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Hydraulic Test Bench Circuit Construction, Testing, and Analysis

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ABSTRACT

Hydraulic power control systems are a common and important part of mechanical and agricultural systems. In hydraulic power system design, power, pressure, flow rates, and mechanism of circuitry are all important factors when analyzing any hydraulic system. Pumps, electric motors, reservoirs, working fluid properties, hydraulic circuitry, and a large variety of valves make up a functional hydraulic system. Applications for hydraulic systems vary widely from automotive, agricultural, mechanical etc. It is the engineers' job to design a hydraulic system that will be functional, efficient, and safe.

INTRODUCTION

This SDSU undergraduate research project consisted of circuit analysis using a Hydraulic Test Bench which contained a pump and variety of valves. By using different circuits and pressure gauges our research group was able to analyze the effects of pressure reducing valves, directional control valves, load testing, hydraulic motors, and sequence valves. This research was done to test the hydraulic bench capabilities and model a potential hydraulics laboratory class for mechanical engineering undergraduates at SDSU. In order to analyze the capabilities of the hydraulic test bench, it was necessary to research hydraulic circuit diagrams and construct a circuit for each valve to be tested. Once the hydraulic circuits were constructed the system was run at two different system pressures of 200psia and 400psia. Various qualitative behavioral data and quantitative data of each circuit were recorded. Continued research will implement servomechanism controls to the closed loop hydraulic system followed by testing and analysis. A hydraulic motor was selected based on the pump specifications and capabilities to be installed on the bench for further circuit analysis.

MATERIALS AND METHODS

The Hydraulic Test Bench was donated by SDSU mechanical engineering alumni. Figure 1 and table 1, below provide a system schematic for the mentioned test bench. The first step in the project was to identify each valve component attached to the bench. After recording pump and motor specifications, the hydraulic circuits for the various valves were created and tested. Pressure gauges were used to record the system pressures during various operating conditions.

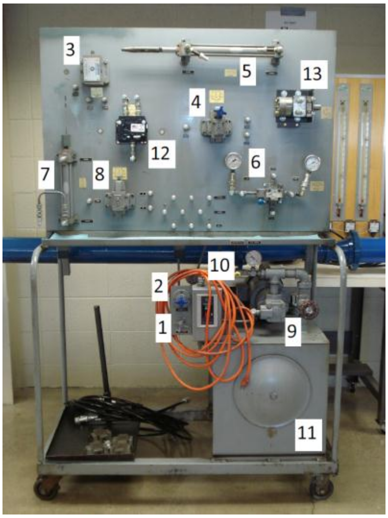

Figure 1: Hydraulic Test Bench Components

Table 1: Bench Components

Part Number	Part Description
1	Bypass Valve
2	System PSI Regulator
3	Directional Control Valve
4	Sequence Valve

5	Horizontal Cylinder
6	Directional Control Valve
7	Vertical Cylinder
8	Pressure-Reducing Valve
9	Pump
10	Electrical Motor
11	Reservoir
12	Flow Rate Control Valve
13	Hydraulic Motor
	Hose × 3 × 40″
	Hose × 6 × 52″
	Hose × 1 × 76″

RESULTS

Directional Control Circuit

The Directional Control Circuit Part 6 as shown in Figure 2, implemented the use of a directional control valve. This circuit also included the horizontal extendable cylinder. The directional control valve contains two ports in which the hydraulic fluid is outputted. When the fluid was directed to port A the cylinder extended and when directed to Port B, the cylinder retracted. The running pressures were then recorded for both ports A and B, along with the final static state pressures. The process was performed at a system pressure of 200 and 400 psi. The data collected can be seen below in Table 2.

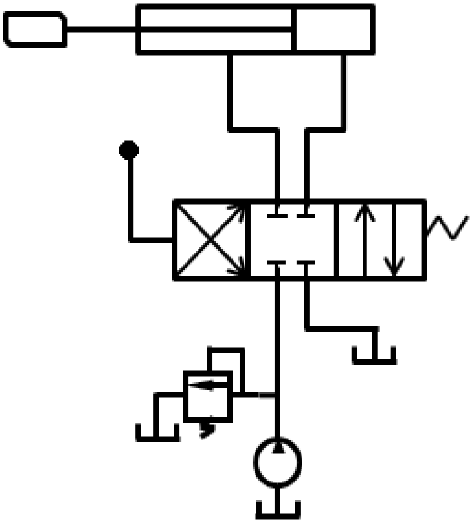

Figure 2: Directional Control Circuit Diagram

Table 2: Directional Control Circuit

	Pressures			
Cylinder Position	Pump Input	System	Port A	Port B
Static Retracted	neg 0.19 Bar	200 PSI	20 PSI	205 PSI
Extending	neg 0.19 Bar	110 PSI	75 PSI	30 PSI
Static Fully Extended	neg 0.19 Bar	200 PSI	200 PSI	20 PSI
Static Retracted	neg 0.19 Bar	400 PSI	20 PSI	405 PSI
Extending	neg 0.19 Bar	175 PSI	90 PSI	30 PSI
Static Fully Extended	neg 0.19 Bar	400 PSI	400 PSI	20 PSI

Pressure Control Circuit

The Pressure Control Circuit was implemented using pressure-reducing valve 8 which was outputted to the directional control valve then to the horizontal cylinder. The pressure reducing valve lowered the pressure input to the directional control valve and operational pressure of the cylinder. When fully extended or retracted the operational pressure was equal to the system pressure. The reduced pressure due to the reducing valve was only present during expansion or retraction of the cylinder. The process was performed at a system pressure of 200 and 400 psi. The data obtained at various presres and cylinder positions can be seen below in Table 3.

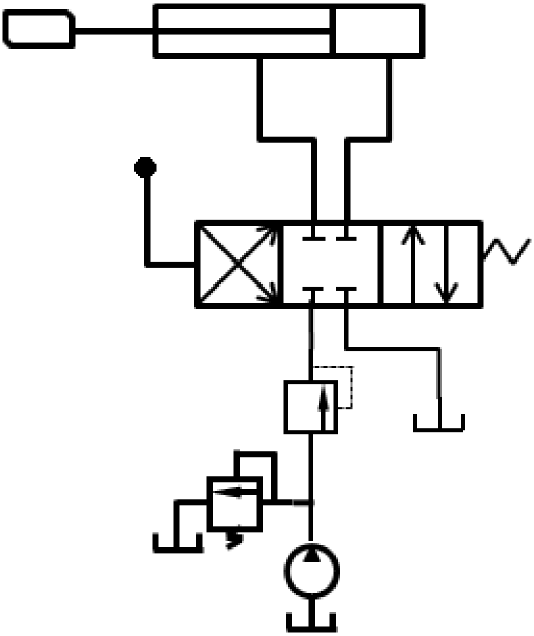

Figure 3: Pressure Control Circuit Diagram

Table 3: Pressure Control Circuit

	Pressures			
Cylinder Position	Pump Input	System	Port A	Port B
Static Retracted	neg 0.19 Bar	200 PSI	20 PSI	200 PSI

Extending	neg 0.19 Bar	140 PSI	55 PSI	20 PSI
Static Fully Extended	neg 0.19 Bar	200 PSI	200 PSI	20 PSI
Static Retracted	neg 0.19 Bar	400 PSI	20 PSI	400 PSI
Extending	neg 0.19 Bar	190 PSI	75 PSI	30 PSI
Static Fully Extended	neg 0.19 Bar	400 PSI	400 PSI	20 PSI

Load Testing Circuit

Using the Directional Control Valve and the extendable vertical cylinder 7, it was possible to study the effects of loading on the system. A five pound mount to hold incremental weights was fabricated and placed onto the vertical cylinder. Taking into account the mount, 55 and 105 pound loads were raised and lowered at a system pressure of 200psi. Using the pressure gauges, the operational pressures were recorded illustrating the effects of the loading on the system. As expected by increasing the loading, the pressure required to extend the cylinder increased and the pressure required to lower the cylinder decreased. The operational pressure increased from 110psia to 140psi when loading the cylinder with 105lbs. The decrease in the required retracting pressure is due to the force of the loading acting in the direction cylinder movement. The recorded pressure with respective loadings can be seen below in Table 4.

Table 4: Load Testing Data

Vertical Cylinder Load Testing		
Weight	Raising pressure	Lowering pressure
105 lbs	140 PSI	110 PSI
weight holder		5 lbs
weights		2 x 50 lbs

Flow Rate Control Circuit

The circuit shown in figure 5 implemented a flow rate control circuit using flow rate control valve 12. Using a flow meter following the valve it is possible to measure the flow rate of the fluid. If a flow meter is unavailable it is also possible to measure flow rate by timing the extension and retraction of a hydraulic cylinder following the flow control valve, by taking the velocity of the fluid and the area of the cylinder. An example of this calculation can be found in the Fluid Mechanic Analysis section. The results of the flow control valve circuit are presented in table 4.

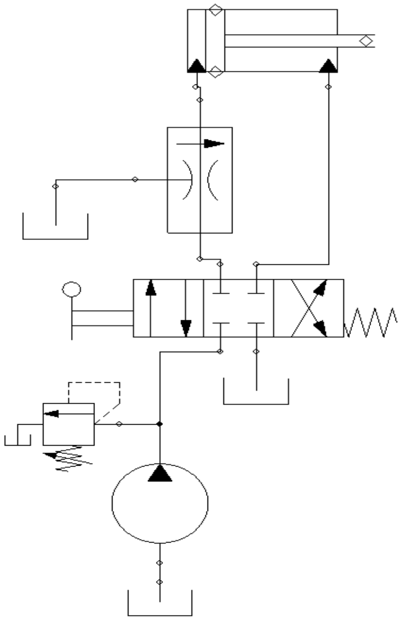

Figure 4: Flow Control Circuit

Table 5: Flow Rate Control Valve Data

Fully Open Flow Control Valve		
System Pressure (psi)	300	400
Metered Flow Rate (in^3/s)	5.56	5.56
Half Open Flow Control Valve		
System Pressure (psi)	300	400
Metered Flow Rate (in^3/s)	4.23	4.28

Hydraulic Motor

Using the flow rates and systems pressures from the previous circuit test, a hydraulic motor was tested for functionality. Due to a low powered pump and flow rates, the rotational output of the motor is low. It was concluded the rotating output shaft of the motor could easily be used as another flow meter device. The circuit diagram is show below followed by the data collected. As expected with higher system pressure, higher rotational speeds are achieved by the output shaft. As pressure is increased more force acts on the impeller of the hydraulic motor causing increased output speeds if under no load.

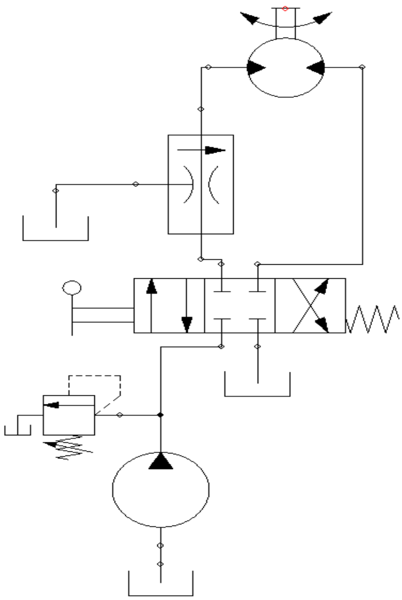

Figure 5: Hydraulic Motor Circuit

Table 6: Hydraulic Motor Data

Fully Open Flow Control Valve		
System Pressure (psi)	300	400
Metered Flow Rate (in^3/s)	5.56	5.56
Motor Rotational Speed (rpm)	32	45
Half Open Flow Control Valve		
System Pressure (psi)	300	400
Metered Flow Rate (in^3/s)	4.23	4.28
Motor Rotational Speed (rpm)	30	41

Sequence Valve Circuit

This implemented to output devices, a directional control valve, and a sequencing valve. The outputs were the hydraulic cylinders and the test was performed at five different system pressures tested when the vale was fully open and fully closed. The flow rate entering the sequencing valve was recorded along with the metered flow rate calculated from the cylinders. The circuit diagram for this test is shown in figure 6. When running, the second cylinder following the sequencing valve extends. Once fully extended, the pressure increases and the sequence valve would actuate and direct flow to the other cylinder at the metered flow rate. The sequence valve vents the rest of the flow back to the tank through the drain port. The data for the sequence valve are presented in table 7.

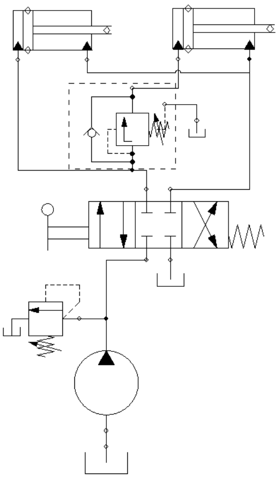

Figure 6: Sequencing Control Circuit

Table 7: Sequencing Valve Control Circuit Data

Fully Open Valve					
System Pressure (psi)	100	200	300	400	500
Flow Rate Entering Valve (in^3/s)	3.44	5.06	5.17	5.32	5.68
Metered Flow Rate (in^3/s)	1.42	2.82	3.8	4.08	4.5
Fully Closed Valve					
System Pressure (psi)	100	200	300	400	500
Flow Rate Entering Valve (in^3/s)	3.37	5.21	5.58	5.62	5.65
Metered Flow Rate (in^3/s)	2.05	3.42	4.77	5.48	5.54

Fluid Mechanic Analysis

The flow rate *Q* of the hydraulic fluid was calculated by measuring the time taken for the horizontal cylinder to expand and retract. Using this time, travel distance and the geometric sizes of the cylinder, the flow rate equation was obtained:

$$Q = vA \qquad (1)$$

Where *V* is speed of the cylinder and A is effective area of the cylinder piston. At 200 psia system pressure: Q=5.05 in^3/s. At 400 psia system pressure: Q=5.44 in^3/s. As expected, running the directional control valve circuit at higher system pressure resulted in higher flow rates.

Force *F* was calculated by the following equation:

$$F = pA \qquad (2)$$

where *p* is equal to the operating pressure of supply port and *A* is same as in equation (1).

CONCLUSION

By constructing and testing circuits that implemented the use of each valve and cylinders on the hydraulic test bench, it was concluded that the bench is 100 percent functional. Following the procedures used in analyzing the hydraulic circuits completed in this research would provide a valuable hydraulic lab course structure for the SDSU mechanical engineering students. The bench proves to be a useful tool in illustrating the functionality of sequence, pressure reducing, and directional control valves. The effects of different system pressures and resulting operational pressures were recorded successfully for the various circuits. By analyzing the fluid mechanics provided by the hydraulic pump students can apply hydraulic power and fluid analysis theoretically and validate experimentally with the test bench. Our research group believes the implementation of high accuracy flow meters to verify calculations would add significantly to the lab course. A servo control system would also greatly enhance the research and lab capabilities of the bench.

REFERENCES

White, Frank M. Fluid Mechanics. 7th ed. New York, NY: McGraw-Hill, 2009. Print.

Zhang, Qin. Basics of Hydraulic Systems. Boca Raton: CRC, 2009. Print.