Automatic Tool Change Control System for Computerized Numerical Control Machines

Hla Myo Tun and Myat Su Nwe

***Abstract* – The research paper highlights on tool change control system for computer numerical control (CNC) machine. Various types of actuators are used to get the entailed characteristics and response of the control equipments. Due to the characteristics of time-varying parameters, load disturbances and motor nonlinear, it is difficult to model for the tool change control system precisely. They are robust, reliable and durable. This paper launches the control of CNC tool turret control system based on the hydraulic control circuit. The controller is applied to control the hydraulic system and gained better control performance. And then, the principles of hydraulic mechanisms are articulated with their feedback components which are applied in CNC machines. The CNC system generates the instructions for position and velocity control based on the part program and respective actuators are controlled based on the instructions generated. This paper expresses the design and detail analysis of hydraulic motor based tool change systems in CNC machines. The simulation model is developed by MATLAB GUI. The simulation results pointed out the accurate control responses for automatic tool change control system based on numerical techniques.**

***Index Terms* – Automatic Tool Change System, MATLAB, Graphical User Interface, Software Development, CNC, Industrial Automation**

I. INTRODUCTION

CNC machines comprise machine tools that have a mechanical component and a numerical control system that is an electrical component. The machine tool is called “mother machine” in the sense that it is a machine that makes machines. In particular, as machine tools have advanced from manual machine tools to Numerical Control (NC) machines, these have become perfect in the role of mother machines with the improvement of accuracy and machining speed. NC machine tools can be classified as “cutting machines” and “non-cutting machines”[1-3]. A cutting machine means a machine that performs a removal process to make a finished part; milling machines, turning machines and EDM machines being good examples. Non-cutting machine tools change the shape of the blank material by applying force. Press machines are good examples. In addition, robot systems for welding, cutting, and painting can be included in a broad sense. Hydraulic control system plays an important role in the high power application such as lift, press, buffo, CNC lathe turret and in the CNC milling machine control. The hydraulic system include the prime mover, pump, flow control or restriction valve, actuator and the actuating mechanism. The hydraulic control system controls the immediate element (valves) to control the interest process. Hydraulic system similar the operation likes the pneumatic control system but the pneumatic control is used in the light loads control when the hydraulic system is used for the high loads control. A hydraulic (fluid) power system uses either liquid or gas to perform desired tasks. Operation of both the liquid systems (hydraulic systems) and the gas systems (pneumatic systems) is based on the same principles. A fluid power system typically consists of a hydraulic pump, a line relief valve, a proportional direction control valve, and an actuator. Fluid power systems are widely used on aerospace, industrial, and mobile equipment because of their remarkable advantages over other control systems. The major advantages include high power-to-weight ratio, capability of being stalled, reversed, or operated intermittently, capability of fast response and acceleration, and reliable operation and long service life[4]. Rafal Golebski has presented the parametric programming of CNC machine tools [5]. After building a parametric program, the user could create the new dialogue window to enable the efficient management of the program and, using relevant program structures, to reduce the likelihood of making errors for tool change control system. M. Mori also discussed on the remote monitoring and maintenance system for CNC machine tools [6]. A system to remotely monitor an operation status of machine tools has been developed for customer productivity efficiency.

The rest of paper is organized as follows. Section II describes the operation of all tools in CNC lathe machine. Section III mentions the transfer functions of tool turret control system. Section IV presents the implementation of the operation of tool changer controller. Section V discusses on simulation results.

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II. OPERATION OF ALL TOOLS IN CNC LATHE MACHINE

There are normally ten machining tool for the machining operations: namely cutting tool, facing tool, roughing tool, finishing tool, point marking tool, drilling tool, boring tool, two threading tool (external and internal) and reaming tool. The operations of each of these tools are explained below briefly;

- The cutting tool: The cutting tool is for cutting unnecessary metal strip on the CNC lathe. The cutting tool is a long strip hardened stainless steel or carbide tip material harder than the metal.
- The facing tool: The facing tool is used for facing the rough iron metal strip. The metal strips in origin are not good in their facing smoothness. So that to achieve the intended measurement of the work piece the metal strip is faced first when machined.

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- The roughing tool: The roughing tool is used for rough turning the work piece the rough turning tool is usually more cutting angle and less clearance angle than the finishing tool, so it is good to fed the work thicker.
- The finishing tool: The finishing tool is used for finishing the work pieces. Unlike the roughing tool, the finishing tool generally has less cutting angle and more clearance angle. So it has the good capability to produced good surface finish.
- The point making tool: This tool is used for producing the drill center point at the intended position on the work piece. This tool is always used before the drilling process is begun.
- The drilling tool: The drilling tool is used for drilling holes on the work. Then drilling tool is used as a pre tool for the boring process and internal threading operation. The drilling tool may be any diameter depending on the requirement. But the hole with large diameter cannot be drilled directly, in this situation two drills with unequal diameter is used to drill.
- Boring tool: This tool is used when the hole larger than 1 ¼ diameter on the work piece. The boring tool is like with hook in shape.
- Threading tool: There are two threading tools namely: internal threading tool and external threading tool. The internal threading tool is used for making threads in nut and the external threading tool is used for making threads on the bolt.

Reaming tool: The reaming tool is used for reaming the drilled holes. The reaming operation is the process of smoothing the drilled surface which has small and tiny metal strips which cause many problems in components where the friction and wear is the problems [7].

III. TRANSFER FUNCTIONS OF TOOL TURRET CONTROL SYSTEM

Based on the related works on tools control system, the proposed system of CNC tool turret control system based on the hydraulic control circuit is superior to existing systems. The mathematical model for standard transfer system was come from the building block of hydraulic control system. The tool turret control circuit of the CNC tool changer is shown in Figure 1. Motors and cylinder can't operate at the same time.

Cylinder can work when changing tools. After changing tools, cylinder is set to be clamped. Therefore, the control circuit is divided into two parts. The portion with cylinder is defined by hydraulic cylinder part. The second portion with motor is defined motor part. The tool turret control circuit of the CNC tool changer consists of a double acting cylinder, vane type hydraulic motor, 4/2 ways directional control valve and 4/3 ways directional control valve. The 4/2 ways directional control valve is used to control clamp and unclamp condition. The 4/3 ways directional control valve is used to control clockwise and counter clockwise motor direction. The position sensors are widely used to show odd and even numbers of tool changers and to show whether the cylinder is set to be clamped or unclamped. Close loop control system is clearly used to control speed of hydraulic motor and displacement of cylinder piston. Therefore each portion has its own transfer function. These transfer function are derived firstly before modeling and simulating the control system of tool turret control circuit.

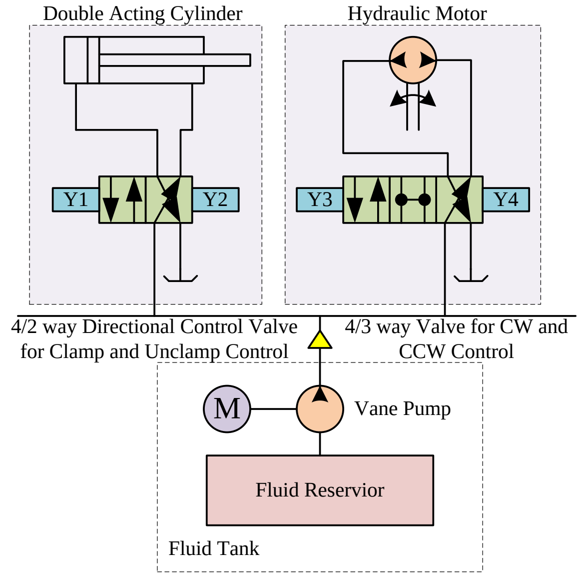

Fig. 1 Two Paths in Tool Turret Control Circuit

For cylinder part, the close loop control transfer function is:

$$G(s)H(s)=\frac{K}{s\left[1+\frac{2\zeta_1 s}{\omega_{n,1}}+\frac{s^2}{\omega_{n,1}}\right]} \qquad (1)$$

where, $G_1(s)$ = cylinder and valve gain

$H(s)$ = feedback gain

ζ_1 = dumping ratio for path 1

K = linear controller = 3

$$G_1(s)H(s)=\frac{3}{s\left[1+\frac{2\times 0.039s}{4.69}+\frac{s^2}{4.69}\right]}$$

$$G_1(s)H(s)=\frac{3}{0.0483s^3+0.01575s^2+s} \qquad (2)$$

The SIMULINK model is designed in MATLAB as shown in Figure 2. The value of gain is available. By simulating the system SIMULINK model with variable gain values it can be seen that the gain value 35 is the best condition. The step response curve for hydraulic cylinder part is shown in Figure 3. It can be seen that it has a peak at the first operating time due to the step response and it gradually becomes stable. So, the cylinder can clamp or unclamp fittingly while using tool turret.

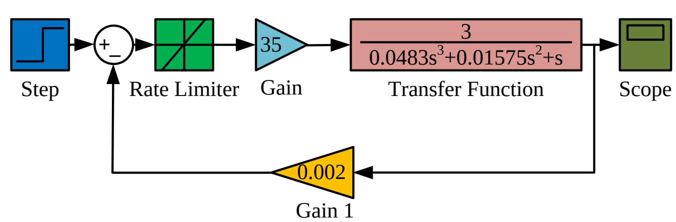

Fig. 2 SIMULINK Model for Hydraulic Cylinder Part

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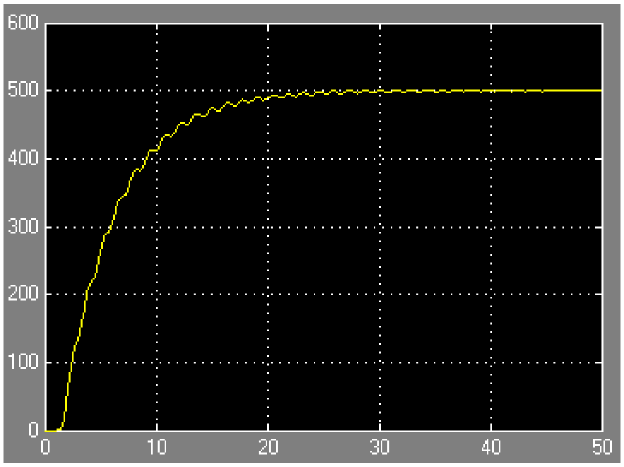

Fig. 3 Step Response for Cylinder under Position Control

The transfer function of the hydraulic motor is:

$$G_2(s)H(s)=\frac{K_{\omega}\sqrt{1-\overline{P}_1}}{T_1(s)+\frac{2R_V}{L_{m,2}}T_2(s)} \qquad (3)$$

Where, $G_2(s)$ = motor gain

$H(s)$ = feedback gain

$T_1(s)$ = lump resistance $=(1+\frac{R}{R_V})s$

$T_2(s)$ = lump resistance = 1

R = 1.76 motor's vane resistance

Thus transfer function of hydraulic motor,

$$G_2(s)H(s)=\frac{1.722}{1.195s+60}$$

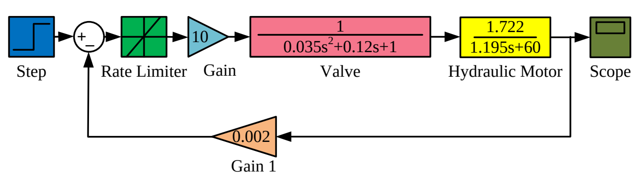

Fig. 4 SIMULINK Model of Hydraulic Motor Portion

The SIMULINK model of path 2 is provided with MATLAB as shown in Figure 4. The simulation result for hydraulic motor part control system is shown in Figure 5. In this result, it has high overshoot between time 1 and 3. Then the system approaches to the stability state about t 4 seconds.

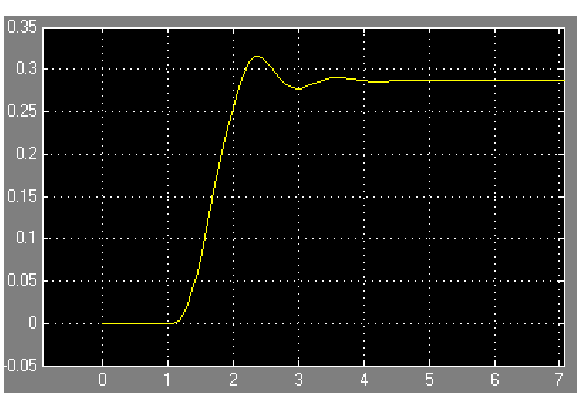

Fig. 5 Simulation Result of Hydraulic Motor for Step Input

A. Operation of the CNC Tool Changer

At first, the tool turret is clamped at the tool position number 1. When the user changes the required tool position, the turret clamp cylinder must be unclamped to rotate the tool changer. After this, the turret controller checks the present turret tool position. If it is not at the tool position number 1, the controller will reverse the hydraulic motor until it reaches the tool position number 1. When the present tool is position number 1 the turret tool controller will rotate clockwise or counter clockwise to reach to the request tool position. The tool changer controller save the current tool position and performed action. Whenever the tool change is active it will check the tool position to know where the tool is located and to manipulate how much amount must be rotate the tool turret [8-9].

The rotation of the tool changer is controlled by the 4/2 ways valve and 4/3 ways valve. The 4/3 way valve control the operation of the hydraulic motor and the 4/2 ways valve control the operation of the hydraulic cylinder clamp or unclamp. The valves are controlled via the solenoid operated on the DC 24 V power supply. Four solenoids are used to control the operation of the forward and reversed rotation of the hydraulic motor and clamp and unclamp operation of the hydraulic cylinder.

According to the Figure 1 the solenoid Y1 is responsible for controlling the cylinder to retract, Y2 is for extending cylinder. The solenoid Y3 and Y4 assembled on the 4/3 way valve. If both solenoids (Y3 and Y4) are not active, the valve is in absolute position; the motor will stop at this position. When the solenoid Y3 active, the motor will rotate forward and if Y4 is active the motor will reversed. But both the solenoid Y3 and Y4 must be de-energized to stop the motor. The tool changer controller accept the command from the main host computer and provided the required sequence to the tool turret control solenoid Y1, Y2, Y3 and Y4. The tool turret is initially located at the tool position number 1. When the user want to rotate from tool number 1 to tool number 2 or 3 or 4, the turret will rotate clockwise direction and it will rotate counter clockwise for changing tool position number 5 to number 8.

B. Connection of Tool Changer Solenoid to I/O Module

The turret unclamp sensor of the tool turret is connected to I/O Card input number 1 as shown in Figure 6. It is used for clamping or unclamping the tool holder disc. The counting sensor is connected to I/O Card input number 2. It is also used for counting tool number. The turret origin sensor is connected to I/O Card input number 3. It is used for checking the position of tool number 1. The indexing sensor of the tool turret is connected to I/O Card input number 4. It is used for checking tool position.

I/O Card output number 1 is connected to the turret clamp solenoid 2/3 way valve. It controls to the turret clamp solenoid signal. I/O Card output number 2 is connected to the unclamp solenoid. It controls turret unclamp solenoid signal. I/O output number 3 is connected to hydraulic motor clockwise solenoid. It controls to rotate the tool turret with clockwise direction. I/O output number 4 is connected to

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hydraulic motor clockwise solenoid for output of the turret motor counter clockwise signal.

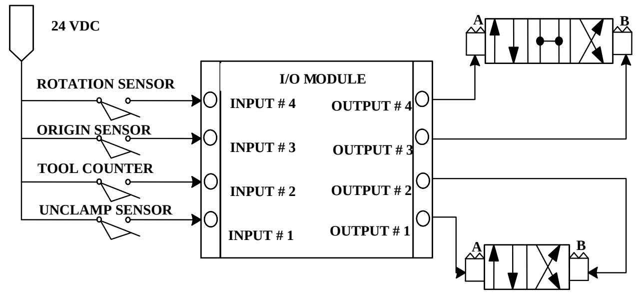

Fig. 6 Interfacing Tool Sensor and Solenoid to I/O Module

IV. IMPLEMENTATION OF THE OPERATION OF TOOL CHANGER CONTROLLER

The flow chart of the operation of tool changer controller is shown in the Figure 7. It is the actual operation sequence of the CNC tool changer controller [10-12].

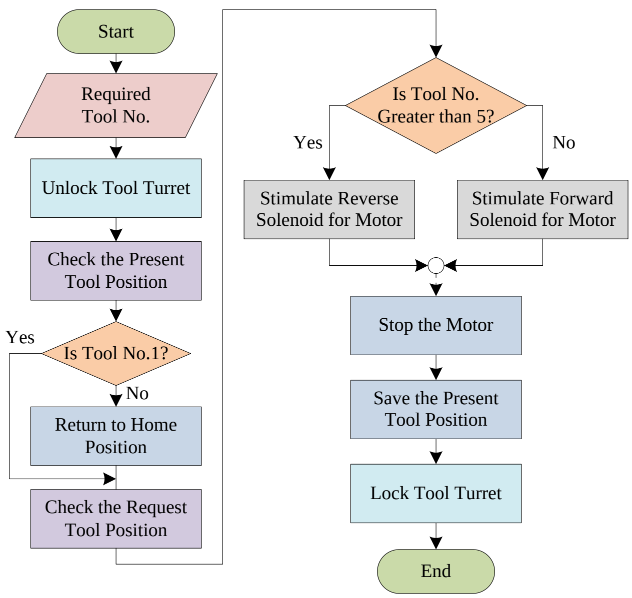

Fig. 7 Flowchart of Operation of Tool Changer Controller

Initially, the requested tool number is accepted. Then unlock the turret pin. Then the tool change controller detects the current tool number. If the current tool number is not 1, then the controller will reversed the tool changer's hydraulic motor to tool position number 1.

After moving to the original position number 1 checks the requested tool position to determine the direction of rotation. The motor will be rotated to reverse direction for the tool number 5 to 8 and forward direction for the tool number 2 to 4. After moving to the requested position, the tool changer controller relocks the turret lock pin, for rigidity in machining operations [13-16].

V. SIMULATION RESULTS

According to the software implementation for tools change control system with the help of MATLAB GUI, the desired tool position could easily find and the desired tools could be caught by the tool holders in CNC machine. When the program starts, the user has to enter the requested tool number at the first edit text box. The current tool number shows the default number on at the current tool edit text box. Other text areas are blank and the upper plot axis is also empty. The tool position display box shows the default tool position which is one.

A. *Tool Change Sequence for Changing Tool No.1 to Tool No.3*

At the default position, the current tool number is one. So the user wants to change tool position directly, after pressing the "TOOL CHANGE" button. The tool changer needs 2.8 seconds to move 45 degree because the speed of hydraulic motor is nearly 0.28 rad/sec or in the other word 16 degree/sec. For changing the tool number one to tool number three, the operating angle is needed 90 degree and the required time is 6 seconds. The direction will be clockwise. Figure 8 shows the inputting the desired tool number is 3. In this situation, the current tool is 1 which is the default position. The tool position display box is shown at the lower right corner of the simulation GUI. The turret moves to desired position directly. The message "Now the tool changer moves to desire position" is displayed and operation time 6 seconds and operation angle 90 degree are also shown in Figure 9.

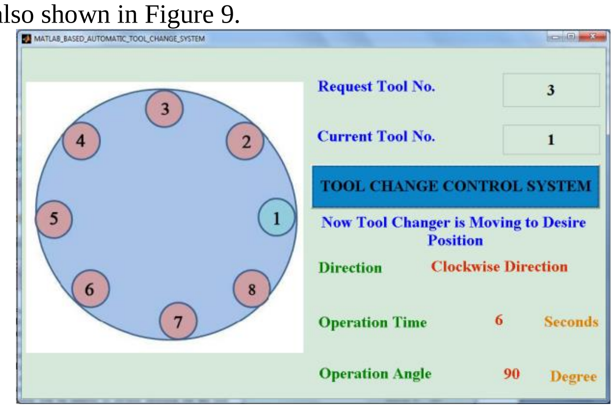

Fig. 8 Screen Shot of Operating to Desire Tool Number 3

Figure 9 shows the result of complete changing condition and the message "Tool is ready" is displayed in red color. So it shows that the current tool number is also 3 and the tool position display box is also displayed the tool number 3.

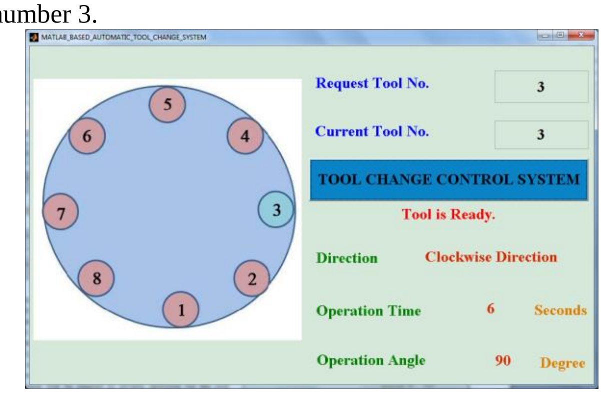

Fig. 9 Tool No.3 is ready for the Machining Operation

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B. *Tool Change Sequence for Changing Tool No.1 to Tool No.5*

For changing the tool number one to tool number five, the operating angle is needed 180 degree and the required time is 12 seconds. The direction will be counterclockwise. Figure 10 shows the inputting the desired tool number is 5. In this situation, the current tool is 1 which is the default position.

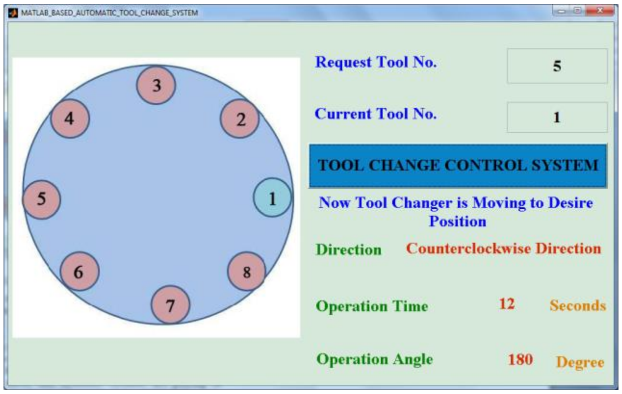

Fig. 10 Screen Shot of Operating to Desire Tool Number 5

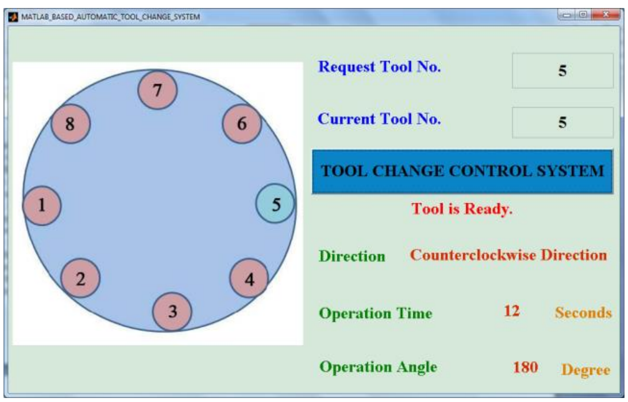

Fig. 11 Tool No.5 is ready for the Machining Operation

The tool position display box is shown at the lower right corner of the simulation GUI. The turret moves to desired position directly. The message "Now the tool changer moves to desire position" is displayed and operation time 12 seconds and operation angle 180 degree are also shown in Figure 11. Figure 11 shows the result of complete changing condition and the message "Tool is ready" is displayed in red color. So it shows that the current tool number is also 5 and the tool position display box is also displayed the tool number 5.

VI. COMPARISON WITH EXPERIMENTAL TEST

The developed tools change control system has been installed in the personnel computer for interfacing with real hardware system. The control panel for user to control the desired tool position with GUI window in the computer of CNC lathe machine. After that the command for desired tool position has been gave by the keyboard, the tool has changed the desired position from the existing position through the home position of tool number 1. The tools could change with clockwise and counter-clockwise directions. The statistic table for experimental test with the proposed system is shown in Table I. Table I shows the performance accuracy of the experimental test is 100% because of the accurate control system for tool changing system.

TABLE. I. STATISTIC TABLE FOR EXPERIMENTAL TEST WITH THE PROPOSED SYSTEM

Analysis	Present Tool Position	Desired Tool Position	Accuracy
1	1	3	100%
2	3	5	100%
3	5	8	100%
4	8	2	100%
5	2	7	100%
6	7	6	100%
7	6	4	100%
8	4	1	100%

VII. CONCLUSION

Automatic tool changer control systems are used in the CNC machine to control the movement of tool turret in the machining processes for the purposes of the intended operations in this paper. The system uses the hydraulic actuator for controlling the turret movement. The relay and solenoid are used as the immediate actuator for activating the solenoid to move the hydraulic valve. In the tool change system, the hydraulic motor and hydraulic cylinder are playing as important role. For their operations, the SIMULINK models are tested by varying system parameters and the response of the transfer functions is checked to achieve the stable state. The MATLAB GUI interface is also constructed for the tool changer simulation by conveying the response of SIMULINK model. The duration of the steady state condition is taken to the GUI and the response plot is drawn at the user interface window. The hydraulic motor speed is achieved 2.8 rad/sec or 16 degree/sec from the SIMULINK model. In the GUI, the numbers of tools in the turret is defined to eight which is equivalent to 360 degree. Therefore, the tool change step size is calculated as 45 degree per tool. The simulation results have been confirmed the accuracy of the tools position on the holder at exact time. The experimental test with the software analysis on tool change control system meets the performance of the system in real world.

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