Experiment M4
Hydraulic System
Procedure

Deliverables: checked lab notebook, demonstration of working device to Lab TA, servo mount for M5 lab

Recommended Reading:

You do NOT have to write a tech memo for this lab. Just make sure the TA fills out the score sheet as you complete each part of the lab. **Each item on the score sheet must be completed before the end of lab for you to receive credit for it.**

Overview

Designing and building complex systems is challenging. It is critical that every component be individually tested before being integrated into the larger system. Failure to do this has ruined many senior design projects, as students often construct their entire system without first testing any components or subsystems. The unhappy result is that the entire system does not function, and it is extremely difficult to locate and isolate the problem.

This lab will demonstrate how to properly test individual components and subsystems before integrating them into a larger system. The larger system being the hydraulic system shown below in Fig. 1, where the tank is repeatedly filled by a pump, then drained via a motorized ball valve.

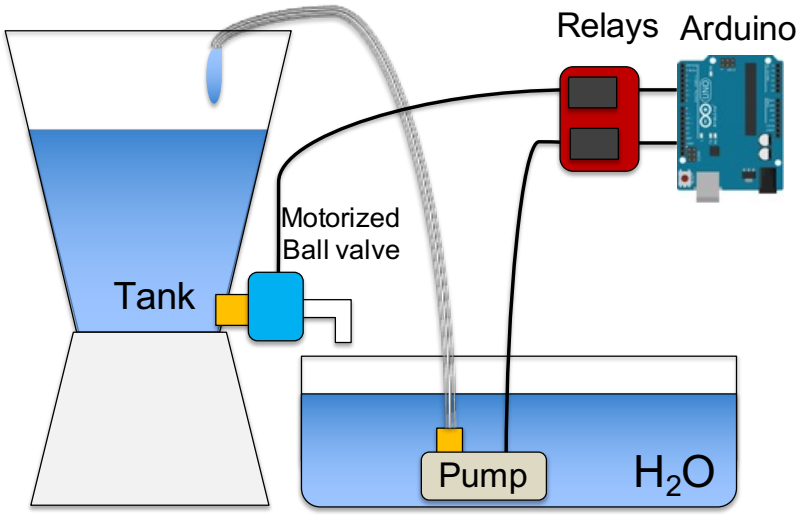


Figure 1 – A hydraulic system consists of a pump in a reservoir and a tank with a motorized ball valve. An electromechanical relay and an Arduino UNO microcontroller will be used to sequentially switch the pump and valve ON and OFF to fill and drain the tank.

Subsystem A: Microcontroller and Electromechanical Relays

An electromechanical relay is a mechanical switch that can be opened and closed by an electromagnetic coil. The most common relay switch configuration is a *single pole, double throw* (SPDT), illustrated in the top left corner of Fig. 2. Applying a voltage to the coil creates a magnetic field that throws the pole switch (COM) from the normally closed (NC) terminal to the normally open (NO) terminal.

We will use the 2 channel relay model illustrated in Fig. 2 to switch the pump and valve ON and OFF. The first step is to connect the relay, power supply, and Arduino and test that this subsystem works.

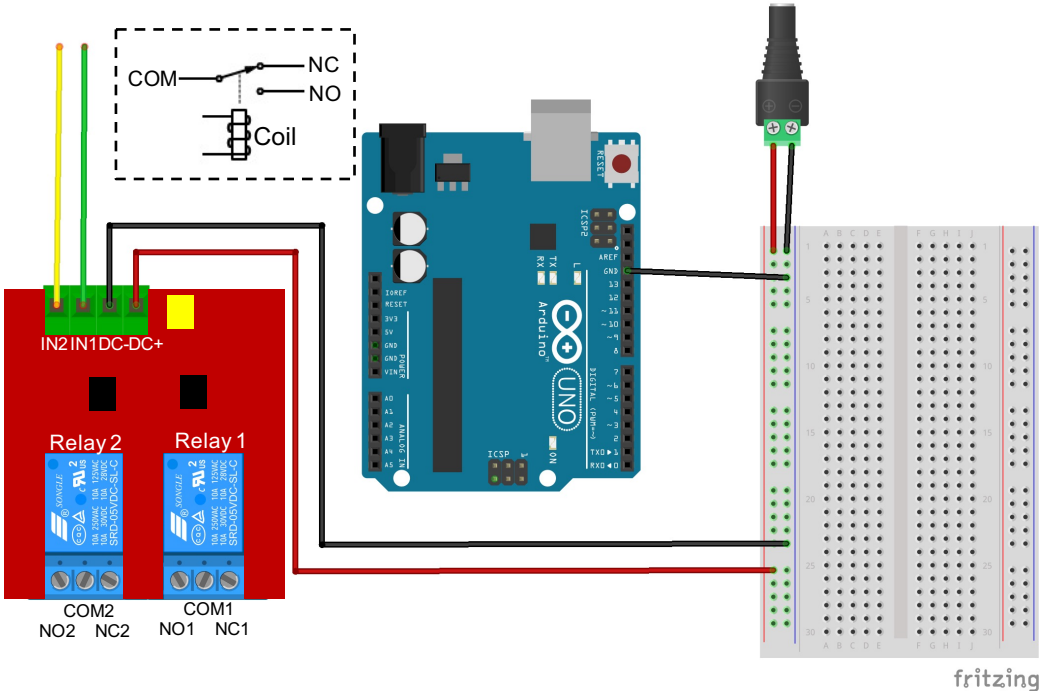


Figure 2 – Subsystem A contains a 2-channel relay module, an Arduino microcontroller, 12V DC power supply, and various electrical connections.

Procedure

1. Sketch the complete hydraulic system in Fig. 1 in your lab notebook
2. Sketch the wiring diagram in Fig. 2 in your lab notebook.
3. Connect the 5.5mm barrel connector on the 12V DC power supply to the inline kill switch. Connect the other end of the kill switch to the screw terminal adapter.
4. Insert red and black dupont pin jumper wires into the + and – screw terminals on the 12V output of the DC power supply. Use the screwdriver to tighten down the screw terminals.
5. Plug in the DC power supply. Use the handheld DMM to verify that the power supply works by measuring its voltage output. Flip the kill switch ON and OFF to verify that it works, as well.

6. Unplug the DC power supply, and make the following connections illustrated in Fig. 2.
   a. Connect the DC power supply to the + and – vertical bus lines on the breadboard.
   b. Connect GND on the Arduino UNO microcontroller to the negative bus lines on the breadboard.
   c. Connect the DC- and DC+ screw terminals on the relay module to the vertical bus lines on the breadboard.
   d. Connect yellow and green jumper wires to the IN1 and IN2 screw terminals on the relay module. Leave the other end of these wires unconnected.
7. When you are confident you made the connections correctly, plug in the power supply and set the kill switch to the on position. You should see an LED on the relay module light up.
8. Make sure the Arduino is connected to the computer via the USB cable. The green LED on the Arduino should be lit up.
9. Manually connect the green wire from IN1 to 5V on the Arduino. You should hear relay 1 make a click sound as the COM pole switches from NC to NO. Disconnect it from 5V, and it should click again.
10. Manually connect the yellow wire from IN2 to 5V on the Arduino. You should hear relay 2 make a similar click sound. Disconnect it from 5V, and it should click again.
11. Connect the green wire from IN1 to digital I/O pin 6 on the Arduino.
12. Connect the yellow wire from IN2 to digital I/O pin 7 on the Arduino.
13. Download the "B12_Relay_Template" code template from the lab webpage, read the comments, and modify it.
    a. Replace the *** in the beginning with the correct digital I/O pin numbers for the relay connections.
    b. Save the code with an intelligent file name (i.e. "B9_relays_yourName.ino").
14. In the Arduino IDE software, go to "Tools" > "Board" and make sure either "Arduino/Genuino" or "Arduino UNO" is selected.
15. In the Arduino IDE software, go to "Tools" > "Port" and select the COM port that says "(Arduino/Genuino Uno)" next to it.
16. Click the check mark at the top of the Arduino program to check the code for errors.
17. Press the arrow button to compile the program and send it to the Arduino.
18. When the code begins running, you should hear the relay switching sequentially, as indicated in the main loop of the code.
19. **Demonstrate the working subsystem to the TA, so you can be awarded points on your score sheet.**
20. Unplug the green and yellow wires from pins 6 and 7 on the Arduino. Leave everything else connected. You will use this subsystem again at the end to cycle the pump and drain valve ON and OFF.

Subsystem B: Hydraulic Pump

You will now test and calibrate the centrifugal pump used to fill the large tank.

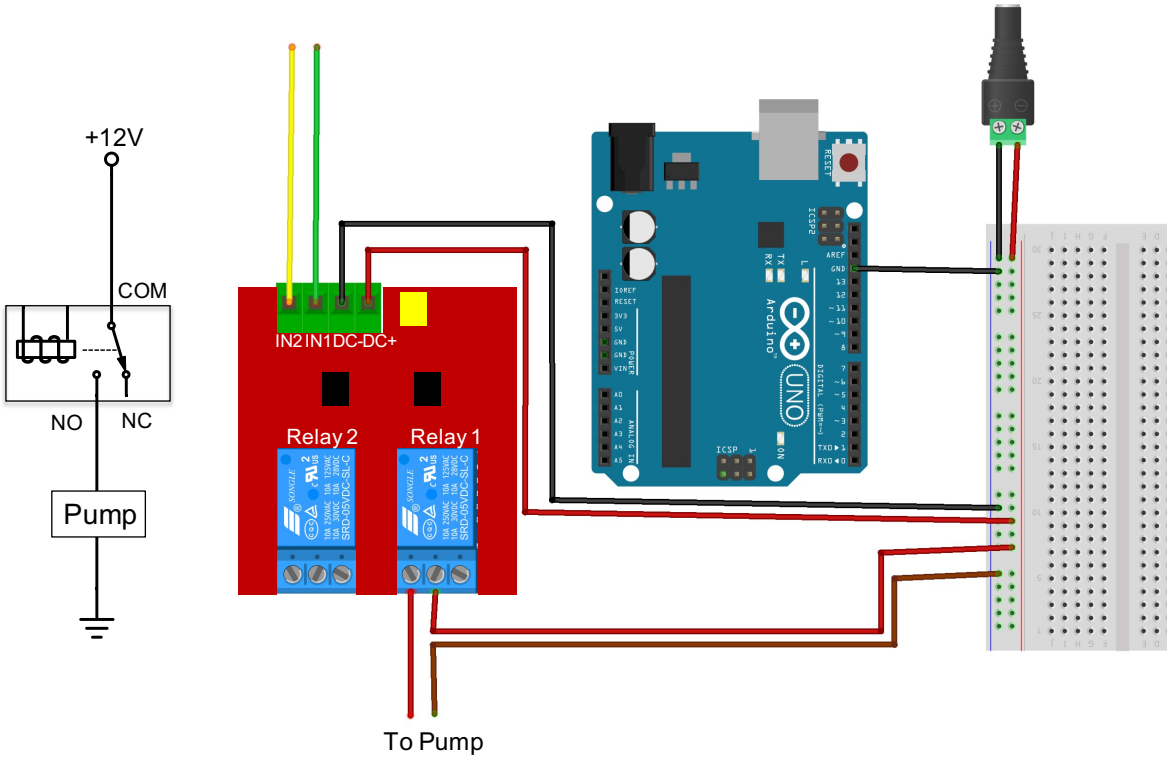


Figure 3 – The hydraulic pump is connected to the normally open (NO) terminal on Relay 1. Sending a HIGH signal to IN1 energizes the relay and connects the pump to the 12V DC power supply.

Caution: Make sure your hands are dry, if you are working with live wires!

Procedure

1. Sketch the SPDT relay circuit on the left side of Fig. 3 in your lab notebook.
2. Turn off the 12V DC power supply.
3. Locate the beige centrifugal pump. With the pump sitting high and dry, connect the pump, breadboard, and relay as shown in Figure 3. (The pump wires are red and brown.)
4. Test the pump/relay circuit. Turn on the DC power supply. Manually connect the green IN1 wire to 5V on the Arduino. You should hear the relay click and the pump should start running. Disconnect the green IN1 wire from 5V immediately after you have confirmed that it works.
5. Fill up the reservoir (dishpan) 3/4 full with water and place it on the floor. Set the tank next to it, such that it will drain into the reservoir.
6. Place the pump in the reservoir. Make sure the tube is firmly connected to the brass outlet on the pump. Run the tube up into the tank. Use the lab stand and beaker clamp to secure the tube in place.

7. Connect IN1 to 5V for just a few seconds. The relay should click and the pump should begin moving water into the tank.
8. Gently pick up the tank and pour out any water in the bottom.
9. Use the stopwatch to determine how much time it takes to fill the tank to the black line. Write down the value in your lab notebook.
10. **Demonstrate the working subsystem to the TA, so you can be awarded points on your score sheet.**
11. Leave the circuit intact for the next part of the lab.

Subsystem C: Motorized Drain Valve

You will now test and calibrate the motorized drain valve.

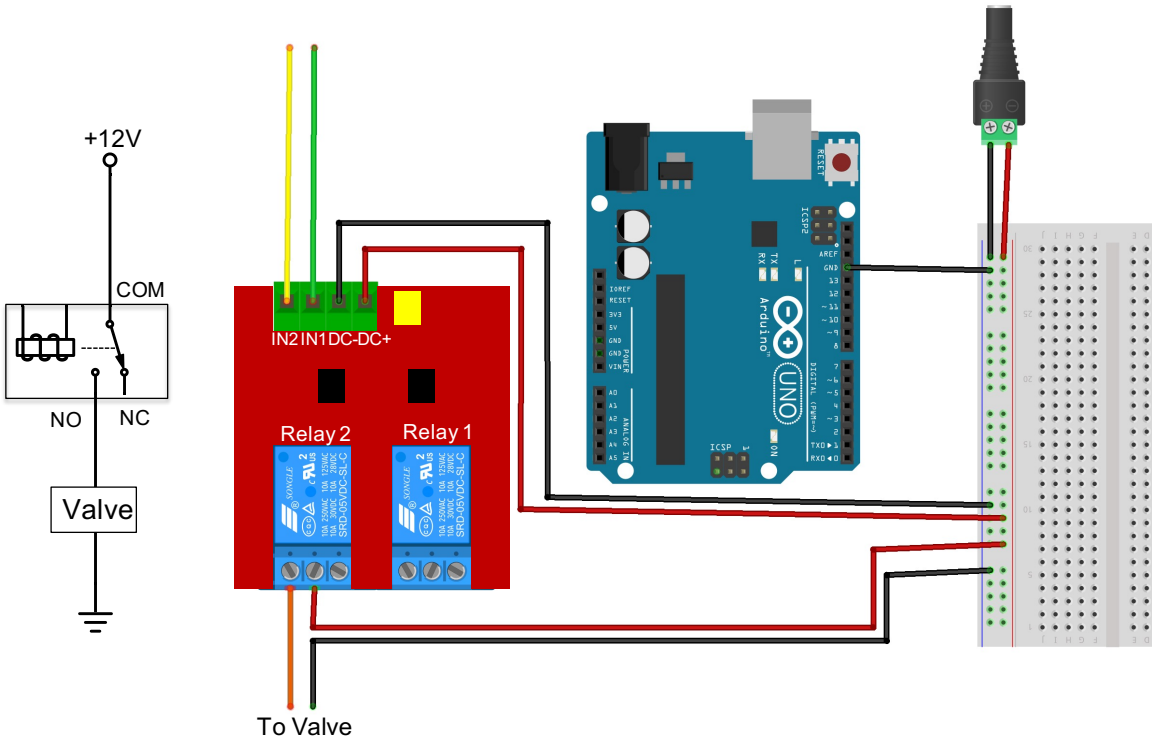


Figure 4 – The motorized ball valve is connected to the normally open (NO) terminal on Relay 2. Sending a HIGH signal to IN2 energizes the relay and connects the valve to the 12V DC power supply, thus opening the valve and draining the tank.

Procedure

1. Turn off the 12V DC power supply.
2. Connect valve, breadboard, and relay as shown in Fig. 4. (The valve wires are orange and black.)

3. Test the valve/relay circuit. Turn on the DC power supply. Manually connect the yellow IN2 wire to 5V on the Arduino. You should hear the relay click and the motorized ball valve hum as it turns. Allow the valve to run until it is fully open.
4. Disconnect the yellow IN2 wire from 5V. The relay should click again, and the ball valve should hum as it returns to its normally closed position.
5. When you have confirmed the valve works, use the pump to fill up the tank up to the black line. Manually engaged the pump relay as you did earlier.
6. Actuate the valve, and use the stopwatch to measure how much time it takes to completely drain the tank. Write down the value in your lab notebook.
7. **Demonstrate the working system to the TA, so you can be awarded points on your score sheet.**
8. Leave the circuit intact for the next part of the lab.

Complete Hydraulic System

You will now integrate Subsystems A, B, and C to create the complete hydraulic system. The system must repeat the following steps in an infinite loop:

1. **Pump** – The pump should completely fill the tank up to the black line.
2. **Pause** – After the tank is full, the water should sit in the tank for 5 seconds.
3. **Drain** – The tank should completely drain.
4. **Pause** – The tank should sit empty for 3 seconds after completely draining.

This can be achieved by modifying the time of the “delay()” functions in the provided code.

Design Challenge

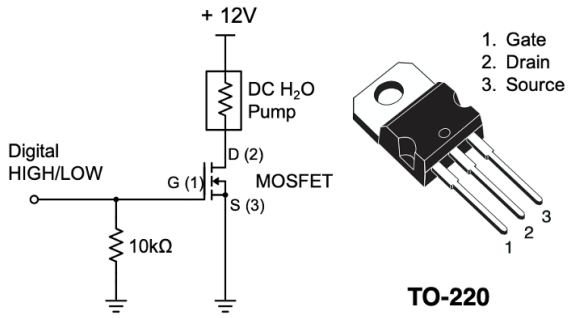
Consider a process where various chemical are mixed in prespecified quantities. (i.e. an industrial dishwasher, or a machine for mixing cocktails!)

- 20 ± 2 mL of water from a separate reservoir will need to be added to the tank after it has been initially filled.
- **Engineering decision:** Choose a pump. A smaller centrifugal pump and a peristaltic pump are available, as shown in Fig. 5. Both pumps operate off the same 12V. Perform some tests on these pumps to determine which one can accurately and reliably deliver 20 ± 2 mL of water.
- **Engineering decision:** Choose a switching mechanism. The current relay module only has 2 channels. You may replace it with a similar 4 channel relay module, or you may use the MOSFET circuit that you used in the previous labs.
- The tank should still drain after all the fluid has been added, and the process should repeat.
- Write a few sentences in your lab notebook to justify each of your decisions.
- Demonstrate the working system to the TA or lab instructor, who will use a small beaker to collect the 20 mL of fluid from the smaller reservoir.

Peristaltic Pump

Small Centrifugal Pump

MOSFET Switch



4 Channel Relay Module

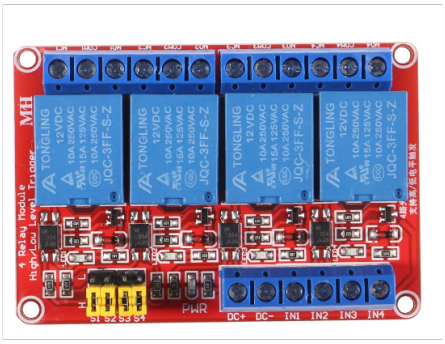


Figure 5 – Engineering Decisions: You must decide whether to use the peristaltic pump or the centrifugal pump with either the MOSFET switch or the 4 channel relay module.

Clean-up

To receive full credit, you must return the lab bench to its initial state:

- Make sure your codes have been saved to your code library.
- Unplug the DC power supply. Remove the kill switch and screw terminal adapter.
- Disassemble the circuit. Disconnect the wires from the relays, Arduino, and breadboard.
- Disconnect the USB cable from the computer.
- Wipe up any water that may have spilled. Hang any wet towels around the edge of the trash can or sink.

Deliverables

Make a servo mount for next week's lab using the 1/8" thick sheet of basswood and 8-32 hardware provided. (See the drawings in Appendix B.) You will need the mount for the M5 and M7 lab exercises.

- Make 4 through holes for 8-32 screws in the basswood to match the hole pattern on the servo. (See the CAD drawing in Appendix B for the dimension in mm.)
- Make a CAD drawing of the hole pattern with dimensions in inches. Print the drawing and show it to the machinist in the EIH. **Do not go to the machine shop without a printed CAD drawing with dimensions.**
- You may laser cut the hole pattern or drill it. Alternatively, you may use a plastic sheet and cut the holes with the water jet.
- Use a drill to countersink the 4 holes so the screw heads do not protrude from the surface. This will allow the wood sheet to sit flush against the table or floor.
- Use the 8-32 stand-offs, screws, and nuts to mount the servo to the wood sheet, so that it stands upright with the shaft pointing upwards.

Appendix A

Equipment

- 12V DC power supply w/ inline kill switch and screw terminal adapter
- Arduino UNO Microcontroller
- 6ft USB cable
- 2-channel relay module (12V DC) – Amazon Part # B099MRT96C
- 4-channel relay module (12V DC) – Amazon Part # B098DXRTT8
- Breadboard mounted to small plywood sheet
- 3M Velcro command strips
- Pump (12V DC) – Amazon Part # B0196WL55G
- Small Centrifugal Pump (12V DC) – Amazon Part # B0BGNYKX7Z
    - 7mm ID tubing – McMaster Part # 3902N3
- Peristaltic Pump (12V DC) – Amazon Part # B0B4RH4MTP
    - 3mm ID tubing - McMaster Part # 3902N288
- Motorized ball valve, 2 wire auto return (U.S. Solid) – Amazon Part # B06X9LWXMW
- 1.5 Gallon plastic beverage dispenser w/ motorized ball valve and spout
- Dishpan
- Male-Male DuPont pin jumper wires
- Lab stand with one beaker clamp

Appendix B – Servo Mount