credibility of the fluid flow experiments. This two techniques are rather used for the design of fluid flow measuring devices.

2. CFD method can also be very resource intensive in terms of compute resources. Softwares used for this method requires a hefty license fee.

3. The application of the analytical method involves tedious calculations and several assumptions which can produce untrustworthy results.

4. The use of the Synthetic Hydro-Experimental machine with a manual discharge collection unit often produce results with huge error margins.

This project proposal will be entirely focused on addressing gap number four with the application of techniques such as pneumatics or electromagnetism. This will close in the technological gap with the use of CFD, and simplify the use of analytical methods by providing data for the computation of fluid flow properties.

3 Methodology

3.1 Overview

This project consists of three main units: a discharge flow control unit, a discharge collection unit, and a software and control unit.

3.2 Discharge flow control unit

This unit consist of two main sub units:

1. Flow control sub-unit

   This unit is solely responsible for controlling the flow from the discharge pipe in steps.

2. Flow diversion sub-unit

   This unit is used to divert the flow from the main pipe either to the discharge collection tank during discharge collection or to the main reservoir.

3.2.1 Flow control sub-unit

The unit serves to open the main discharge pipe in steps. The current state-of-art of the Synthetic Hydro Experimental machine is as shown in figure 3.1.

Figure 3.1: Current discharge control unit

The valve is opened in steps by hand using the lever.

Automation of this unit utilizes the existing ball valve. In addition, the opening and closing of the valve is automated using a motorized system that can open the valve in precise steps. To achieve the precise steps, the following consideration were made.

3.2.2 Design Considerations

1. The torque required to open and close the ball valve.

2. The steps size or the number of steps the system can open the valve.

Based on these two considerations, the following two options were feasible.

1. **Stepper Motor**

   This motor operates by accurately synchronizing position with the pulse signal output from the controller to the driver, achieving highly accurate positioning and speed control. Stepper motors feature high torque and low vibration at low speeds ideally below 1500rpm, ideal for applications requiring quick fixed positioning in a short distance [13]. Furthermore, stepper motor rotates with a fixed step angle typically 1.8 degrees for a 2-phase. However, to achieve this requires the use of a micro-step driver.

Besides having full control of rotation and speed, the simple structure of stepper motors is achieved without using electrical components, such as an encoder within the motor. For this reason, stepper motors are very robust and have high reliability with very few failures. As for stopping accuracy, $\pm 0.05°$ (without cumulative pitch errors) is very accurate [13]. Because the positioning of stepper motors is performed by open-loop control, and operated by the magnetized stator and magnetic rotor with small teeth, stepper motors have a higher follow-up mechanism toward commands than the servo motors. Also, no hunting occurs when stopping stepper motors.

2. **Servo Motor**

   Servo motors run significantly faster than stepper motors, with speeds greater than 1500rpm [14]. This enables servo motors to be used with gearboxes to deliver much higher torque at useful speeds. They also deliver more consistent torque across the speed range of the motor. Unlike stepper motors, they do not have holding torque. Closed-loop operation enables the controller/drive to command that the load remain at a specific position, however, and the motor will make continual adjustments to hold it there. Thus, servo motors can deliver de facto holding torque [14]. The Servo motor rotates with a fixed step angle as low as 1 degree with or without the use of a driver. Furthermore, when powered, servo motors tend to move their shaft position to the zero position, a phenomenon referred to as hunting.

3.2.3 Motor Sizing and Selection

The motor shaft is required to turn 90^0 in this application since the ball valve should only turn an angle of 90^0 to open and return through the same angle to close. Accurate position control is therefore a key factor in the determination of the motor.

The load torque that is acting on the motor is given by equation 3.2

$$T = F * r \tag{3.1}$$

T is the torque required to overcome the ball valve and interface load, F is the maximum axial force on the motor(in this case it is the weight of both the ball valve and the interface) and r is the perpendicular distance from the point of action of force. The torque required to overcome ball valve and interface load was then calculated to be approximately 5N/cm.

3.2.4 Choice

Servo motor(MG996/12kg.cm/0.13s per 60 degrees turn) was selected for this operation. Its torque supply of 3kg/cm is above the required to overcome the load torque of both the ball valve and the interface. Furthermore, servo motor was selected to drive this unit because of the small step angle (1 degree) that it can turn as compared to a stepper with a typical step angle of 1.8 degrees. The smaller the angle, the more the number of steps hence the experiment could be conducted as many times as possible for higher accuracy. Furthermore, the fact that servo motors do not necessarily need a micro-step driver for their operation reduces the overall cost.

3.2.5 Flow control sub-unit designs

In order to support a stepper motor in place above the valve so that it can operate in place of the lever, the design had the following components:

1. Motor cage

   This unit is used to bolt down the motor to a rotating plate as shown in figure 3.3 The design of the cage was guided by the dimensions of a standard servo motor(MG996 Metal Gear high Torque) which was 53.70mm by 19.70mm by 38.70mm.Taking into

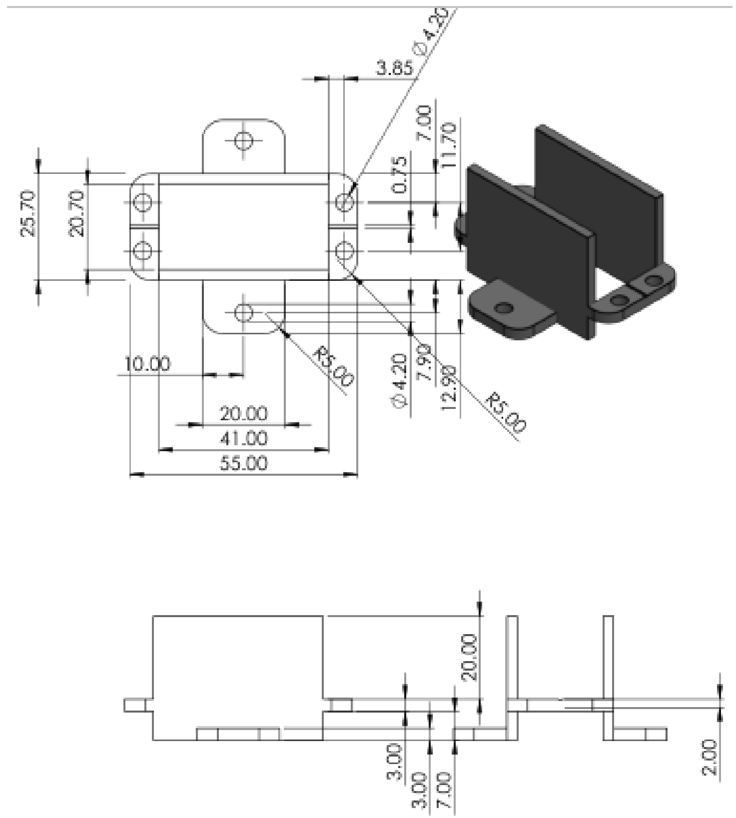


Figure 3.2: Servo Motor Holder

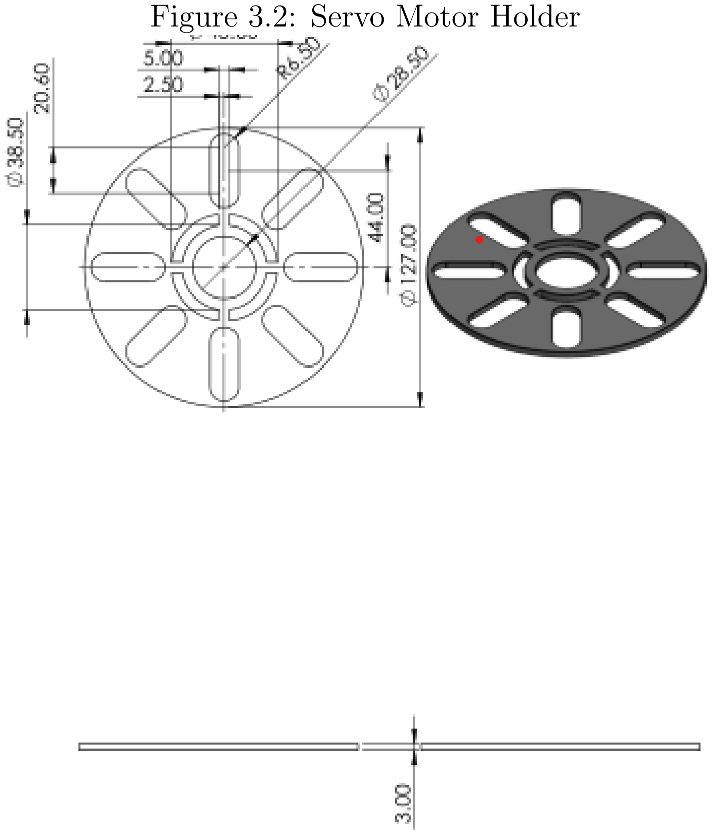


Figure 3.3: Servo Motor Holder Mount

considerations the tolerance to allow for cooling of the motor during operation and at the same time providing a firm support to the motor, the dimensions of the motor cage will be 55.00mm by 20.70mm by 20.00mm.

2. Motor rotary mount

   This unit provides a base to bolt the motor cage as shown in figure 3.3. It motor rotary mount will be supported by the supporting rods hinged to the valve with the help of serrated straps. The diameter of the mount was based on how far apart the the supporting rods were. Based on this, the diameter of mount will be 127.00mm.

3. Interface

   The interface is used in place of the lever. It connects the rotor of the stator motor to the axle of the ball valve. Its design is as shown in the figure 3.5

4. Supporting rods

   These rods supports the mounting base of the motor just above the ball valve. It is bolted to the discharge pipe through the two straps. Its design is as shown in figure 3.5

5. Seratted Straps

   These are used to mount the whole unit on the circular surface of the pipe. Their design is as shown in the figure 3.5. Since the traps are hinged onto the ball valve casing, the design dimensions was guided by the diameter of the ball valve. The choice to use the serrated valve was to enhance on the grip to the valve to avoid slidding.

3.2.6 Flow diversion sub-unit

The sub-unit is responsible for diverting the discharge from the main pipe system to either the collection tank or into the main reservoir.

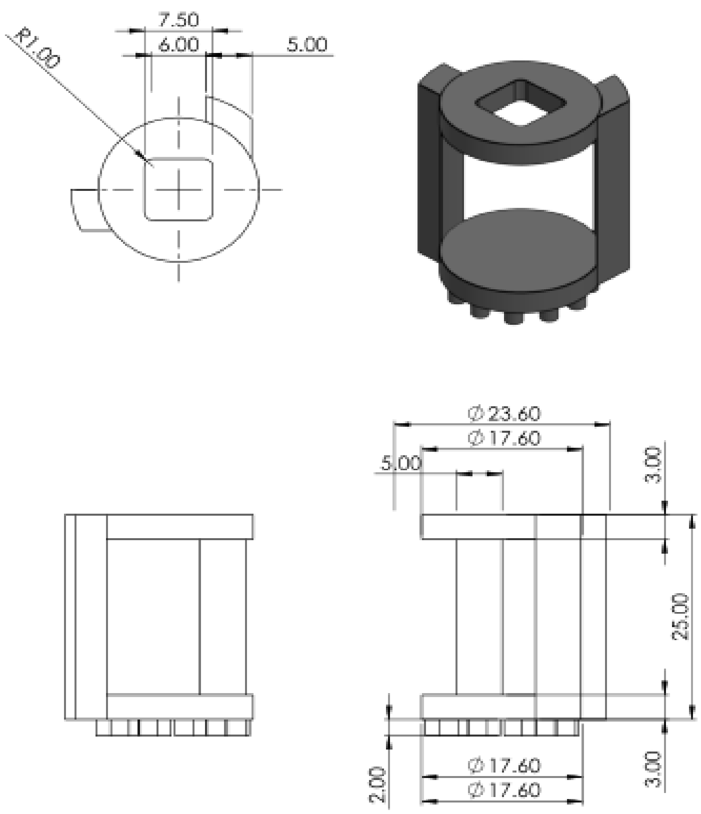


Figure 3.4: Motor-Valve interface

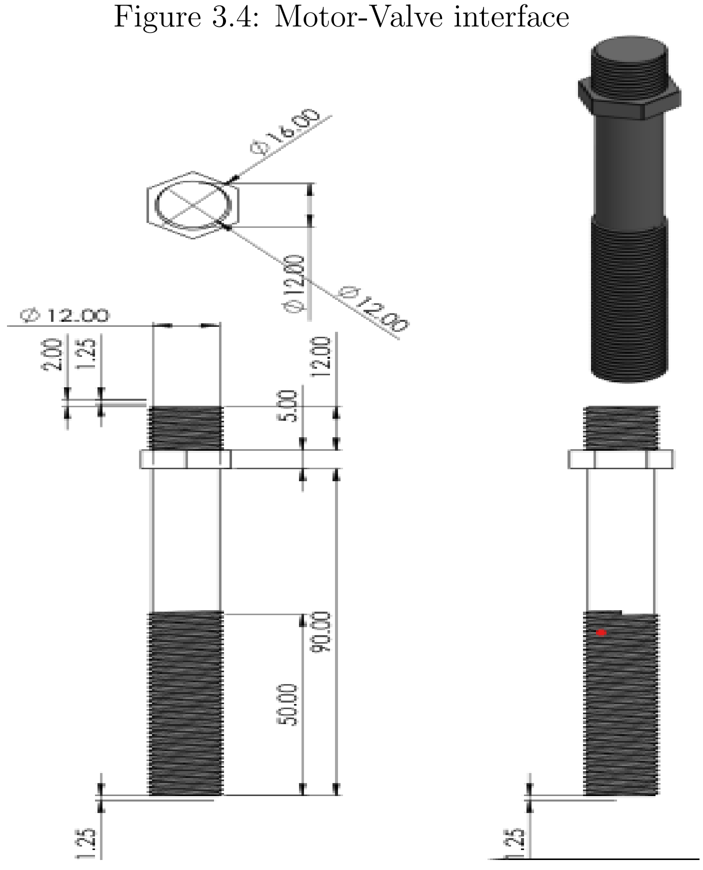


Figure 3.5: Supporting rods

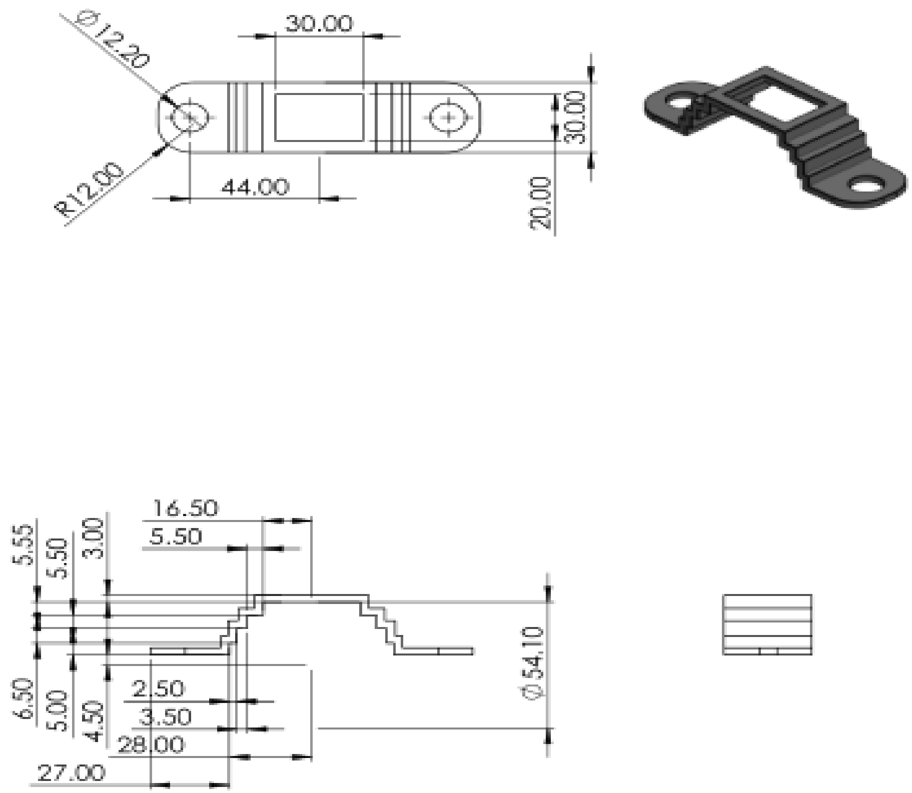


Figure 3.6: Top serrated strap

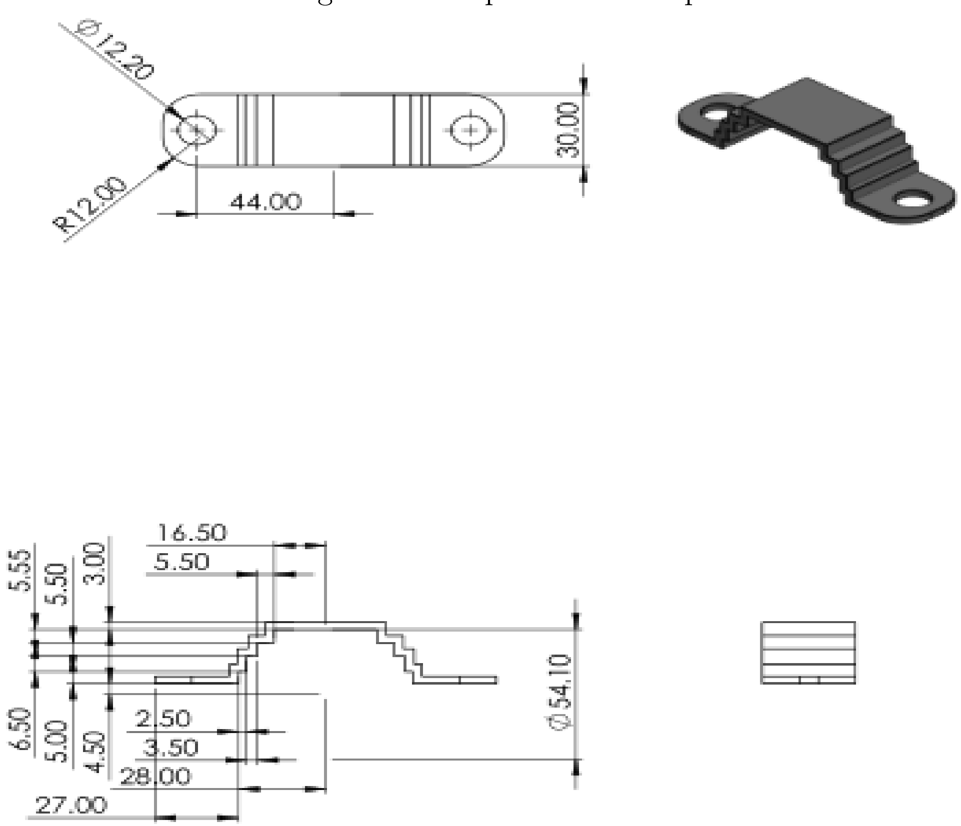


Figure 3.7: Bottom serrated strap

3.2.7 Design Consideration

The sub-unit is to have a faster response and large linear displacement capabilities Piezoelectric actuators and electromagnets were considered for this application.

3.2.8 Piezoelectric Actuators

Piezoelectric actuators are transducers that convert electrical energy into a mechanical displacement or stress based on a piezoelectric effect, or vice versa. They are used widely as a high precision positioning mechanism since they can control a small mechanical displacement at high speed, with the advantages of large generated force, stable displacement, and ease of use [15]. However, problems include insufficient displacement and the large voltage up to a few hundred volts, which is needed.

3.2.9 Electromagnets

Electromagnetic devices leverage the unique ability of magnetic metals such as iron to generate a magnetic field when electric current is applied. One of the biggest advantages offered by electromagnetic devices is durability. Unlike piezoelectric devices, which have the potential for shattered crystals, or electrostatic solutions with their required precise measurements, electromagnetic offerings can withstand high-volume, high-intensity use without suffering output or capacity loss [16]. This makes them ideal for applications in which on-demand power and magnetism are required. Furthermore, as compared to piezoelectric actuators, electromagnets have a faster response and larger displacements which is actually ideal for our application.

3.2.10 Choice

JF-0530B DC12V push-pull electromagnet was selected as the main actuation mechanism for the flow diversion sub unit due to its faster response when energized as compared to piezoelectric actuators. Furthermore, as compared to electromagnets, piezoelectric actuators produce very small mechanical linear displacements as compared to electromagnets.

3.2.11 Flow diversion sub-unit designs

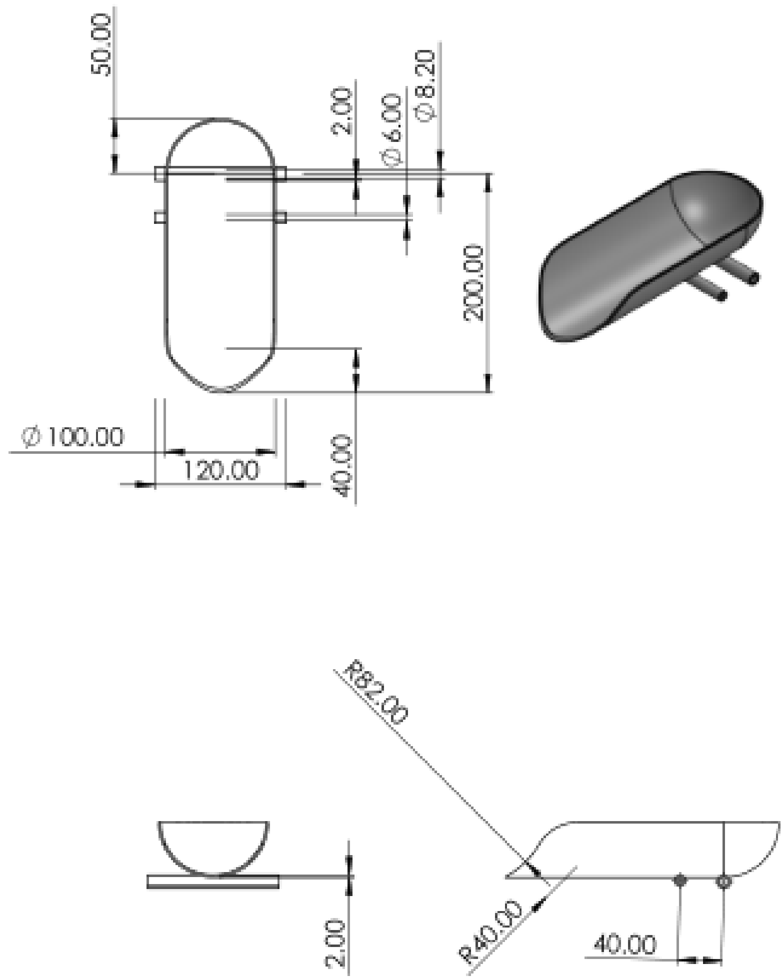


Figure 3.8: Flap

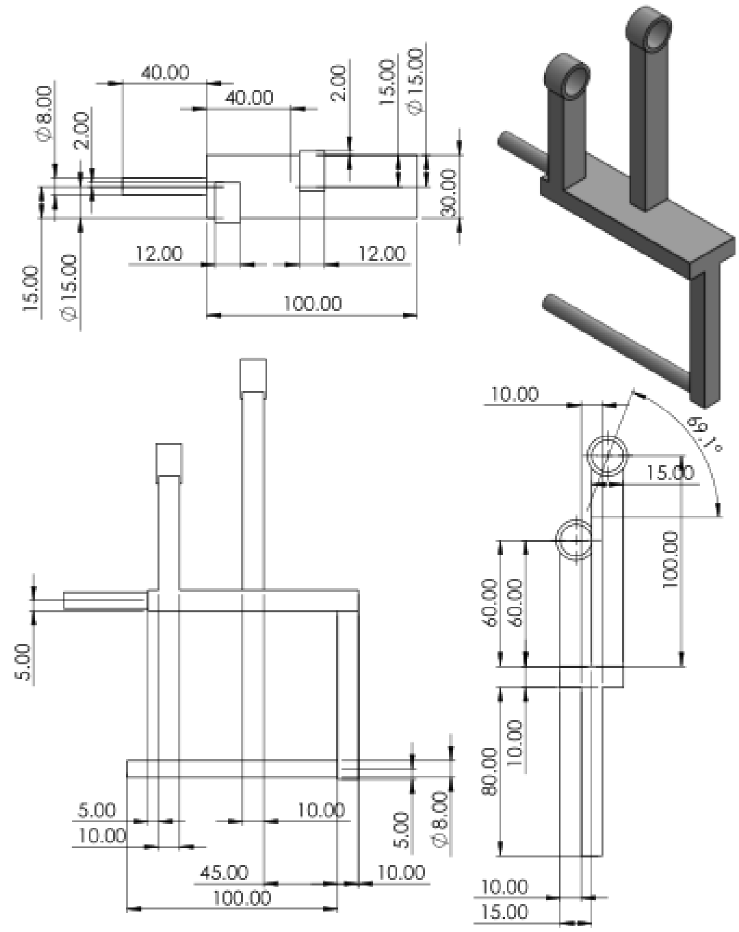


Figure 3.9: Flow Diversion Support

3.3 Discharge Collection Unit

It is the core part of the experiment. The discharge collection unit comprises the flow diversion sub-unit, a discharge collection tank, an outlet valve, and weight and temperature measurements sub-units.

3.3.1 Discharge collection tank

The collection tank is used to temporarily collect the discharge from the pipeline during each phase of the experiment after which it is released to the main reservoir. Furthermore, it is the point at which both the weight and temperature of the discharge are measured. The discharge is to be collected for a specified amount of time after which it is released into the reservoir to allow for the next phase of the experiment. To ensure that there is motivated discharge into the main reservoir, the shape of the tank was critical hence the following design considerations were taken into account.

3.3.2 Design Considerations

3.3.3 The Shape of the Tank

The shape of the tank not only influences how fast the discharge is released into the main reservoir but also the positioning of the outlet valve. Besides, it has an influence on the final weight of the discharge. This is so since a tank that holds discharge even after being released into the reservoir introduces a positive error into the load cells, which upon accumulation will eventually lead to incorrect results.

1. Horizontal Cylindrical Tanks
   Horizontal cylindrical tanks provide the fastest way to release the discharge through a solenoid valve into the reservoir due to their shape. Additionally, there shapes ensures that no discharge is left into the tank.

2. Rectangular Tanks

   Rectangular tanks offer the same storage capacity as to cylindrical tank. However, unlike cylindrical tanks, these tanks may allow for accumulation of discharge which will affect the overall weight.

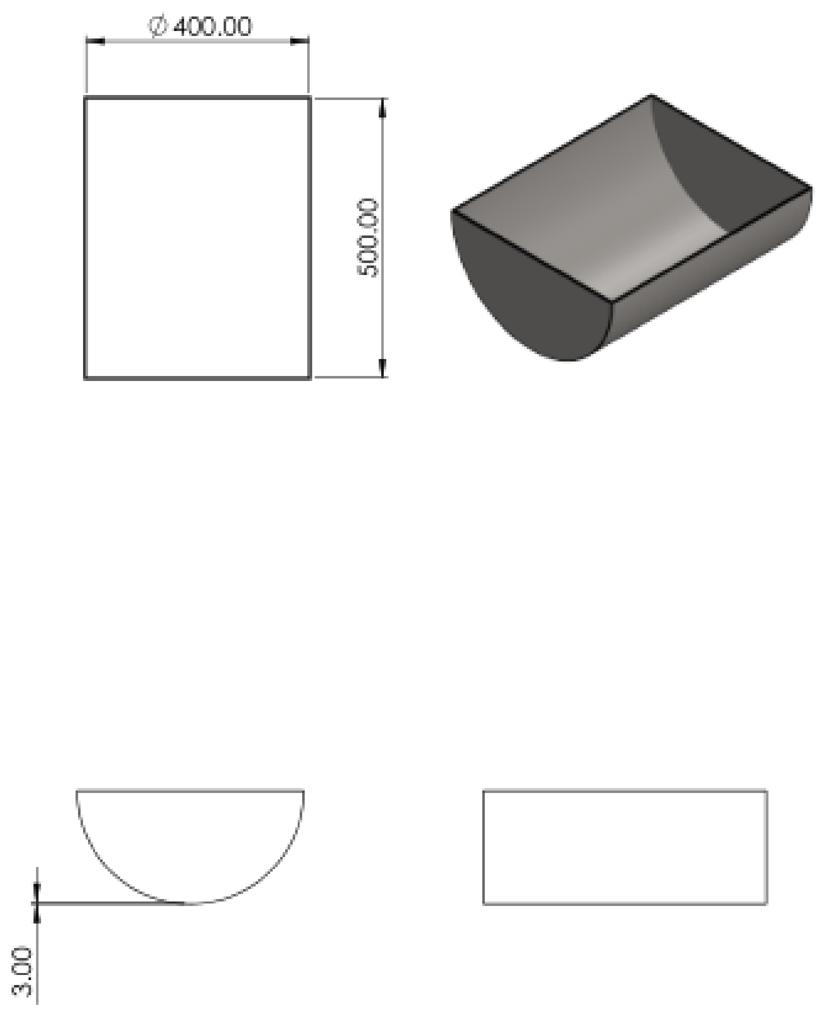


Figure 3.10: Discharge Collection Tank

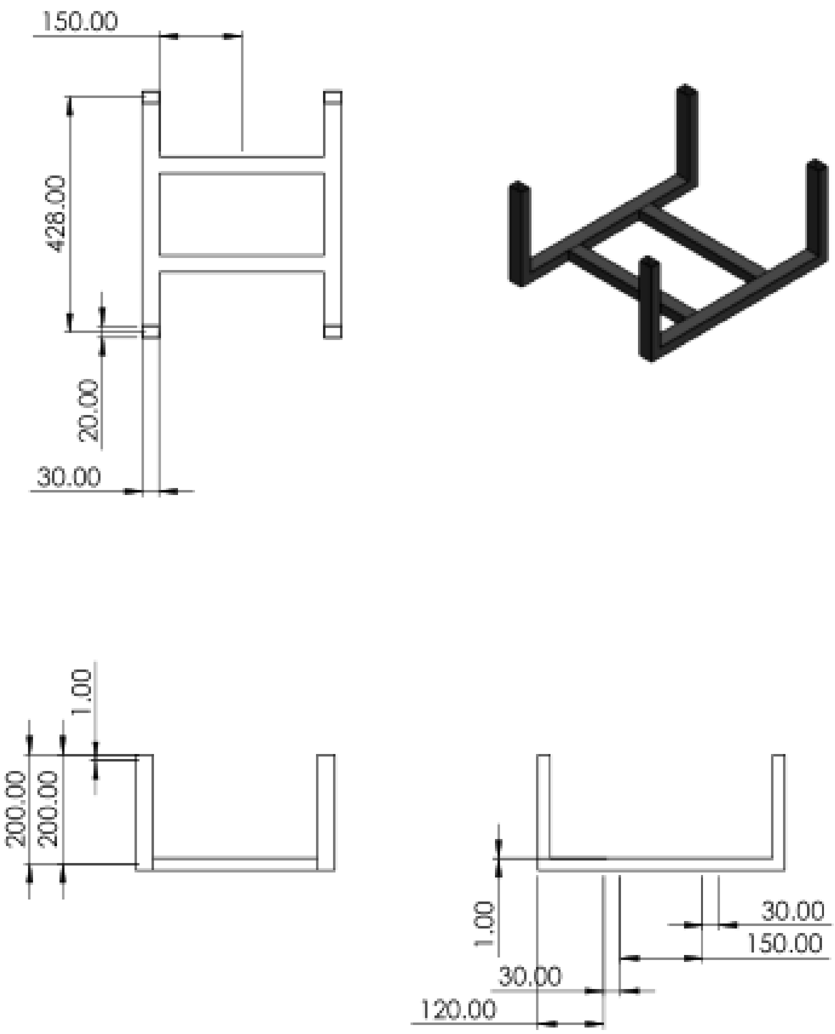


Figure 3.11: Collection tank support

3.3.4 Position

The positioning of the tank was also a critical aspect in the design. Ideally, the collection tank was to be either positioned directly just below the flow diversion unit or at the periphery of the main reservoir. Positioning the collection tank directly below the flow diversion unit mitigates the need for additional components like diverting pipes. This simply implies that the collection tank would just be provided with a holding mechanism for support upon which it is fitted with a solenoid outlet valve directly into the reservoir.

On the contrary, positioning the collection tank at the periphery introduces the need for extra components. This includes a pump system to pump the discharge back into the reservoir which adds to the overall cost of the project. Positioning the collection tank below the diversion unit was the feasible option.

3.3.5 Choice

The horizontal cylindrical tank is ideal this application since as compared to the rectangular one, there is motivated discharge. This actually means that there is ease of flow of the discharge into he reservoir. Besides, with horizontal cylindrical tank, chances of discharge remaining into the tank are very minimal due to point concentration. This implies that errors in weight measurement due to discharge accumulation is minimized. This sub-unit will be used to measure the weight of the discharge in the collection tank. The following approaches will be considered for this unit :

1. Ultrasonic

   Ultrasonic waves are used to determine the depth of the discharge in the tank. This is used together with the cross-sectional area of the tank, and the density of the discharge to determine the weight of the discharge based on the following equation 3.2. Assuming a cylindrical collection tank, then mass is given by;

   $$m = \rho * r^2(h - h_1) \tag{3.2}$$

   Where m is the mass of the collected discharge

   $$\rho$$

   is the density of the discharge

   h is the height of the cylindrical tank

   h_1 is the height measured by the ultrasonic sensor.

Considering the reliability and resolution of the ultrasonic waves, the resolution depends on the pulse rate of the ultrasonic wave generator. Furthermore, the use of ultrasonic waves requires the consideration of other factors such as the cross-sectional area and the shape of the tank. This will not be the case with the load cells.

2. Load cells

   A load cell is essentially a force transducer or force sensor. It is used principally to measure weight. Load cells are used for quick and precise measurements. Compared with other sensors, load cells are relatively more affordable and have a longer life span. The choice of the weight measurement unit was to use four load cells which are positioned just below the collection tank on the four edges of the tank holder. It should be noted that the collection tank and the tank holder introduce a positive error in the weight measurement hence the total weight is accounted for by the software.

3.4 Interface and Control Unit

3.4.1 Interface sub-unit

This sub-unit provides a means of interaction between the system and the user. Ideally, the sub unit enables the user to input instructions and control the discharge collection process to ensure that the right results are obtained. The choice of this system depended on the following factors

1. Aesthetics

   This refers to the perception of the user while operating the interface. It dictates how the user feels.For the case of our machine, the interface should provide for ease of navigation through various components and in terms of inputting commands like the time and the number of steps.

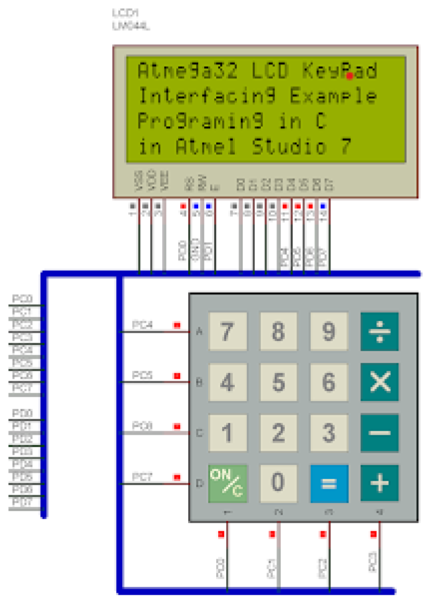


Figure 3.12: LCD with keypad [5]

2. Ergonomics

   This refers to the impact of the interface on the user, and the ease of operation. It dictates the ease and the efficiency the user experience while operating it.

3. Size.

   This is the size of the operable part interface. It affects contributes to the two factors mentioned above.

Based on the above considerations, the following choices were feasible:

1. LCD With keypad

   With this setup shown in figure 3.12, one can navigate, read and provide input where it is required on the LCD display using the keypad.

2. LCD with touch

   One can navigate such interface easily by touching or using a virtual keyboard to provide input. This is shown in figure 3.13.

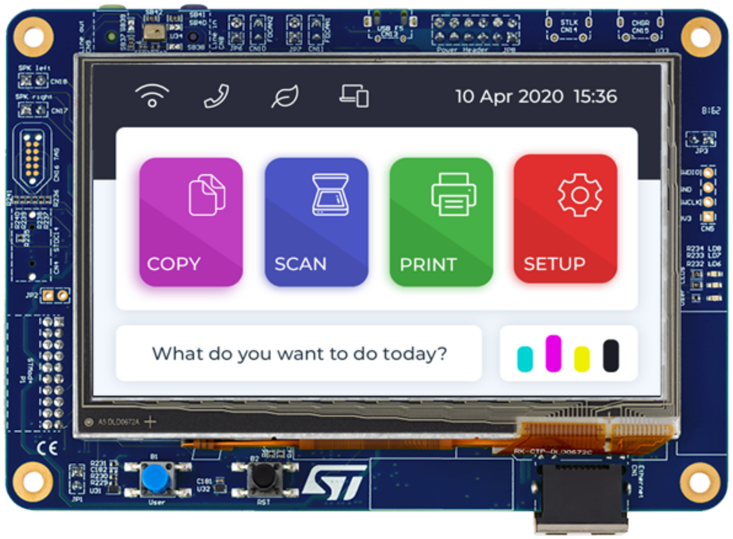


Figure 3.13: LCD with touch [6]

This kind of LCD communicates with the micro-controller through an 8-bit parallel interface. In order to support to touch, this LCD requires at least four ports(32 pins).

3. LCD with Knobs

   The interface can be controlled by a knob. Navigation from page to page, or from field to field is achieved by turning the knob. This is shown in figure 3.14.

3.4.2 Choice

The optimum choice was to use of an LCD with touch capability. This choice serves all the requirements of an interface for this system. In addition, one can also improve on the design by just tweaking the GUI software with no hardware changes.

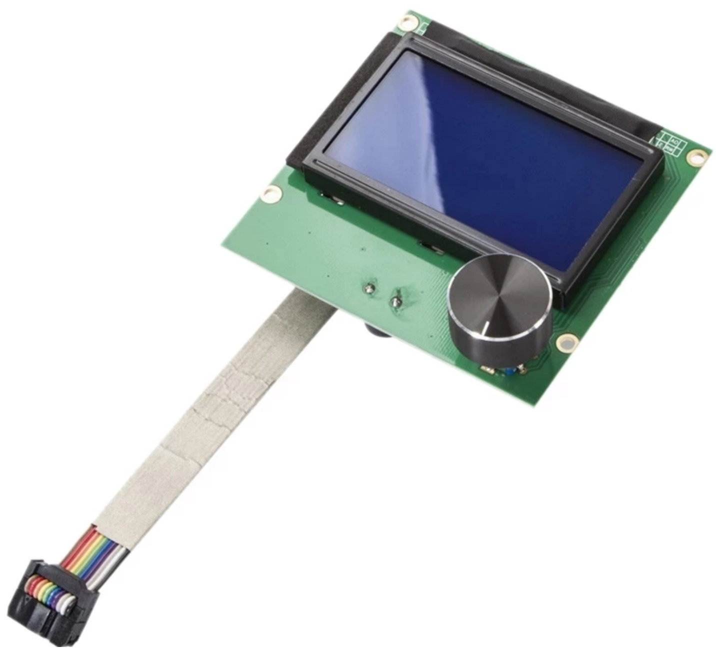


Figure 3.14: LCD with knob [7]

3.4.3 Interface GUI design

The design of the user interface is as shown in figure 3.15.

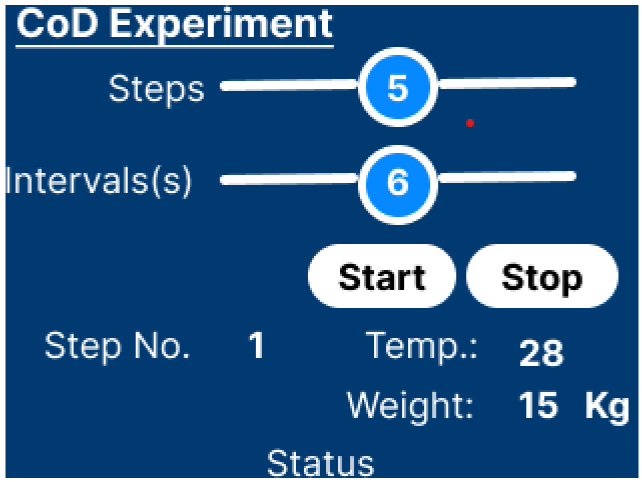


Figure 3.15: GUI interface

3.4.4 Processing and control sub-unit

This sub-unit executes the application logic, send instructions to the actuators, and reads inputs from sensors in the system. It is responsible for synchronizing the GUI with the processes in the hardware. The unit monitors and controls the parameters of the input devices and generates output signals to implement desired tasks.

As shown in figure 3.16, the user from the human interface will be prompted to start the experiment and input the number of steps and the time to conduct the experiment.The system will then automatically check several parameters like whether the number of steps and time interval are feasible. The system will then start the timer, collect the timer and at the same time measure both the temperature and weight of the discharge collected. The averages values from the temperature sensors and load cells are computed and the results displayed on the LCD. A solenoid valve then opens to allow the discharge to flow into the reservoir.

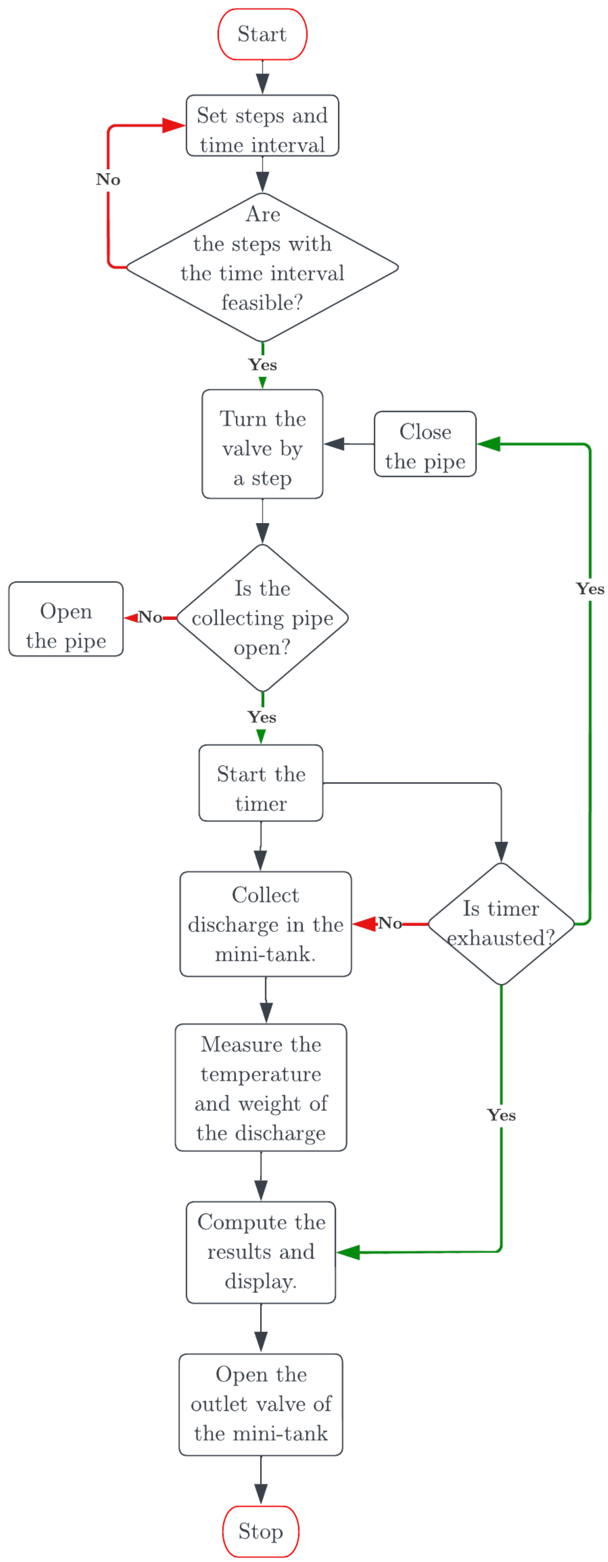


Figure 3.16: Application logic

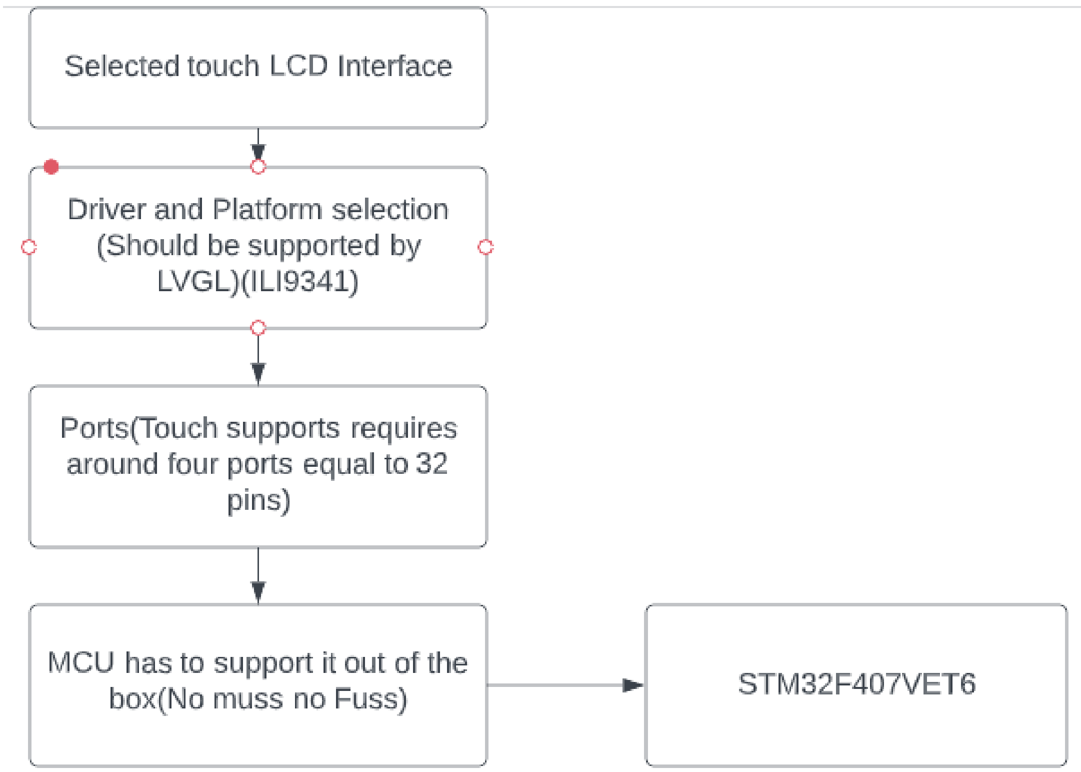


Figure 3.17: Microprocessor Control Unit selection process

3.4.5 Microprocessor Control Unit selection process

The choice of a micro-controller for the processing unit was guided by the selected human machine interface, which was an LCD with touch capabilities. Figure 3.17 shows the considerations in the Microprocessor Control Unit selection process.

1. Platform and Driver Support
   With an LCD with touch capabilities, the choice of the platform was between Light and Versatile Embedded Graphics Library (LVGL) and Mbed.The platform also had to support the driver used in the programming of the LCD. Based on the two platforms,LVGL was selected since it supports ILI9341, a driver intergrated circuit used in the control of LCDs. LVGL is an open-source graphics library providing everything you need to create embedded GUI with easy-to-use graphical elements,

beautiful visual effects and low memory footprint.

2. General Purpose Input Output(GPIO)s

   Touch support requires approximately four ports which is equivalent to thirty two pins. Finally, the MCU had to support it out of the box (No muss no fuss). The choice of the MCU was to accommodate for all the thirty pins.

3. Processing Power

   This refers to the processing capacity of a micro-controller. A multi-core processor is faster and consumes more power as compared to a single-core processor. A multi-core processor can also render intense graphics on displays which would be essential for the LCD. The amount of input processing will guide one in choosing the best micro-controller or microprocessor for the task.

Based on the above considerations, STM32F407VET6 was selected for the application.

4 Results and Discussion

This section contains the result obtained during the design phase of the project.

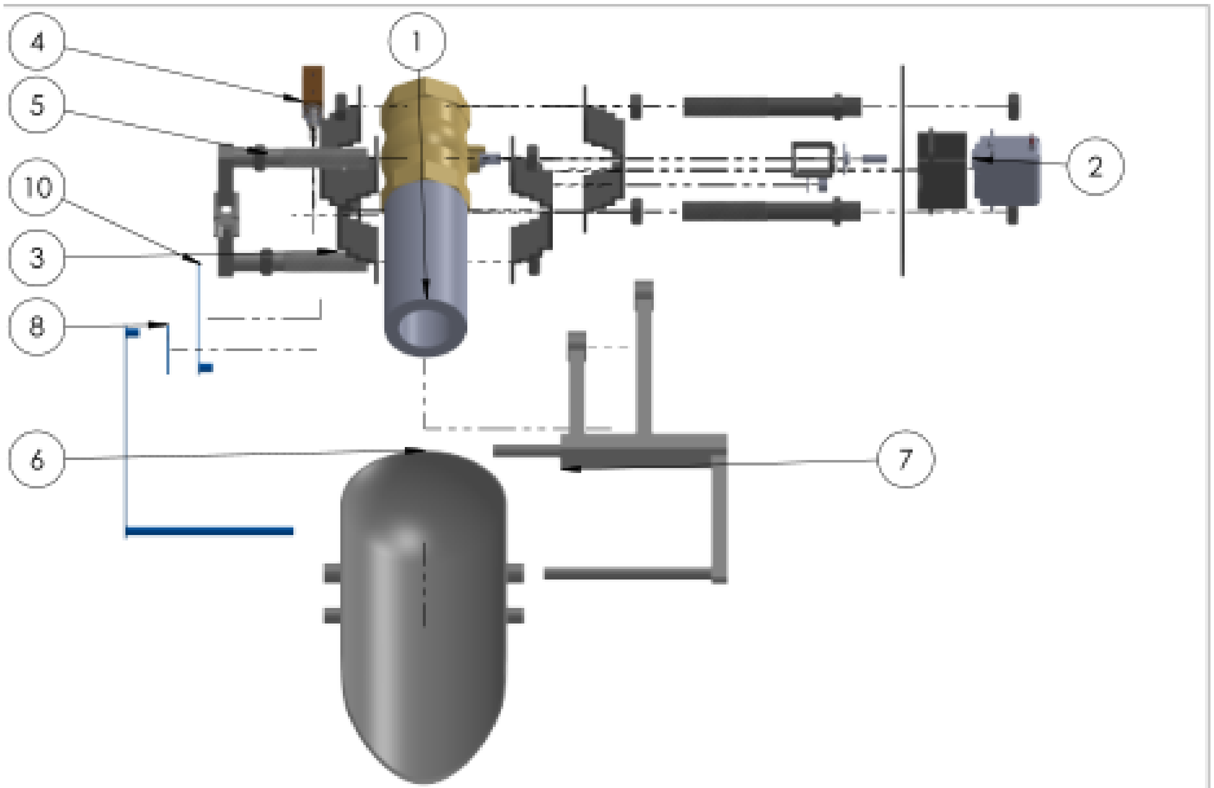
4.1 Discharge Flow Control Unit Assembly

The assembly regulates the discharge flow in precise steps as per the users specifications through the use of a servo motor. Furthermore, to ensure that no sliding of the motor and the motor mounts along the valve, the assembly utilizes the use of serrated straps to enhance grip. The slots in the servo motor holder mount allows for the servo motor to be aligned with the ball valves shaft during setup before the start of the experiment.

4.2 Discharge Flow Collection assembly

The sub assembly efficiently and correctly diverts the discharge either to the main collection tank or into the main reservoir through the use of flaps. This is achieved through the use of an electromagnet. The electromagnet is also correctly positioned to ensure minimal splashes which would otherwise interfere with the electrical components. Furthermore, the fast response of the unit is achieved by the use of an electromagnet whose linear motion is amplified by the use of a lever system hence providing the flap with a wider angle.

Additionally, to ensure that only the required amount of water is collected and there are minimal splashes, the sub assembly uses a curved flap. The weight of the collected discharge is also measured by use of correctly positioned load cells which are evenly distributed at the four edges of the collection tank. The weight values from the four load cells are taken after which the average is computed which is taken as the final weight of the discharge. The use of a horizontal cylindrical tank enhances motivated discharge into the main reservoir, in that the discharge fluid is released within a stipulated time through the use of the solenoid valve.



ITEM NO.	QTY.	PART NUMBER
1	1	Small Pipe Extension
2	1	Servo Holder Ball Valve Assembly
3	2	two Rail Straps Bottom
4	1	ElectromagnetAssembly
5	4	Straps Nut
6	1	flap
7	1	Diversion Support
8	1	Kinematic Link 1
9	1	Kinematic Link 2
10	1	Kinematic Link 3

Figure 4.1: Discharge Flow Control Unit and Discharge Collection Unit Assembly

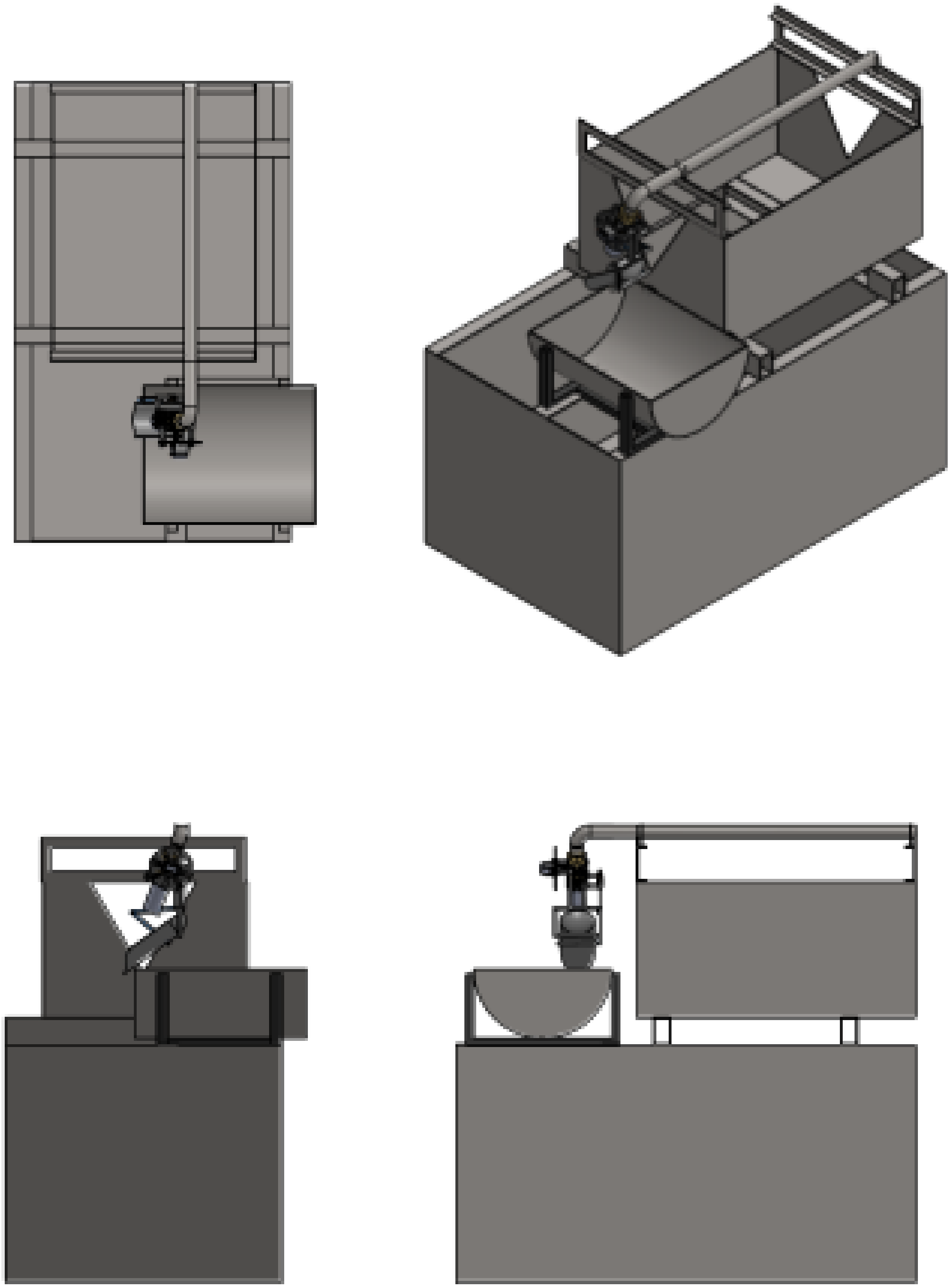


Figure 4.2: Final Assembly

4.3 Budget

Item No.	Item	Quantity	Unit cost	Cost
1	Servo Motor MG996	1	800	800
2	JF-0530B DC12V electromagnet Push-Pull solenoid	1	550	550
3	1M/3M DS18b20 temperature probe	1	400	400
4	LCD Touch (ILI9341 driver)	1	1300	1300
5	STM32F407VET6	1	4300	4300
6	50Kg Load cells	4	150	600
7	HX711 Weight amplifier	1	50	50
8	3D printing			10000
9	Miscellaneous			2000
Total				20000

Table 4.1: Budget

5 Conclusion

The objective of this project was to design and fabricate an automated discharge collection process which entailed the design of the discharge flow control unit, the discharge collection unit, the electrical and electronic and the control algorithm which were clearly met. This phase only involved the design work which has been done conclusively.

The next phase to be implemented will involve the fabrication of the developed design. However, it is expected that during this phase, few modifications and redesigns will have to be done to further optimize the design.

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A Appendix

A.1 Semester 1 Time Plan

Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Project proposal														
Continous presentation														
Literature review														
Discharge flow control design														
Discharge collection design														
Interface and control design														
Assembly, Analysis, Simulation														
Interim report														

Table A.1: Semester 1 Timeplan

A.2 Semester 2 Time Plan

Week	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Design for fabrication	■														
Generating fabrication files	■	■													
Procurement of fabrication materials		■	■												
Procurement of electrical and electronics components			■	■											
Fabrication of the discharge flow control unit(DFCU)			■	■	■										
Writing drivers and firmware for the electronics in DFCU					■	■									
Assembly and testing of the DFCU							■								
Fabrication of the discharge collection unit(DCU)								■	■	■					
Writing drivers and firmware for the electronics in DCU										■	■				
Assembly and testing of the DCU												■			
Development of the LCD driver and GUI												■	■		
Assembly and testing of the system														■	
Final Presentation															■

Table A.2: Semester 2 Timeplan

A.3 Servo Motor

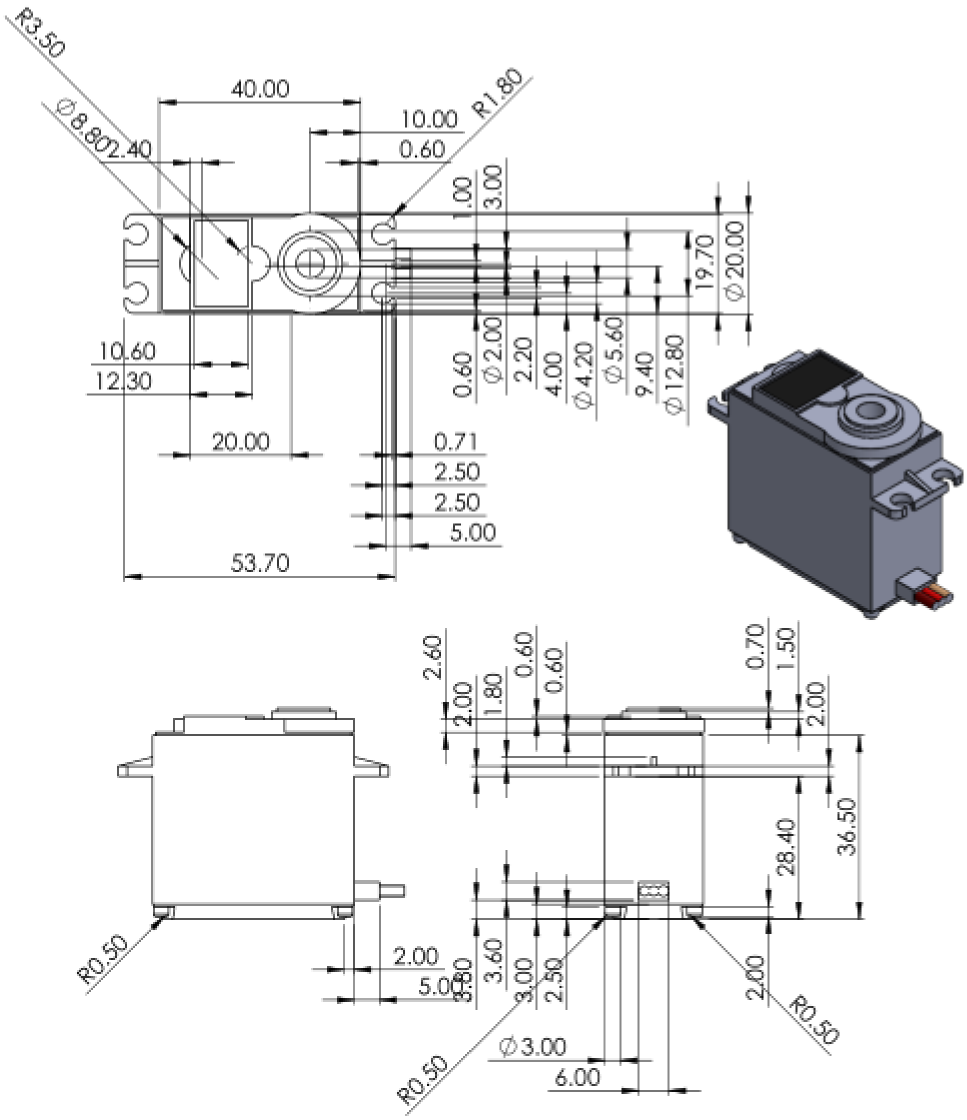

Figure A.1: Servo Motor

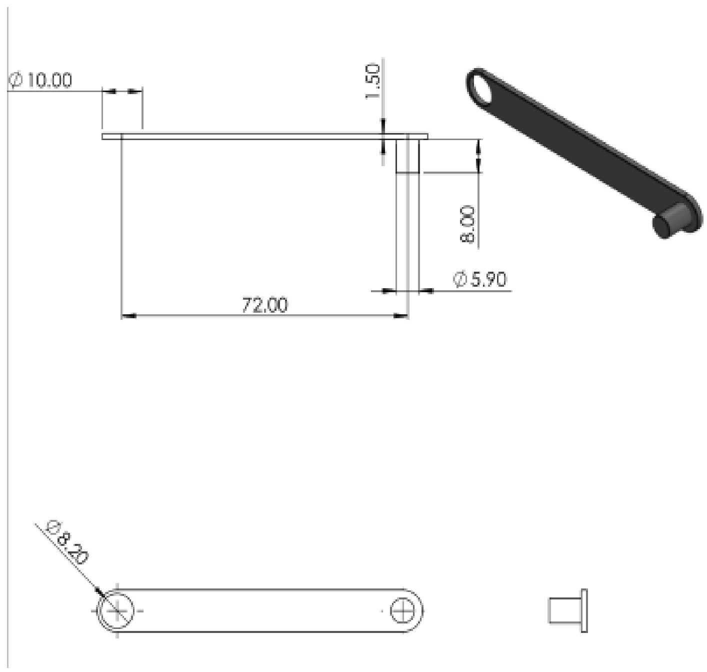

Figure A.2: Link 1

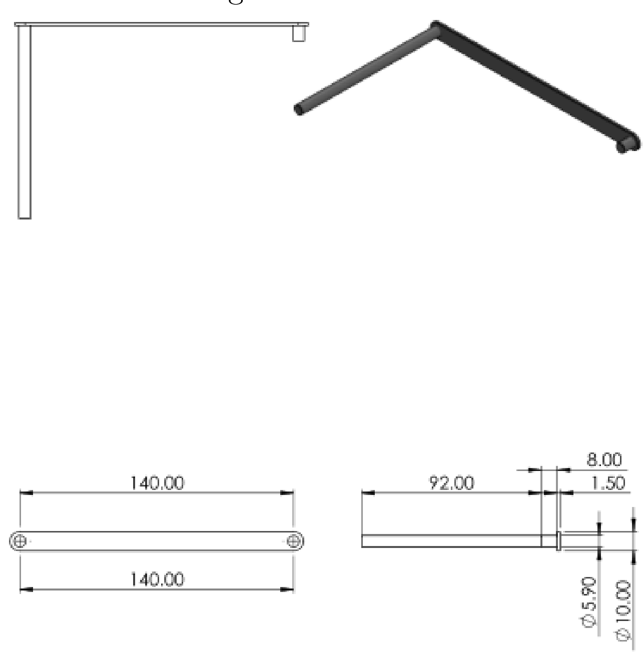

Figure A.3: Link 2

A.4 Kinematic Link 1 and 2

A.4.1 Kinematic Link 3

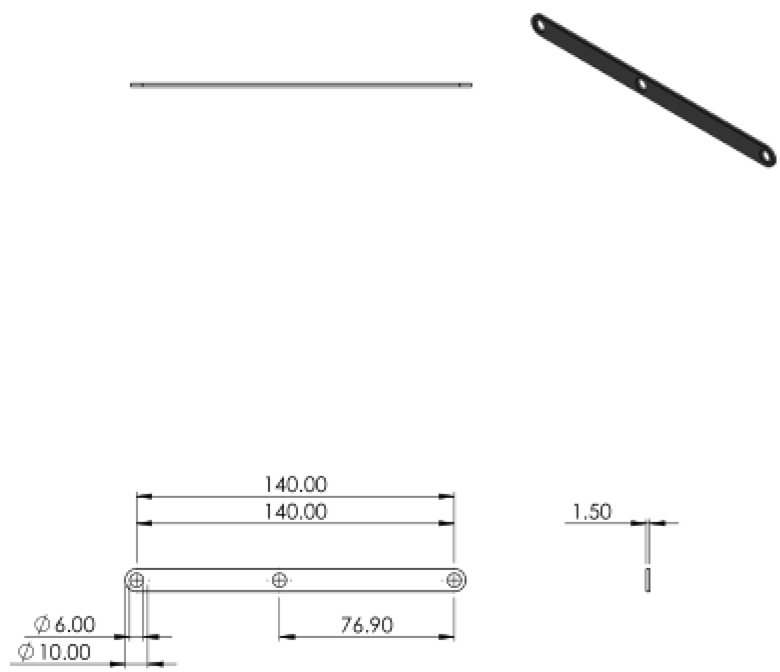

Figure A.4: Link 3

A.5 Electromagnetic actuator

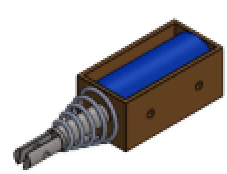

Figure A.5: Electromagnet

A.6 Coil

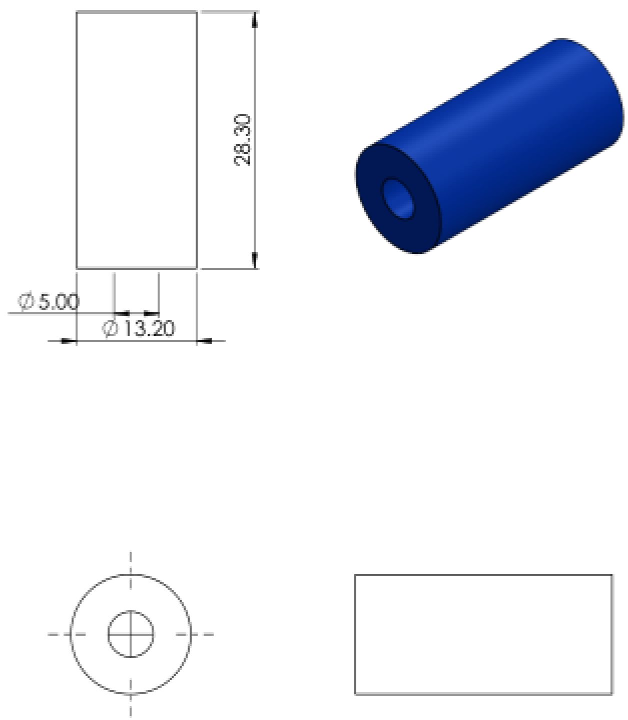

Figure A.6: Coil

A.7 Electromagnet Holder

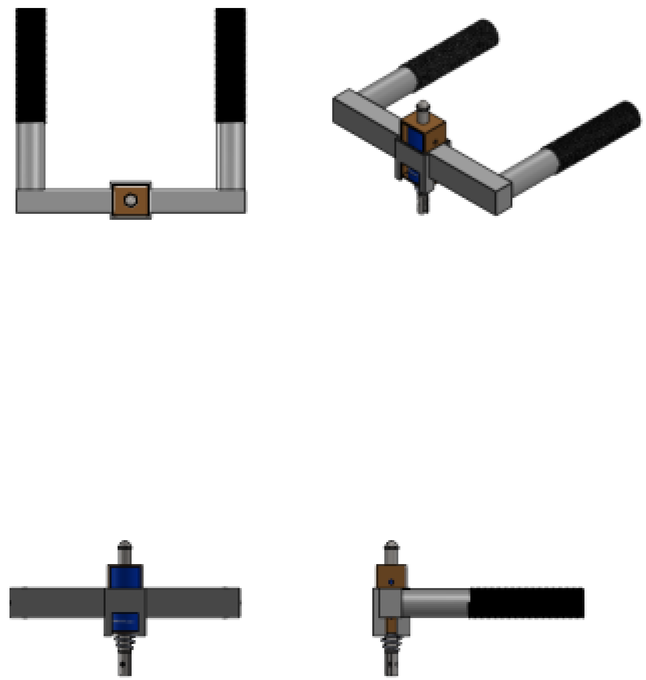

Figure A.7: Electromagnet Holder

A.8 Servo Motor Hold Interface

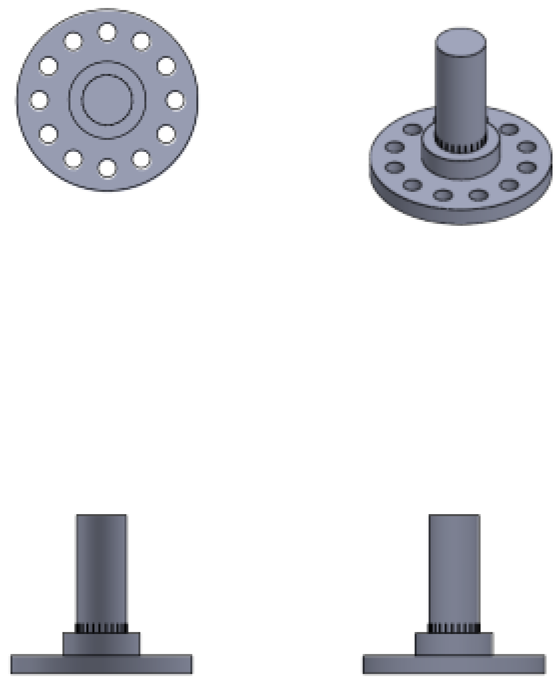

Figure A.8: Servo Motor Hold Interface