4.0 Design Overview

This chapter provides an overview of the pedicab design. Both spatial arrangements and system models will be described here. First, the selected pedicab will be described. Next, the fluid power schematic will be explained, which gives the pedicab its regenerative capabilities. Once the system schematic is fully understood, spatial arrangements of the hydraulic components will be shown with CAD models and pictures. Finally, all the placed components need to be controlled by an operator. Description of the user interface will conclude the design overview. A photo of the completed prototype during testing is shown in Figure 4.1.

![Final Prototype - Pedicab with Hydraulic System](image)

Figure 4.1: Final Prototype - Pedicab with Hydraulic System
4.1 The Pedicab Chassis

Figure 4.2: Purchased “EBay” Pedicab

Figure 4.2 shows the pedicab which was purchased and used for the team’s prototype. This pedicab has room for three people: two as passengers in the rear bench seat and one as the driver in the front. There is ample room beneath the pedicab’s bench seat for the hydraulic components which were added. The driver will have full control of the hydraulic system by using a mechanism that controls the Directional Control Valve (DCV), which is mounted beneath the pedicab seat. The drivetrain of the pedicab has a 1.5:1 gear ratio with a coasting freewheel. Safety features include a mechanical front brake, front fender, and a safety bell. Further detail is shown later in this chapter.

4.2 The Fluid Power System

Once the pedicab chassis was selected, a fluid power schematic was created. This system, which controls the capture and release of braking energy, can be seen in its neutral / running position in Figure 4.3.
Figure 4.3  Regenerative Braking Fluid Power Schematic in Neutral Position

This system consists of eight components: a pump-motor, a pressure relief valve, a check valve to prevent backflow in the circuit, a spring-centered float center directional control valve (DCV), a Nitrogen-charged piston accumulator, a pressure gauge, a bleed-off valve to discharge the accumulator in case of emergency, and a reservoir. Each serves a specific purpose that is necessary for the proper operation of charge and discharge cycles.

Aside from the user-operated DCV, the system’s input and output occur at the pump. The shaft of the pump is directly connected via a chain drive to the pedicab’s drive axle. Because of this direct connection, the pump shaft will always rotate when the driveshaft is rotating. The sprocket connection between the pump-motor shaft and driveshaft is 1:1. Depending on the location of high and low pressure in the system, the pump can either act as a flow creator (pump) or a torque creator (motor). There are three positions the system can take: the “neutral” position, the “charging” position, and the “discharging” position.

In Figure 4.3 above, the schematic is shown in the neutral position. This is the default position when the pedicab undergoes normal operation (e.g. the operator is pedaling with no assistance). In this position, the pump shaft is rotating from the driveshaft. This creates flow in a clockwise fashion in the schematic. The flow travels through hose to
the center position of the DCV and then right back into the pump, closing the loop. The path the fluid takes in this schematic is shown in blue.

The DCV has what is called a “float center,” which allows flow to pass to a reservoir during this process. The reservoir, shown on the right side of the DCV, is at atmospheric pressure. Since the reservoir is at atmospheric pressure, the fluid in the neutral position loop will also be at atmospheric pressure. This prevents pressure build-up in the circuit, which minimizes pipe loss and, ultimately, torque loss to the driveshaft.

Now let us consider the “charging” position. The operator shifts the hydraulic system into this position when they want to decelerate. The system engages and begins storing energy in an accumulator, charging it. The directional control valve is now in the position shown in Figure 4.4 below.

![Figure 4.4: Hydraulic Schematic in Charging Position](image)

With the drive axle still rotating, the pump is still rotating in the same direction as before. Now, the pump pulls fluid from the reservoir through the DCV, then through a check valve and finally back through the other port of the DCV into the accumulator. The accumulator, which has a piston separating the hydraulic fluid from compressed Nitrogen
gas, begins to fill with hydraulic fluid. This further compresses the Nitrogen gas, which acts similar to a spring, and stores energy.

Eventually, the accumulator will reach its maximum pressure (1500 psi), and all excess hydraulic fluid that is still being pumped will be discharged back to the reservoir through the pressure relief valve. This valve only opens when the pressure at its inlet exceeds 1500 psi. At the end of the charging cycle, the DCV is returned back to its neutral position and the accumulator stores hydraulic fluid at a high pressure.

The final arrangement of the above schematic is during the discharge cycle; when the operator wants to use stored energy to accelerate. The schematic for this cycle is shown below in Figure 4.5.

**Figure 4.5 Hydraulic Schematic in Discharging Position**

The discharge cycle begins with a fully charged accumulator. When the DCV is moved into its bottom position, hydraulic fluid flows from the accumulator through the pump-motor. This causes the pump-motor’s shaft to rotate, which supplies torque to the chain drive which powers the driveshaft. The fluid which passes through the pump-motor is discharged back through the DCV to the reservoir.
As more fluid drains from the accumulator through the pump-motor, the rotational speeds of the two shafts are increasing. At the same time, however, the pressure being supplied becomes less and less, and eventually the discharge cycle is complete. The operator returns the DCV to its neutral position and continues to pedal the pedicab with no assist.

4.3 Hydraulic Component Placement

Now that the components are selected and the system works as it should, all fluid power components must be placed efficiently and neatly within the pedicab’s seat container. Some CAD models were obtained from the parts suppliers to aid with this task. Figure 4.6 shows the space underneath the pedicab seat where the hydraulic components will be stored.

![Figure 4.6 Views of Hydraulic Component Storage underneath Pedicab Seat](image-url)
The CAD model in Figure 4.7 shows the final placement of the fluid power components. For the hose and fitting information, refer to the hydraulic schematics in Chapter 4.2. The pump-motor is mounted under the passenger foot rest via an inverted L-bracket and carriage bolts. The motor has a 21 tooth sprocket, which is connected via chain drive to a 21 tooth sprocket on the driveshaft, creating an overall ratio of 1:1.

The pump-motor was mounted underneath the pedicab instead of within the bench because of relative motion concerns. The rear of the pedicab bench is supported on two spring coils, which act as suspension. This creates an overall smoother ride for the passengers. If the pump-motor were mounted within the pedicab bench, raising and lowering of the bench from spring deviation would cause the pump-motor chain to tighten and slacken, creating potential operational hazards. Mounting the pump-motor underneath the pedicab footrest offers the least relative motion between the pump-motor shaft and driveshaft, keeping the most efficient and safe chain line.

The reservoir, shown above, has a 1 gallon volume. The back end of the reservoir (non-ported end) is raised a few inches above the entrance and exit holes. This acts to create a
small amount of head to increase pump-motor effectiveness. The reservoir has a breather cap, which allows the hydraulic oil to remain at atmospheric pressure. This ensures little pressure build up in the system, which translates to low pressure drop and pipe losses.

The accumulator, shown in its position in the pedicab bench above, is a Nitrogen charged piston accumulator. The precharge pressure in the accumulator is 400 psi. The accumulator’s effective volume is 2 liters. A cutaway view of the accumulator can be seen in Figure 4.8.

![Figure 4.8: Gas Accumulator Cut-Away View](image)

There are two chambers in the accumulator. One is filled with a fixed mass of inert Nitrogen gas, and the other is filled variably with hydraulic oil. As the oil volume in one chamber increases, the Nitrogen pressure increases in the other chamber – storing more energy. All hydraulic components, with exception of the pump-motor, will be mounted within the space under the pedicab bench.

### 4.4 Operator Interface / DCV Control

Up to this point, the pedicab chassis, the hydraulic schematic, and the spatial arrangement of all components have been defined. The last unit which ties the system together is the operator interface and directional control valve. The actual four bar mechanism which connects the user input link to the output link (DCV handle) on the pedicab is shown in Figure 4.9. Also shown is the unscaled kinematic diagram equivalent 4.10.
As stated earlier, the DCV will be mounted underneath the pedicab bench. The operator controls the DCV remotely via a 4-bar mechanism, pictured above. There is a handle mounted on the top tube of the pedicab frame between the operator’s legs. When the operator pulls the input link towards themselves, the DCV shifts into the charging position. Similarly, when the operator pushes the input link forwards, the DCV is shifted into the charging position.
discharging position. The DCV’s spring centering action moves the operator handle to the neutral position. The Directional Control Valve is shown in Figure 4.11.

![Figure 4.11: Mechanically Operated Directional Control Valve](image1)

A more accurate depiction of the float center is shown in Figure 4.12.

![Figure 4.12: Float Center for a Directional Control Valve](image2)

When the operator wants to begin deceleration, they will use one hand to shift the input lever into the charging position. The operator will continue to hold the lever in place until the charging process is complete. When the operator lets go, the accumulator remains charged and the valve and lever spring back to their neutral position. When it comes time to discharge, the operator pushes the input link in the other direction. The internal spool shifts, causing high pressure oil from the accumulator to flow back through to the pump-motor, creating the necessary torque for acceleration.
To conclude, there are three necessary components to this design. The first is the pedicab. The geometry of the pedicab let the design team know what was possible for prototyping. From there, a hydraulic schematic was created such that power could be stored and released, all while not creating great torque losses for the system. Finally, the system is complete with the user-operated directional control valve. The operator, who controls the charging and discharging of the system, is the final link in the functioning of this regenerative fluid powered pedicab.