Programmable Logic Control of an Electro-hydraulic System for a Reconfigurable Assembly Fixture used for Press Brake assembly

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Abstract - The inconsistent demand of product configurations by users increases the variety of assembly tasks. This situation calls for reconfigurable assembly systems (RAS). A reconfigurable assembly system requires equipment that will provide a gripping force to dynamic models of products during assembly. This equipment requires adequate and efficient control devices for effective work-holding and accurate positioning of products. In this article, a novel electro-hydraulic system comprising of six actuators was designed for a reconfigurable assembly fixture, which will be used for assembly of press brakes. The system was designed using FESTO FluidSIM Electro-hydraulics. The programmable logic controller model was connected using a logic circuit, and the output of the actuators was obtained graphically, in order to depict the functionality of the system. The PLC was designed using Automation Studio 5.0. The designed circuit was also simulated using FESTO didactic electro-hydraulics equipment in order to demonstrate uniform extension and retraction of the actuators. Results confirm the feasibility of the approach for practical application in RAS.

Keywords- Programmable Logic Controller; Electro-hydraulic system; Reconfigurable assembly fixture

I. INTRODUCTION

The demands for customized and personalized products make manufacturing and assembly systems complex and dynamic. Reconfigurable assembly systems are designed to assemble products with customized flexibility within a part family. The development of manufacturing and assembly systems for a product or customized product within a part family is a concurrent activity that needs to be done in line with the product development [1]. Considering the assembly system, one of the major subsystems that needs to be designed is a reconfigurable assembly fixture (RAF). A reconfigurable assembly fixture is a work-holding device that accurately locates positions and grips the work in progress part, during assembly. The part of the product supported by a reconfigurable assembly fixture varies according to production requirements [2-3]. In essence, the development of a RAF requires efficient controlling devices for effective performance [4]. Press brakes are machine tools used for non-cutting operations in manufacturing. Due to numerous functions of press brakes, there are different types in use. Assembly of press brakes starts by accurately locating and positioning of the frame, which is the heaviest part of the equipment. Other components of the press brakes are assembled to the frame which is securely positioned during the assembly process. During the assembly process, the frame needs to be clamped with a high force so that other parts can be fitted in the correct alignment. The motion of parts in a RAF is complex and dynamic. A model for reconfiguration is usually developed, and used to control the fixture either through an agent system or a controller.

Complex motion and force requirements of RAF are usually achieved by hydraulic systems. These hydraulic systems are controlled by electrical devices. A hydraulic system can either be pump controlled or valve controlled. Valve controlled systems use electro-hydraulic valves which are used to control the flow of fluid in the system [5-7]. The ability of hydraulic systems to produce a high clamping force and accurate positioning makes them applicable in the design of fixtures and other modern equipment [8-9]. The hydraulic gadgets are the muscles in the system while the electrical wiring is the brain controlling the hydraulic system [10]. Programmable logic controllers (PLC) were developed in the late 1960s to deal with the problems of hard-wired panels which are time-consuming to wire or debug. PLCs are special coordinating computers which are used to control the activities of process equipment and machines [11]. Reconfigurable equipment is controlled by microcontrollers or PLCs [12-14].

Microcontrollers use programs which are loaded on chips, and inserted into the panel of the machine. These programs are set to perform defined instructions which in most cases can be reprogrammed and used with the same chips [15]. PLCs are used in tough industrial environments. They are used to control the performance of equipment and processes that are logical and sequential in nature [5], [16-20]. The function of a PLC in reconfigurable device is such that it receives commands from the reconfiguration model and interprets the instructions to the physical system based on a set of reprogrammable instructions of the PLC [20-24]. In this article, an electro-hydraulic system for reconfigurable assembly fixture was designed, and controlled using a PLC. A logic diagram was designed to
control the PLC, based on some set of instructions or sequence of operation of the fixture. The electro-hydraulic system comprises of six hydraulic actuators which output force, velocity and position are presented graphically in fig 9-10.

II. LITERATURE REVIEW

The construction and position control of a translational hydraulic servomechanism for two hydraulic actuators was done by Sijum and Lobrovic [8]. A control algorithm was developed and implemented using three devices, which are a programmable logic controller, an industrial computer, and a combination of both. The system was not cost effective because it uses three directional control valves (DCVs). However, it produces an effective force control due to the usage of three DCVs. The factors for selecting a suitable controller were identified as:

- Compatibility of controller with electrical components, I/O requirements and needed signal types.
- Controller operations in the working environment,
- Requirements for special features of the controller hardware, for both local and remote process control,
- Programmability and requirements for advanced functions and data manipulation, etc.

A double acting hydraulic cylinder with a limit position sensor was designed by Bader [15]. Bader’s position control system was achieved using a microcontroller interfaced with position sensors to detect the position of the actuator. A proportional directional control valve was linked to the microcontroller through the PID controller, and the system was simulated using Simulink. The analogue signal was converted to digital values which may provide resolution errors during conversion.

The step response of the system yielded a high accuracy but there could be an error due to backlash of the actuator piston. A novel control design was developed by Földi, Béres, and Sárközi [11], to realize fast and accurate position of pneumatic actuator. The system uses a 5/3 way directional single solenoid valve, and an analogue displacement encoder for metering the piston’s position and velocity. The system has the advantage of using inexpensive on/off solenoid valves, and operates an on chatter free air compression with no pressure sensor, making it cost effective compared to servo-pneumatic positioning systems. However, when large forces are required, pressure requirements increase which makes it difficult for detecting pressure.

III. THE ELECTRO-HYDRAULIC SYSTEM

The electro-hydraulic system comprises of two movable jaw cylinders (MJC), and four finger cylinders (FC). The FC and MJC are controlled by DCV (A) and DCV (B) respectively, as shown in fig 1 (presented at the end of this article). Three way flow control valves and pressure reducing valves are used to control the flow of hydraulic fluid into the actuators, in order to obtain synchronized motion and equal positioning. The directional control valves, three way flow control valves, and pressure reducing valves are sized in order to be suitable for the configurations of the actuators and external loads. The three way control valve regulates the flow of fluid into the cylinders and also adjusts the pressures with the help of the pressure reducing valves. The clamping force of the reconfigurable assembly fixture is the extension force of the actuators which varies with the weight of the press brake to be assembled. The reconfiguration model of the fixture computes the travel length of the hydraulic actuator and sends the information to the PLC through a computer. The PLC sends the information to the electrical system and a PID controller which then controls the hydraulic system. The description of the control architecture and operation process for the reconfigurable assembly fixture is presented in fig 2 (as presented at the end of this article).

The operation of the hydraulic equipment depends on the electrical connections. The electrical components are connected with reference to the sequence of operation of the hydraulic actuator. The electrical system is presented in Figure 3. The part list for the hydraulic and electrical connection is presented in Table I (as presented at the end of this article). A logic module was used to design the PLC based on the sequence of the operation. The limit switch in the system F1, F2, F3, and F4 were used as inputs in the module which controls the solenoids used as outputs through the logic gates. The truth table used for the connection of the gates is presented in Table I. The logic module is presented in Figure 4. The electrical connection was used to design the rung diagram which is connected to the PLC cards. The ladder logic was designed using Automation Studio 5, as shown in Figure 5. The simulation of the ladder diagram with AB PLC, and IEC standard for electrical control is shown in fig 6.

<table>
<thead>
<tr>
<th>Start/F1</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>SOL A</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>SOL B</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>SOL C</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>SOL D</td>
</tr>
</tbody>
</table>
Fig 3. Electrical System for the Reconfigurable assembly Fixture

Fig 4. Logic Module for Electrical system of the RAF
Fig 5. PLC connection for the RAF

Fig 6. Simulation of the PLC Circuit.
IV. EXPERIMENTAL SET-UP
In order to demonstrate the designed hydraulic system and observe the synchronization of the cylinders, the designed hydraulic circuit was set up in the laboratory using the FESTO hydraulic test bench.

The extension and retraction of the actuators was equal which signifies that the system will have optimal function during operation. Fig 7 and 8 represent the pictures of the experimental set-up, and extension of the cylinders during the experiment respectively. The description of components for the experimental set-up is presented in table III.

![Fig 7. Experimental set-up for the Hydraulic System of RAF](image)

<table>
<thead>
<tr>
<th>PART</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Finger cylinders</td>
</tr>
<tr>
<td>b</td>
<td>Movable jaw cylinders</td>
</tr>
<tr>
<td>c</td>
<td>Limit switch</td>
</tr>
<tr>
<td>d</td>
<td>Pump unit</td>
</tr>
<tr>
<td>e</td>
<td>Directional control valve B</td>
</tr>
<tr>
<td>f</td>
<td>Hose connector (discharging to the tank)</td>
</tr>
<tr>
<td>g</td>
<td>Flow distributor to inlet ports of movable jaw cylinders</td>
</tr>
<tr>
<td>h</td>
<td>Pump switch</td>
</tr>
<tr>
<td>i</td>
<td>Directional control valve A</td>
</tr>
<tr>
<td>j</td>
<td>Hose connector (supplying from the pump)</td>
</tr>
<tr>
<td>k</td>
<td>Flow distributor to outlet ports of finger cylinders</td>
</tr>
<tr>
<td>l</td>
<td>Electrical connection unit</td>
</tr>
<tr>
<td>m</td>
<td>Flow distributor to outlet ports of movable jaw cylinders</td>
</tr>
<tr>
<td>n</td>
<td>Flow distributor to inlet ports of finger cylinders</td>
</tr>
</tbody>
</table>

Fig 8. Experimental set-up for Synchronized Extension of FC and MJC

V. RESULTS
The parameters of the actuators and other hydraulic equipment were used to run the simulation and the parameters of the actuator were compared graphically, as shown in fig 9 and 10. Considering fig 9, the displacement of the finger cylinders is equal which shows that the synchronization of the cylinders works. This can also be confirmed with the parameters of the actuators such as the velocity and force. Each actuator was simulated using variable force in order to depict the changes in each cylinder. The increase in force of the cylinders was constant which signifies accurate synchronization. More so the velocity of the cylinders is equal but at the start the velocity tends to be unstable as shown by the shaded area in the velocity graph in fig 9. However the instability of the velocity is the same in all the actuators. The result is the same for movable jaw cylinders as shown in fig. 10.
Fig 9. Graphical presentation of output parameters for Finger Cylinders

Fig 10. Graphical presentation of output parameters for movable jaw Cylinders
VI. CONCLUSION
A variety of industrial applications require hydraulic systems, because of their durability and large force. More so, advanced manufacturing systems and equipment such as reconfigurable assembly fixtures require the use of a PLC in order to achieve effective performance. An electro-hydraulic system was designed for a reconfigurable assembly fixture, and the designed circuit was simulated experimentally using the FESTO hydraulic test bench. The electrical components of the circuit were connected by considering the sequence of operation of the hydraulic equipment and the logic module of the PLC using FluidSIM electro-hydraulics 4.0. The results of the simulation show that the output parameters of the cylinders such as the length, velocity, and force are equal. This signifies that the actuators are fully synchronized. In addition the PLC was designed using Automation Studio 5.0. The rung diagram was connected with the input and output cards of the AB PLC. The simulation shows that all the solenoids are actuated in operating sequence. In essence, simultaneous control of position and force of multi-actuator system has been addressed in this article. The novelty of the hydraulic system is the use of the three way flow control valve in conjunction with two pressure reducing valves per actuator, rather than the conventional flow divider. The three way control valve regulates the flow of fluid into the cylinders and also adjusts the pressures with the help of the pressure reducing valves. This article provides relevant information in the design of hydraulic circuits, control and automation and it will serve as a tool for synchronization of multi actuator hydraulic systems without the use of directional control valves for each cylinder or actuator.

REFERENCES
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Fig 1. Hydraulic System for Reconfigurable Assembly Fixture
TABLE I. Part list for the Electro-hydraulic system

<table>
<thead>
<tr>
<th>S/N</th>
<th>Designation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DCV (A) and DCV (B)</td>
<td>4/3 Way solenoid valve with shut off position</td>
</tr>
<tr>
<td>2</td>
<td>F1, F2, F4, K1, K2, K3, K4</td>
<td>Make Switch</td>
</tr>
<tr>
<td>3</td>
<td>F3, K2, K3, K4</td>
<td>Break Switch</td>
</tr>
<tr>
<td>4</td>
<td>K1, K2, K3, K4</td>
<td>Relay</td>
</tr>
<tr>
<td>5</td>
<td>FC1-FC4, MJC1-MJC2</td>
<td>Double acting Cylinders</td>
</tr>
<tr>
<td>6</td>
<td>SOL A-SOL D</td>
<td>Valve solenoid</td>
</tr>
<tr>
<td>7</td>
<td>PU</td>
<td>Pump unit</td>
</tr>
<tr>
<td>8</td>
<td>RR1-PR12</td>
<td>Pressure Reducing Valve 1 to 12</td>
</tr>
<tr>
<td>9</td>
<td>PLC logic</td>
<td>Logic Module</td>
</tr>
<tr>
<td>10</td>
<td>FC LS and MJC LS</td>
<td>Distance Rule</td>
</tr>
<tr>
<td>11</td>
<td>FCV 1-FCV 12</td>
<td>Three way flow control valves 1 to 12</td>
</tr>
</tbody>
</table>

Fig 2. Control Architecture for the Reconfigurable Assembly Fixture