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DESIGN AND DEMONSTRATION OF HYDRAULIC CIRCUIT FOR METER-IN AND METER-OUT CIRCUITS

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ABSTRACT:

This project presents the design, operation and comparative analysis of Meter-In and Meter-Out hydraulic flow-control circuits used for regulating actuator speed in fluid-power systems. Both circuits employ similar components—such as a hydraulic pump, directional control valve, flow control valve, and double-acting cylinder—but differ in the placement of the flow control valve, resulting in distinct functional characteristics. In the Meter-In circuit, flow is regulated as it enters the actuator, providing effective speed control under resisting loads. Conversely, the Meter-Out circuit controls flow leaving the actuator, making it suitable for overrunning or aiding loads by preventing cylinder acceleration and ensuring stable motion. Experimental demonstration of both circuits highlights their performance differences in terms of load handling, speed stability, and energy efficiency. The study concludes that proper selection between meter-in and meter-out configurations is essential for achieving safe, efficient, and precise hydraulic motion control in industrial applications.

1. Introduction

Fluid power systems, specifically hydraulics, are integral to modern industrial automation, construction, aerospace, and manufacturing. These systems utilize pressurized incompressible fluids (typically oil) to transmit power, offering distinct advantages such as high force-to-weight ratio, rigidity, and precise control over linear and rotary motion. The operation, maintenance, and troubleshooting of hydraulic systems require a strong foundational understanding of fluid mechanics, system components, and circuit design principles.

However, a gap often exists between theoretical knowledge acquired in the classroom and the practical application required in the industry. Training equipment, such as a Hydraulic Circuit, serves as a crucial bridge, allowing engineering students to assemble, visualize, and test fundamental and advanced hydraulic circuits in a controlled, safe, and modular environment.

2. Meter-In Circuit and Meter-Out Circuit Model

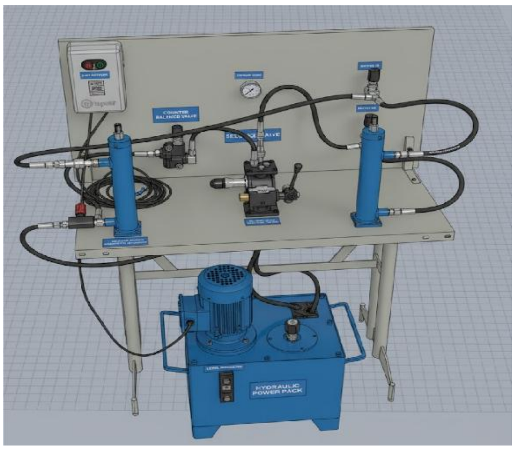

Fig.1 Design And Development Of Hydraulic Circuit For Meter-In & Meter-Out circuit

METER-IN CIRCUIT

The Meter-in Circuit is used for precise speed control by throttling the flow of oil entering the cylinder chamber. It is best suited for applications where the load is resistive (the cylinder must push against it) and not prone to running away.
A. Circuit Components
One-Way Flow Control Valve (FCV): Installed in the pressure line leading to the cylinder chamber that governs the controlled stroke (Port A for extension). The valve has a fixed flow orifice for the controlled direction and a check valve for free flow in the reverse direction.
B. Working Principle (Extension Stroke Controlled)
1. DCV Shifted (Extend): The pump flow is directed towards Port A (piston side).
2. Flow Restriction: The FCV is installed directly in line with Port A. The pump flow encounters the flow control needle (the metering element) of the FCV, which severely restricts the volume of fluid allowed to enter the piston chamber.
3. Speed Control: Since the cylinder velocity (V) is directly proportional to the flow rate (Q) and inversely proportional to the piston area (A) (V = Q/A), reducing the flow rate (Q) precisely reduces the cylinder's extension speed.

1. Return Flow: During retraction, the fluid exhausting from Port B returns freely through the FCV's check valve (bypassing the restriction) and back through the DCV to the tank. This ensures the retraction speed remains fast and uncontrolled by the FCV.

METER-OUT CIRCUIT

The Meter-in Circuit is used for precise speed control by throttling the flow of oil entering the cylinder chamber. It is best suited for applications where the load is resistive (the cylinder must push against it) and not prone to running away.

A. Circuit Components

• One-Way Flow Control Valve (FCV): Installed in the pressure line leading to the cylinder chamber that governs the controlled stroke (Port A for extension). The valve has a fixed flow orifice for the controlled direction and a check valve for free flow in the reverse direction.

B. Working Principle (Extension Stroke Controlled)

1. DCV Shifted (Extend): The pump flow is directed towards Port A (piston side).
2. Flow Restriction: The FCV is installed directly in line with Port A. The pump flow encounters the flow control needle (the metering element) of the FCV, which severely restricts the volume of fluid allowed to enter the piston chamber.
3. Speed Control: Since the cylinder velocity (V) is directly proportional to the flow rate (Q) and inversely proportional to the piston area (A) (V = Q/A), reducing the flow rate (Q) precisely reduces the cylinder's extension speed
4. Return Flow: During retraction, the fluid exhausting from Port B returns freely through the FCV's check valve (bypassing the restriction) and back through the DCV to the tank. This ensures the retraction speed remains fast and uncontrolled by the FCV.

3. Numerical Results

1. Given Cylinder Specifications

Parameter	Symbol	Value	SI Conversion (m)
Bore Diameter	D	40mm	0.040m
Rod Diameter	d	20mm	0.020m
Stroke Length	L	150mm	0.150m

2. Area Calculations

Piston Area (Extended, A_E) $A_E = \frac{\pi D^2}{4}$

$$A_E = \frac{\pi (40)^2}{4}$$

$$A_E = 1256.64\ mm^2$$

Annulus Area (Retract, A_R) $A_R = \frac{\pi (D^2 - d^2)}{4}$

$A_R = \frac{\pi(40^2-20^2)}{4}$

$A_R = 942.48\ mm^2$

3. Area Ratio

The ratio of the effective areas dictates the force and speed relationship:

$$\alpha = \frac{A_E}{A_R} = \frac{1256.64\ mm^2}{942.48\ mm^2} = 1.33$$

This ratio indicates that the extension force is 1.33 times greater than the retraction force, and the retraction speed is 1.33 times faster than the extension speed.

4. Force Analysis (Based on Design Pressure)

The cylinder's maximum force capability is determined by the design pressure of P = 50bar ($5 N/mm^2$).

1. Extension (Push) Force (F_E)

$F_E = P \times AE$

$F_E = 5\frac{N}{mm^2} \times 1256.64\ mm^2$

$F_E = 6283.2\ N$

$F_E = 6.28\ KN$

2. Retraction (Pull) Force (F_R)

$F_R = P \times AR$

$F_R = 5\frac{N}{mm^2} \times 942.48\ mm^2$

$F_R = 4712.4\ N$

$F_R = 4.71\ KN$

5. Power Pack Performance Analysis

The 0.5hp motor dictates the maximum flow rate available at the design pressure, which in turn determines the cylinder's operating speed.

Assuming a total system efficiency ($\boldsymbol{\eta_{total}}$) of 80%

Motor Power P_{motor} = 0.5 hp = 0.373 kW

$$Q_{max}\ (L/min) = \frac{P_{motor} \times \eta_{total} \times 600}{P\ (bar)}$$

$$\mathbf{Q_{max}} = \frac{\mathbf{0.373 \times 0.8 \times 600}}{\mathbf{50}}$$

$$\mathbf{Q_{max} = 3.58\ L/min}$$

Cylinder Speed and Time Calculations

The flow rate Qmax (equivalent to $5.97 \times 10^{-5}\ m^3/s$) determines the time required to complete the 150 mm stroke.

i. Extension Speed (V_E), $V_E = \frac{Q}{A_E}$

$$V_E = \frac{5.97 \times \frac{10^{-5} m^3}{s}}{1.257 \times 10^{-3} m^2}$$

$V_E = 0.0475\ m/s = 47.5\ mm/s$

ii. Extension Time (t_E), $t_E = \frac{L}{V_E}$

$$t_E = \frac{0.150\ m}{0.0475\ m/s}$$

$t_E = 3.16\ s$

iii. Retraction Speed (V_R), $V_R = \frac{Q}{A_R}$

$$V_R = \frac{5.97\times10^{-5} m^3/s}{9.42\times10^{-4}\ m^2}$$

$$V_R = 0.0634 \text{ m/s}$$

$$V_R = 63.4 \text{ mm/s}$$

iv. Retraction Time (t_R), $t_R = \frac{L}{V_R}$

$$t_R = \frac{0.150\ m}{0.0634\ m/s}$$

$$t_R = 2.37 \text{ s}$$

6. Conclusion

The objective of designing, developing, and validating a Hydraulic Circuit capable of demonstrating the Meter-in/Meter-out circuits has been successfully achieved. The project effectively bridged the gap between theoretical understanding of fluid power and its practical application.

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