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A throttle-less single rod hydraulic cylinder positioning system for switching loads

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ABSTRACT

This paper proposes a low-cost, high precision and efficient throttle-less hydraulic circuit that utilizes off-the-shelf industrial elements to control single rod hydraulic cylinders. The circuit uses an on/off solenoid valve to redirect the differential flow of a single rod hydraulic cylinder, and two counterbalance valves to manage switching (resistive–assistive) loads. Conducted experiments on a prototype system indicated a maximum steady state positional error of 0.2 mm. The circuit consumes only 20% of energy that is required by a valve controlled circuit to follow the same tracking signal. A simple proportional controller, that uses readings of a linear position transducer, is employed for all experiments, which makes the designed circuit easy to be implemented.

1. Introduction

Hydraulic systems are known to be heavy, noisy and inefficient [1]. The conventional way to control a hydraulic cylinder is to use throttling valves. Throttle-less circuits have been well developed and fully implemented for double rod cylinders in industry [2]. Double rod cylinders are symmetric, and flows at two sides of cylinder are the same. The challenge of a throttle-less single rod cylinder is to control differential flows of the cylinder with a symmetric pump [1]. There exist several designs of throttle-less hydraulic single rod cylinders, but none of them has been widely used in industry [3]. Such designs use special and expensive pumps, have controllability issues, or utilize several pumps for each cylinder which makes the machine heavy and complicated [3].

This paper presents the design and evaluation of a low-cost and easy to control single pump throttle-less circuit designed to position a single rod hydraulic cylinder for industrial applications like presses, elevators and tote dumpers. An experimental test rig has been prototyped which comprises an on/off valve and two counterbalance valves. Experiments are conducted to investigate performance of the proposed circuit in terms of position accuracy, position tracking, and energy efficiency. Characteristic of the proposed circuit is explained, followed by explaining the test rig and reporting experimental results. Position accuracy is calculated by subtracting the actual and desired positions of the end-effector while a switching load with varying amplitude square signal is displaced by the system. Quality of position tracking is investigated by applying a trapezoid position signal, and quantitatively observing the response of the system under switching load. Energy efficiency is calculated by reading the pump pressure and the displacement of the end-effector.

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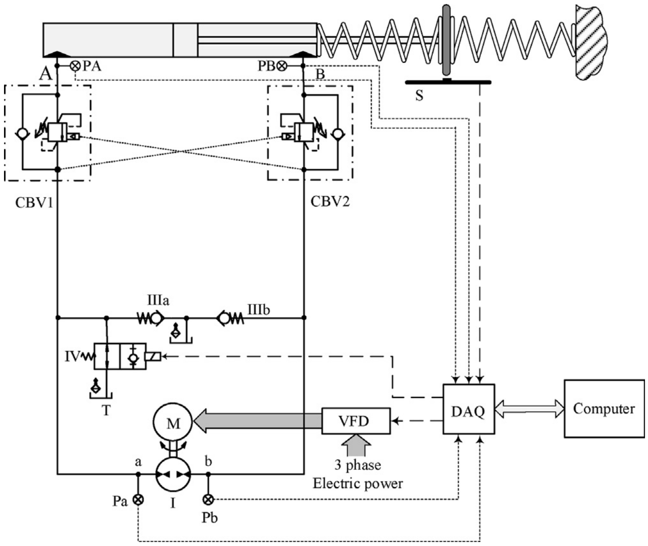

Fig. 1. Schematic of proposed circuit.

2. The proposed circuit

The proposed circuit is shown in Fig. 1. Pump **I** is a fixed displacement gear pump. Prime mover **M** is a variable speed bidirectional electromotor. Pump feeds ports of the cylinder through two counterbalance valves: **CBV1** and **CBV2**. Counterbalance valves are normally used as safety valves for systems working with assistive or suspended loads [4]. As observed in Fig. 1, the counterbalance valve includes a check valve to direct the flow from the pump to the cylinder with no restriction, and a pilot pressure relief valve that blocks the fluid from the cylinder to the pump. Return flow from the cylinder to the pump is regulated by a pilot pressure from the other port of the cylinder. Given that the pump does not rotate, the two counterbalance valves keep the position of the cylinder end-effector fixed without any effort from the pump. Two counterbalance valves keep the pressure higher than the tank pressure at the cylinder ports while check valves **IIIa** and **IIIb** maintain the pressure of at least one of the pump ports at the tank pressure [5]. Counterbalance valves make the hydraulic cylinder controllable in the case of switching loads [3]. Pressures at ports **A** and **B** of the cylinder are dependent on pilot ratios, setting of counterbalance valves, and load dynamics [5,6]. When the pump supplies pressure at port **a**, port **b** sucks oil from tank T (see Fig. 1) through check valve **IIIb**, and the valve **IV** remains closed. Pressure builds up at port **A** of the cylinder through check valve **CBV1**, and the pressure increases at port **B** as well. Counterbalance valve **CBV2** keeps the line closed until its pilot pressure reaches the setting pressure. Once **CBV2** opens, the end-effector extends and pushes the right spring. When the pump feeds oil through port **b**, valve **IV** opens, and the pump sucks oil from the tank through valves **IV** and check valve **IIIa** while check valve **CBV2** opens the pressure to port **B** of the cylinder, and pressure builds up at port **A** of the cylinder as

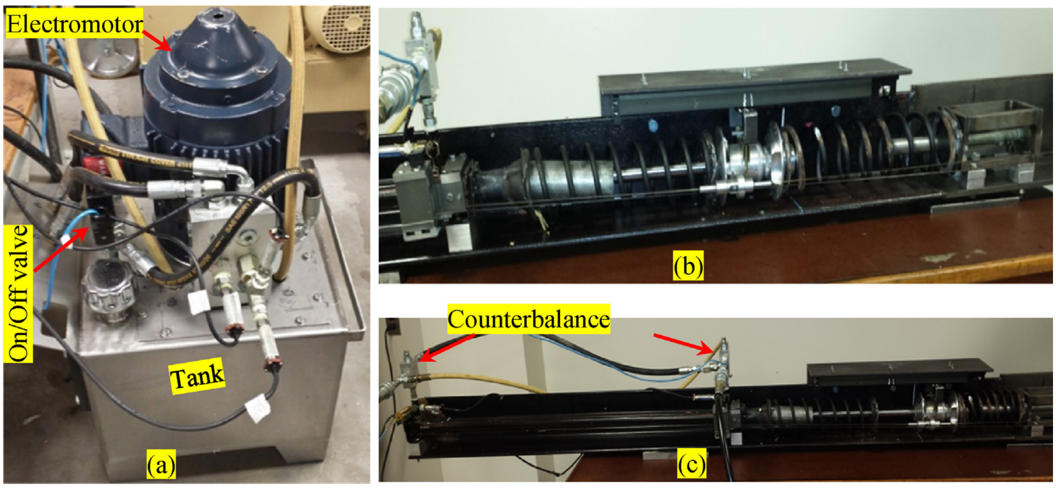

Fig. 2. Prototype rig (a) pump unit; (b) actuator unit; (c) switching load simulator.