Utilizing Electro-Hydraulic Actuators in Motion Control System

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Abstract:

The motion control system with linear movement can be achieved by using several technologies. One of the most commonly used technologies in easy industry is the electro-hydraulic actuators. This is because of their handling rapid motion, high positioning accuracy, and thus producing large forces needed by equipment. The main objective of this work is to provide an electro-hydraulic system which depends on hydraulic actuators to meet motion control system demands. This is achieved by using solenoid directional control valves as well as a double acting single-ended hydraulic cylinder with limiting position electrical switches. Several control system architectures can be used where directional solenoid valve provide the economical option for the application. One electric voltage signal is required for actuating each solenoid while the electro-mechanical limit switches stop the rod of hydraulic cylinder in the set point. The process is carried out using a Matlab/Simulink to simulate hydraulic sub-system .The results show the ability to demonstrate hydraulic circuit containing solenoids directional control valves to control the motion of the rod for the hydraulic cylinder.
1. Introduction

Motion control systems requiring linear movement can be achieved with a variety of different technologies. The most commonly used technologies can be grouped into three categories; linear actuators, linear motors and precision positioning tables. Linear actuators can be hydraulic, pneumatic, or electromechanical. Each type has advantages and drawbacks, so their use depends on the application [1].

Hydraulic actuators are widely used in industrial applications, and in many different automation and mechanization systems [2]. They are characterized by their ability to impart large forces at high speeds and are used in many industrial motion systems [3]. Hydraulic actuators provide a rectilinear movement realized by the stroke of a rod connected to a piston sliding inside the cylinder [4]. The accuracy of such system determines the kind of hydraulic module which is employed and according to the required accuracy the hydraulic control solenoid valves can be selected in which the direction of the load may be controlled by the use of hydraulic valves designed for this purpose [5].

The general classification of the hydraulic valves may be divided into infinite position valves which can take any position between fully closed and fully open, and finite position valves which generally switch the flow of hydraulic oil between different ports and can only be fully open or fully closed such as directional valve [6].

Directional valves can be controlled in various ways manually, by means of devices such as cam; hydraulically, by means of fluids under pressure and electrically depending on the solenoids to convert an electric current to a limited linear motion [2] and [4].

In several applications, a single-rod hydraulic actuators beside the solenoid valves have been employed as the actuation of electro-hydraulic control system such as in the robust motion control and a
mobile hydraulic crane [7], [8], [9] and [10]. Theoretical and practical researches show that hydraulic control systems using switching hydraulic valve can achieve high precision. It is a cheap scheme and can satisfy many purposes [11]. One of the commonest types of finite hydraulic valves is the solenoid directional valve where the basic part of this technology is the conventional directional spool control valves, with its solenoids, provide the ideal interface for electrical controls [12].

The suggested motion control system is based on the implementation of an electro-hydraulic model which containing hydraulic cylinder steering by solenoid directional valve instead of utilizing an electrical model contains electric cylinder as in [1]. The description of the employed controller system has been introduced in the second section while a detailed of the experimental work and the simulation of the electro-hydraulic system is presented in the third and the fourth sections respectively followed by a conclusion.

2. Motion Control System

The motion control system under consideration can be subdivided into electro-hydraulic subsystem working with conventional directional control valve beside a hydraulic actuator (cylinder) which is steered by hydraulic solenoid valve associated with an electrical board, specifically designed for this purpose in addition to electro-mechanical limit switches to sense the required position for the rod of hydraulic cylinder as depicted in figure (1).

![Figure (1) the Schematic Diagram of the Suggested Motion Control System.](image_url)

Solenoids is the simplest electromagnetic actuators that are used in linear as well as rotary actuations for valves, switches, and relays. As the name indicates, a solenoid consists of a stationary iron frame
(stator), a coil (solenoid), and a ferromagnetic plunger (armature) in the center of the coil as shown in figure (2)[4].

![Figure (2) the Solenoid Actuators [4]](image)

If an electrical current is passing into the solenoid, it will induce a corresponding magnetic field. The flux density follows the right-hand rule and the magnitude inside the coil is approximately [4]

\[ B = \frac{\mu N I}{L} \]  

And \[ \mu = \mu_s \mu_r \]  

As the coil is energized, a magnetic field is induced inside the coil. The movable plunger moves to increase the flux linkage by closing the air gap between the plunger and the stationary frame [4].

Solenoid valves take electrical signals as inputs and control the flow of fluids as outputs. The basic principle of operation is a moving ferrous core (a piston) that will move inside the coil. When a voltage is applied to the coil and electrical current flows, the coil builds up a magnetic field that attracts the piston and pulls it into the center of the coil. The symbol of the solenoid valve is shown in figure (3) [13]:

![Figure (3) the Symbol of Solenoid Directional Valve [13]](image)

where
• P represents the high pressure hydraulic port coming from the pump with the pressure supply line inlet and T the return line to the hydraulic tank.
• A and B represent hydraulic conserving port associated with the actuator connection port.

The basic components of the hydraulic valve with the solenoid are shown in figure (4).

![Figure 4](image)

Figure (4) the Schematic Diagram of Solenoid Direction Valve [14].

A directional valve with several positions is represented symbolically by means of quadrants side by side depicting the connections made by each position as shown in figure (5) [4].

![Figure 5](image)

Figure (5) the Symbols Diagram of Hydraulic Valves [4].

The double-acting hydraulic cylinder converts hydraulic energy into mechanical energy in the form of translational motion; it uses pressurized fluid to create a linear motion [4]. The hydraulic fluid is pumped into one side of the cylinder under pressure, causing that side of the cylinder to expand, and advancing the piston. The fluid on the other side of the piston must be allowed to escape freely as shown in figure (6) [13].
3. Experimental work

An actuation system for the employed motion control system consists of the hydraulic control unit and hydraulic power unit. The control unit contains directional spool control valves and their associated electrical solenoid where a DC voltage solenoid valve was selected. The power unit of the hydraulic system comprises all the devices for effecting the movements or actions and consists of a hydraulic pump, a non-return valves, a filter, and a hydraulic tank in addition to a hydraulic cylinder.

The solenoid directional valve controls the direction of movement of the piston of the hydraulic cylinders through changing the direction of the flow of the hydraulic oil that passes from it towards a single ended double acting hydraulic cylinder with a 360 mm stroke of the piston. To investigate this approach two electrical solenoid hydraulic valves have been employed as shown in figure (7).
The valve switching command is coming from the electrical control board. Most industrial solenoids will be powered by 24V DC and draw a few electrical currents, so that they can be used directly by the actuators and the control spool of the direction valve is shifted either to the right or to the left depending on which solenoid is energized to actuate the hydraulic cylinder. The electro-mechanical sensors are of the “ON–OFF” position limit switches type, which are fixed on the end of the stroke for the piston of hydraulic cylinder. These sensors detect the position of the hydraulic rod of the cylinder and send a voltage signal to the electrical control board which indicates that the rod reached the desired point. The employed electrical controller module and electro-hydraulic system of the motion control system is shown in figures (8) and (9) respectively.

Figure (8) the Schematic Electrical Diagram of Motion Control System.  
[Designed by researcher]
Figure (9) the Employed Electro-Hydraulic Motion Control System.

The description of the basic parts of hydraulic components which are used in electro-hydraulic system is summarized in table (1).

<table>
<thead>
<tr>
<th>Item</th>
<th>Symbol</th>
<th>Description</th>
<th>Item</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><img src="image" alt="Solenoid Directional Valve" /></td>
<td>Solenoid Directional Valve</td>
<td>5</td>
<td><img src="image" alt="Hydraulic Pressure Gauge" /></td>
<td>Hydraulic Pressure Gauge</td>
</tr>
<tr>
<td>2</td>
<td><img src="image" alt="Hydraulic Cylinder" /></td>
<td>Hydraulic Cylinder</td>
<td>6</td>
<td><img src="image" alt="Hydraulic Pressure Relief Valve" /></td>
<td>Hydraulic Pressure Relief Valve</td>
</tr>
<tr>
<td>3</td>
<td><img src="image" alt="Hydraulic Pumps" /></td>
<td>Hydraulic Pumps</td>
<td>7</td>
<td><img src="image" alt="Electrical Motor" /></td>
<td>Electrical Motor</td>
</tr>
<tr>
<td>4</td>
<td><img src="image" alt="Hydraulic Pipes" /></td>
<td>Hydraulic Pipes</td>
<td>8</td>
<td><img src="image" alt="Hydraulic Tank" /></td>
<td>Hydraulic Tank</td>
</tr>
</tbody>
</table>

The result of the experimental work, the prototype of the motion control system was built in hydraulic lab in which the position switches were fixed at the end of the stroke for the piston of the hydraulic cylinder as shown in figure (10).
4. Simulation Process

Simulation has been carried out to investigate the performance of the electro-hydraulic model for the motion control system. This was accomplished using SIMULINK/ MATLAB, software package which provides a graphical user interface for building and analyzing system models [15]. The hydraulic blockset in MATLAB provides a collection of hydraulic cylinders, pumps and valves as shown in figure (11).

![Image of hydraulic components](image)

Figure (11) the Library Descriptions for Hydraulic Valve, Cylinder and Pump in Matlab [16].

The actuators, valves and cylinders were modeled using their parameters provided by the manufacturer as shown in figure (12) [16]. The simulated results for different input signals which are supplied to the solenoid of the directional valve can be shown easily and quickly on the display as in figure (13) and the response of the
piston for the hydraulic cylinder due to directional valve can be shown in figure (14).

Figure (12) the Electro-Hydraulic Model for Motion Control System [16].

Figure (13) Input Signals for Electro-Hydraulic Directional Valve.
Figure (14) the Position Response of Hydraulic Cylinder.

The obtained results that are displayed in figure (14) may be compared with the results gained from another research which employed electro-hydraulic system based on proportional hydraulic valve [17] as shown in figure (15).

Figure (15) the Hydraulic Cylinder Response [17].

It can be noticed that the response of the hydraulic cylinder in figure (14) is similar to that in figure (15) although the proportional hydraulic valve is more precise and has a fast response better than the conventional valve but it is still costly.
5. Conclusions

The following remarks can be concluded:

i. This work is based on the implementation of actuator drive by electro-hydraulic valve in a motion control system instead of electric system depending on electric cylinder or pneumatic system.

ii. The design centers on a cheap scheme laboratory prototype hydraulic system containing a hydraulic cylinder in addition to a conventional solenoid hydraulic valve that could be easily interfaced with eclectic control board.

iii. This prototype can be employed in different load categories and up to 100 kg. As a result, it can utilize the strategy of the hydraulic model in actuating other ranges of load.

iv. Simulation of the electro-hydraulic subsystem has been performed and to improve the performance of the hydraulic actuators in the motion control system, a proportional (servo) hydraulic valve interfacing with controller module based on microcontroller may be used for actuating the hydraulic cylinder.

References:


Notations:

\[ B \]: the magnetic flux density (in tesla [T] or (Wb/m^2)).
\[ I \]: the electrical current through the winding of the coil (A).
\[ L \]: the length of the coil of the solenoid valve (m).
\[ N \]: number of turns for the coil of the solenoid valve (in turn [t]).
\[ NC \]: normally closed electrical switches.
\[ NO \]: normally opened electrical switches.
\[ Wb \]: unit of measurement for magnetic flux.
\[ \mu \]: permeability of the material inside the coil (Wb/A.m).
\[ \mu_r \]: the relative permeability.
\[ \mu_o \]: permeability for free space (Wb/A.m).