Reduction of Cycle Time of An Electro-Hydraulic Circuit Used in an Automated Rod Both Ends Chamfering SPM by Simulation and PLC

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Abstract - The rods which are automatically chamfered on both ends simultaneously by this SPM uses electro-hydraulics control system for all of its operations. The operation such as loading-unloading of job onto the v-blocks, clamping- de-clamping of job and feeding the tool over the rod ends all is done by hydraulic cylinders controlled by DCV's which are solenoid operated. The hydraulic circuit used previously is replaced by a improved circuit which is more efficient, reduces the cycle time, all operations are synchronized and improves the production eventually leading to more profits out of same inputs. The existing circuit had unsynchronized clamping, less efficient, idler running pumps and less production than what could have been achieved. These drawbacks were overcome by using two extra DCV's and a sophisticated circuit which is synchronized, more efficient no idle running pumps and yields more production. The new and improved circuit is simulated in FESTO Fluid-Sim hydraulic software using a PLC ladder diagram which agrees with the results obtained analytically.

Keywords- *FESTO Fluid-Sim, electro-hydraulics, SPM, rod chamfering, cycle time reduction, hydraulic circuit, PLC ladder diagram.*

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I. INTRODUCTION

Chamfering is the operation of beveling the extreme end of work piece. This is done to protect the end of work piece from being damaged and to have a better look. Generally for chamfering operations, manually operated chamfering machines are used and for every operation manual human interference is required. In this paper, a special purpose machine for automatic chamfering of rods on both ends is used. A special purpose machine can be defined as a custom design to perform specific operations or combination of some operations on a specific or variety of jobs, in mass scale and short cycle time [1]. On an automation system one can find three families of components, which are sensors, valves and actuators [2]. A solenoid is used in pneumatic valves to act as the actuating element. Most of the control elements used in this special purpose machine, to execute the logic of system are substituted in the PLC [5].

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 [3]. Sensors/switches are plugged as inputs, and the flow/direct control valves for actuators are plugged as outputs. An internal program executes all the logic necessary to the sequence of movements. This special purpose machine consists of Electro-hydraulic Technology, which is formed mainly by three kinds of elements: Actuators or motors, sensors or buttons and control elements like valves. The commands written by an electronic programmer or by a microcomputer. Sensors and switches are plugged as inputs and the direct control valves for the actuators are plugged as outputs. An internal program executes all the logic necessary to the sequence of the movements, simulates other components like counter, timer and control the status of the system [4].

The main advantage of fluid power is the good ratio between forces delivered by the actuator over the weight and size. Moreover the combination between electrical and hydraulic devices also rendered electro-hydraulic system to be more flexible in implementing to real application with advanced control strategies [6].

The main aim of this paper is to analyze the working of existing electro-hydraulic circuit, along with describing various components used, their functions and applications. Also, implementing a new and improved electro-hydraulic circuit, featuring its working and drawbacks overcome by the same. Analysis and discussion on results obtained from both electro-hydraulic circuits will be described further.

II. Machine Working Principle

The above SPM is meant for chamfering the rods on both ends automatically with the help of electro-hydraulic system. The machine consists of provisions such as hydraulic clamping; tool feed mechanisms, job loading mechanism and the base structure as shown in fig.1. The machine chamfers the rod which are used in U-clamps of leaf springs in automobiles.

The main working principle of this machine is the type of relative motion obtained between the tool and workpiece by rotating the tool and holding the workpiece stationary with help of hydraulic clamps. This enables the machine to operate effectively with lower loading and clamping cycle times. All the functions of machine such as clamping, feeding the tool and loading job is done by programming in PLC with help of solenoid operated DCV's and limit switches.

The automatic working achieves to almost 10 products per minute with surface finish of 32µm which is much finer. It also eliminates the need of continuous supervision of human but only requires intermittent visits of worker for stacking the workpieces into the loading mechanism after 10 to 15 min of continuous operation.

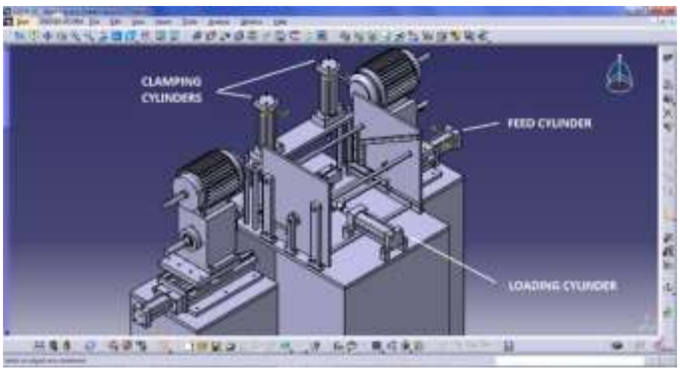

Fig.1 the solid model of the SPM made in CATIA software describing the hydraulic cylinders in the machine.

III. Sequence Of Operation

The overall sequence working is as shown in fig, 2. The operations will start with the loading of job onto the V-blocks followed by clamping. After clamping loading cylinder retracts and feed cylinders take their idle strokes for the chamfering operation. The chamfering takes about 2.5s to complete which follows the retraction stroke of feed cylinders. After this de-clamping of workpiece takes place and finally loading mechanism unloads the finished and loads the new job on the V-blocks. In this way cycle goes on [8].

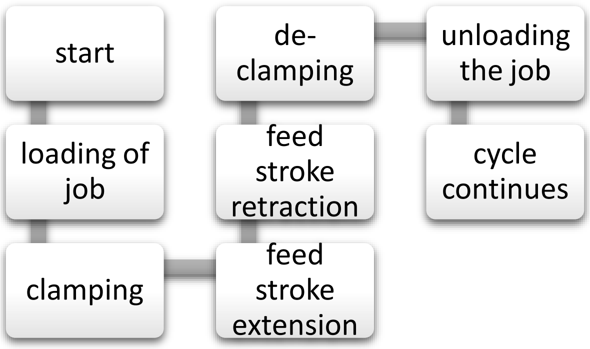

Fig.2 Cyclic flow diagram of the sequence of operations performed in the machine.

IV. Specifcations Of Hydraulic System Designed

- The two gear pumps are selected with 4 lpm and 207 bar pressure rating, connected in tandem with a CG 2 HP motor for synchronizing operations.
- The automation parts include limit switches, solenoid operated, and spring return DCV's, variable flow control valves with unidirectional flow using a check valve [7].
- The limit switches in the ladder diagram are stated as F1, F2, F3, F4, F5 and F6 for both feed cylinders resp., C1, C2, C3 and C4 for two of clamping cylinders and L1 and L2 for loading cylinders.
- Various relay coils required in ladder circuit are stated as K1, K2, K3, K4, etc. and solenoid valves of the DCV's as V1, V2, V3, V4, etc. and all are connected logically to make a working PLC ladder diagram.

V. Existing Hydraulic Circuit

A. *Working:*

- Pumps A & B are connected in tandem with a single 2 HP motor and apart from the time of cycle operations, other DCV's are in neutral position as shown in Fig.3.
- When circuit starts DCV 3 gets in (I) position and pump B, pumps to loading cylinder from L1 to L2.
- When L2 gets active DCV 2 shifts to position (I) and pump A delivers to both clamping cylinders and extends them from C1 & C3 to C2 & C4 resp.
- When C2 & C4 becomes active DCV 3 shifts to position (II) and loading cylinder retracts to L1.

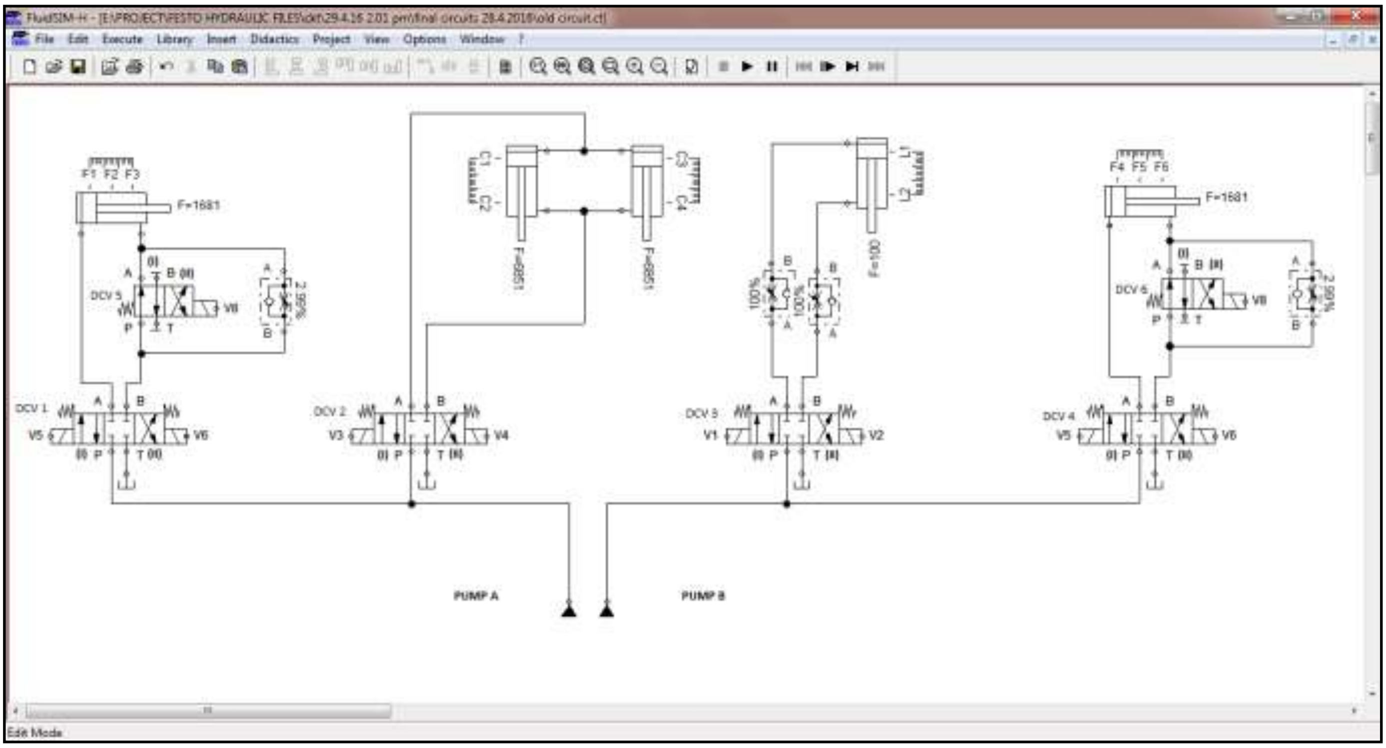

Fig.3 the electro-hydraulic circuit of the existing configuration made in FESTO FluidSim software for simulation.

- When L1, C2 & C4 becomes active DCV 1 shifts to position (I) and pump A & B delivers to both the feed cylinders simultaneously and extends to F2 & F5.
- When F2 & F5 gets active DCV 5 & DCV 6 shifts to position (II) and flow gets controlled to 2.99 % and extends to F3 & F6.

B. *Drawbacks:*

- The clamping operation is not synchronized due to unequal distribution of flow, that is due to unequal lengths of hoses, unequal mounting of cylinders, and unequal friction of piston inside the cylinder.
- Idle running of pump A during loading operation and idle running of pump B during clamping operation, leading to decreased cycle efficiency to 50 %, hence requires more time.

VI. IMPROVED HYDRAULIC CIRCUIT

A. *Improvements Made*

- The flow of both pumps A & B which are connected in tandem for synchronizing, is combined during loading operation using a 3/2 DCV which doubles the flow[11]. This increased flow helps the loading cylinder, which has a stroke of 125 mm to operate at higher traverse speeds leading to reduced cycle time and utilizing both pumps hence increasing cycle efficiency.
- To avoid idle running of pump B during clamping operation by allocating individual pumps to each clamping cylinder which also increased the flow and reduced cycle time.

These improved the utilization efficiency upto 100% which meant complete utilization of the pressurized flow from the both pumps individually or combined

B. Working*:*

- Pumps A & B are connected in tandem with a single 2 HP motor and apart from the time of cycle operations, other DCV's are in neutral position and a ladder diagram is constructed with switches and relays[9][10].
- When circuit starts DCV 3 & DCV 7 gets in (I) position and combined flow from both pumps is delivered to extend loading cylinder from L1 to L2.
- When L2 gets active DCV 2 & DCV 4 shifts to position (I) and both pump delivers to both clamping cylinders and extends them from C1 & C3 to C2 & C4 resp.
- When C2 & C4 becomes active DCV 3 & DCV 7 shifts to position (I) & (II) resp. and loading cylinder retracts to L1.
- When L1, C2 & C4 becomes active DCV 1 & DCV 5 shifts to position (I) and pump A & B delivers to both the feed cylinders simultaneously and extends to F2 & F5.

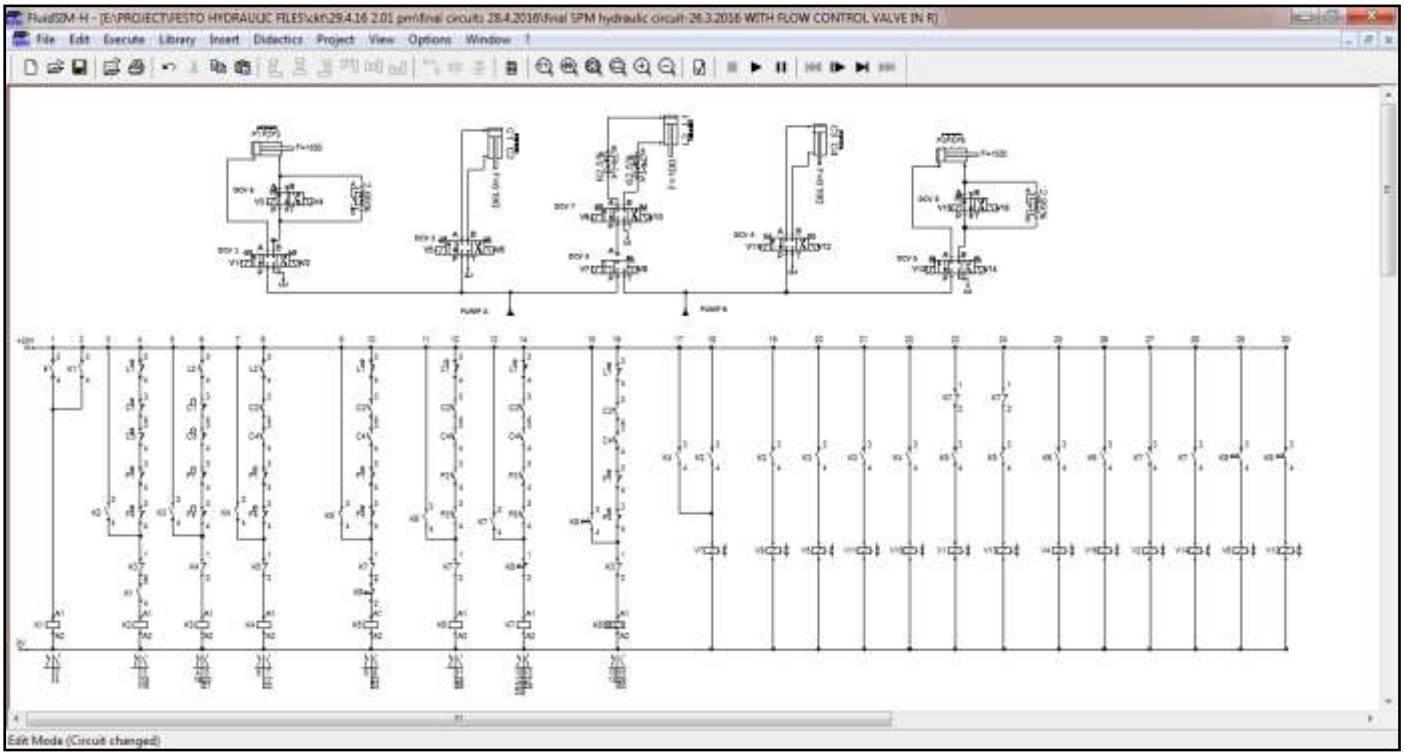

Fig.4 the electro-hydraulic circuit of the improved configuration with the PLC ladder diagram simulated in FESTO FluidSim

- When F2 & F5 gets active DCV 6 & DCV 8 shifts to position (II) and flow gets controlled to 2.99 % and extends to F3 & F6.
- When F3 & F6 becomes active DCV 1 & DCV 5 shifts to position (II) and both feed cylinders retract simultaneously and extends to F1 & F3.
- This actuates the DCV 2 & DCV 4 to position (II) and performs de-clamping which extends cylinders to C1 & C3.
- This initiates DCV 3 & DCV 7 to position (I) and hence unloading and loading of job on V-blocks is done at the same time and the cycle continues.

VII. CALCULATIONS

Required time for all operations is calculated by

$$time = \frac{volume\ \ of\ cylinder}{flow\ rate\ to\ cylinder}\ \text{(s)}$$

Sample time calculation for loading cylinder during extension stroke in improved circuit.

$$time = \frac{\frac{\pi d^2 \times l}{4}}{Q} = \frac{\frac{\pi \times 0.045^2 \times 0.125}{4}}{\frac{5\times 10^{-3}}{60}} = 1.8857\ \text{(s)}$$

Other calculations are tabulated in table.1

		existing ckt		improved ckt	
operation	stroke length (mm)	flow (lpm)	time (s)	flow (lpm)	time (s)
loading ext.	125	4	2.3571	5	1.8857
clamping ext.	30	2	1.1314	4	0.5657
loading ret.	125	4	1.4364	5	1.1491
feed idle ext.	96	4	1.8103	4	1.8103
feed working ext.	4	0.12	2.5017	0.12	2.5017
feed idle ret.	100	4	1.1491	4	1.1491
clamping ret.	30	2	0.6895	4	0.3447
Total			11.075		9.4063

Table.1 The comparison of sequence of operations of the existing machine vs. improved machine, their cylinder strokes, flow pumped to the cylinder and time distribution in seconds.

A. No of products/hr vs time

$$\text{No of products} = \frac{\text{seconds in specified time}}{\textit{cycle time of resp. circuit}}$$

Forexisting circuit

$$\text{No} = \frac{60 \times 60}{11.075} = 324.91 \approx 324 \; products$$

For improved circuit

$$\text{Ni} = \frac{60 \times 60}{9.4063} = 382.73 \approx 382 \; products$$

Increased productivity = 382-324 = 58 products

B. Profit gain

Installing the SPM for chamfering purpose over the manual methods yielded the company with profit of Rs 2 over every chamfered component.

$$Pe = \left(\frac{\frac{sec}{day} \times 24 \; days}{time \; for \; 1 \; cycle} \right) \times profit/product$$

Profit for existing circuit

$$Pe = \left(\frac{3600 \times 8 \times 24}{11.075} \right) \times 2 = \text{Rs}1{,}24{,}765.3$$

Profit for improved circuit

$$Pe = \left(\frac{3600 \times 8 \times 24}{9.4063} \right) \times 2 = \text{Rs}1{,}46{,}970.0$$

Profit gain = 1,46,970.0 -1,24,765.3 = Rs 22,204.68

C. Energy consumption/day

The Machine uses two 1 HP and one 2 HP motor so energy consumption is given by,

$$\text{Energy} = \text{Power} \times \frac{\text{time}}{\text{day}} \quad (kWhr)$$

For existing circuit

$$\text{Energy} = \frac{4 \times 0.745 \times 11.075 \times 325 \times 8}{3600}$$

$$\text{Energy} = 23.8 \quad (kWhr)$$

For improved circuit

$$\text{Energy} = \frac{4 \times 0.745 \times 9.4063 \times 325 \times 8}{3600}$$

$$\text{Energy} = 20.2 \quad (kWhr)$$

Saved energy = 23.8 – 20.2 = 3.6 kWhr

VIII. Results And Discussions

A. The reduction in cycle time using improved electro-hydraulic circuit lead to improved productivity. The results for increased number of products against time is shown in fig.5, it is evident that no. of products chamfered per unit time compared to existing circuit increases from 324 to 382 products.

B. The increased productivity of the system has yielded more profit in one month. It can be seen from the fig.6, that implementing the improved circuit into the machine gives more profit up to Rs 22,000 per month, which also paybacks the extra initial investment required into the improved circuit in forms of DCV's and hoses.

C. The increased cycle efficiency of the electro-hydraulic circuit leads to less energy consumption per day in kWhr when keeping no. of products same. This result is evident from the fig.7 that employing improved circuit in the machine leads to reduced energy consumption by 3.6 kWhr for same no. of products chamfered.

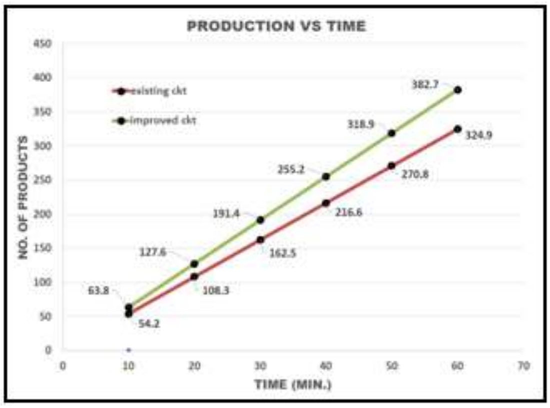

Fig.5 the linear graph of no. of products vs. time compared with the existing and improved circuit.

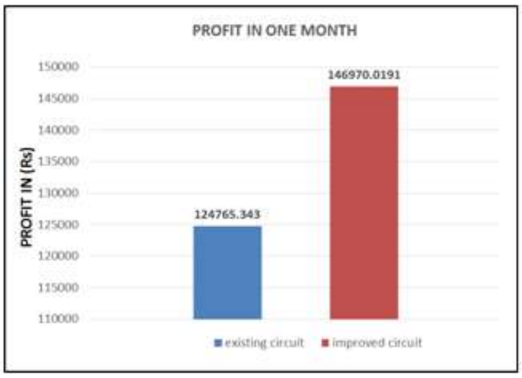

Fig.6 the linear graph of Profit in Rs per day compared with the existing and improved circuit showing more profit in later one.

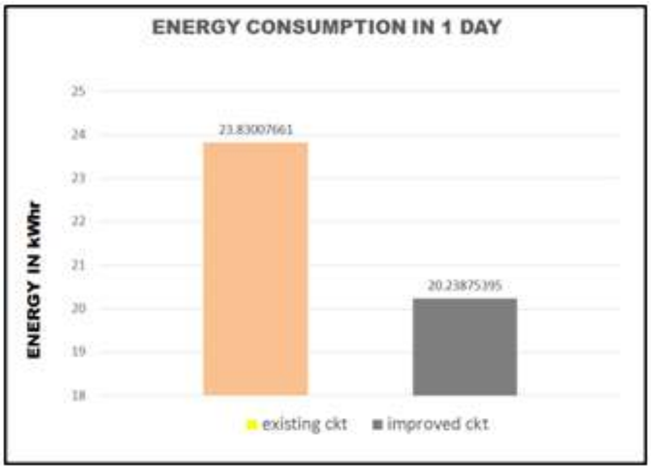

Fig.7 The bar graph of energy consumption in kWhr describes that employing improved circuit reduces energy consumption per day for existing circuit by 3.6 kWhr for same no. of chamfered products.

IX. CONCLUSION

The study performed above allowed us to get acquainted to the importance of synchronization and utilization efficiency in the hydraulic circuits. The validation of the improvements is done by making electro-hydraulic circuits and with help of PLC ladder diagram for simulation in FESTO FluidSim which also verified that improved configuration requires less time for cycle completion. The improvements in the circuit lead to decrease in cycle time, increase in no. of products chamfered per unit time eventually increase in productivity. It also improved the profit for same period of operation time. The improved cycle time also reduced the energy consumption of the machine for same no. of products chamfered. These all results converge that using synchronized operations improves the performance of hydraulic machines.

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