Design and Development of a Novel CNC Controller for Improving Machining Speed

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Received: May 2015 Revised: September 2015 Accepted: September 2015

ABSTRACT:
One of the devices that are widely used in industries in recent years is computer numerical control (CNC) machinery. Many CNC controllers has been designed and employed in CNC machinery during recent years but all of them has some limitations and disadvantages due to their design and used methods. The purpose of this research is designing and modifying a novel multi axis automatic controller (MAAC) for using in CNC machinery which has more advantages compared with used controllers and has an optimized performance. By using MAAC in CNC machinery we can achieve more machining speed and repeatability in a shorter time in implementation of industrial process.

KEYWORDS: CNC Controller, Machining Speed, Operation Time.

1. INTRODUCTION

CNC provides an automatic control of the machine tool by the computer that represent an advanced control system that directs a variety of machine tools, robots and transmission lines in factories[1]. In a CNC machine all data and information are processed by a computer, then the processors convert data to electrical pulses and transmit them to axis's driving motors [2]. The main role of controller in a CNC machine is receiving the position signals from the computer and makes them into mechanical movement in definite axis by the machine's motor and reaching the requested position. Controller is made up of different parts, each part makes machine to move a certain amount in the defined axis [3]. After receiving and interpreting data from NC software, movement command will be transmitted to the motor drivers of each motor and moves the definite parts in the designed routs. USB or printer port will provide the connection [4]. CNC controller parts with synchronized and integrated function will receive the transmitted signal and interpret it into a controlled movement of the machine's motors in the right direction by the right amount [5]. In 2009 a theoretical controller model with the capability of controlling and driving servomotor was designed and the accuracy of the system was confirmed by simulated experimental data [6], in another study an open architecture CNC controller was designed and developed to restore old CNC machines. This motion control system could retrofit old CNC machines [7] and also a reconfigurable hardware controller based on FPGA was designed in order to be used in CNC machines and the experimental results shows the feasibility of the proposed controller [8].

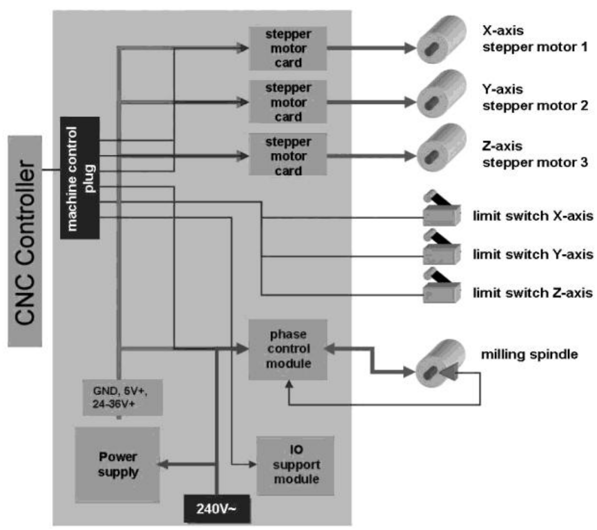

Fig. 1. The CNC controller functional block diagram

Although all the electronic parts of a CNC machine are already built and fully functional, the CNC machine is still built to modify the results of the machine, in 2010 a small typed prototype CNC machine using stepper motor was designed and built with the capability of communication via USB port [9]. In 2012 an embedded numerical control system based on heterogeneous and field bus has been designed and built. The controller has the ability to control and drive servomotors and the experimental results show that system has ability and scalability to use in CNC machinery in a real time control and processing accuracy [10], also a 3 axis CNC machine model based on programmable logic controller was designed and built, CNC model movement was provided by stepper motors and the animated model of the device was designed. This research describes the laboratory task focused on circuit board holes drilling using built CNC [11]. In this year a mini CNC machine is designed and used in order to decrease axial tracking error, contour error and the computational time required for online optimization with Adaptive Feed Rate and predictive control method [12]. Some of the limitations and technical difficulties exist in CNC machines are: the design of the controller which is generally for two main motors, stepper and servomotor driving which have limitations for output power and motor torque output because of their internal design and magnetic flux induction methods, so the burden on the output motor axis have limitations that cause the mechanical part of the machine having a limited movement range. This makes mass production of these CNC motor types not functional. The precision of CNC machines with stepper and servomotor are based on their motor's precision. This means that the motor is the source of CNC precision and machining speed. In open loop systems, the operator circuit of the machine is working with the initiator driver pulse with the motor compartment and there is no feedback, the operator circuit continues to send pulses even if there is a disturbance, this makes the system less functional with less precision and the whole system will fail because of that. Regarding of the design type and the technology of producing of the CNC machines, the machine has limitations in output power in movement axis, so doing vast industrial constructions with high overload is practically impossible. Although the design method and the technology of making CNC machines have influence on the price of these machines, the price is usually high.

This study is conducted to design a modern controller used in CNC machines. This controller is design to reduce the limitations of previous controllers and has the following features: Counter system and power controller circuit is used to enable the CNC machine to connect to most kinds of motors and also hydraulic and pneumatic movement systems. Using the position detector systems and comparators for all the axis, the operation time reduces. This controller makes construction of fully automatic machines with variable sizes possible with multi axis automatic controller (MAAC), increasing the industrial production rates via decreasing operation time (OT), reducing the price of CNC machines and the consuming system power by using novel design.

2. DESIGN AND DEVELOPMENT OF MULTI AXIS AUTOMATIC CONTROLLER

MAAC performs as Decision-making and controller unit in a CNC machine. The number of controllable axis's and tool parts can increase to 12 parts as need in design and manufacturing of MAAC. The first prototype of MAAC has a four channel controller to control a 3-Axis CNC machine. Figure 2 shows the developed MAAC connected to a built mechanical part of a CNC machine. MAAC system consists of the following units:

Data input Unit (DIU): DIU is a middleware between computer and integrated circuits unit. Transmitted data packages from device's computer transferred to DIU via input ports and after buffering sends to main process unit (MPU) and the system's circuit export movement command toward requested point.

MPU: MPU is the center of data processing and system control and also all units are connected via main MPU. Transmitted data packages from computer, are transferred from data DIU to MPU to be processed and designated point from NC software diagnosed.

Input pulse counter unit (IPCU): processed data packages are transferred from MPU to IPCU as pulses and after pulse counting desire point recognized. IPCU has also a display panel which shows the software requested point in real time mode.

Axis position pulse counter unit (APPCU): for each requested movement step a pulse is transmitted from NC software to DIU, in a same way, for each movement step in each axis a pulse is transmitted from movement maintenance and securance unit (MMASU) placed on each axis to APPCU. The number of transmitted pulses from movement MMASU declares the current position of tool in each axis.

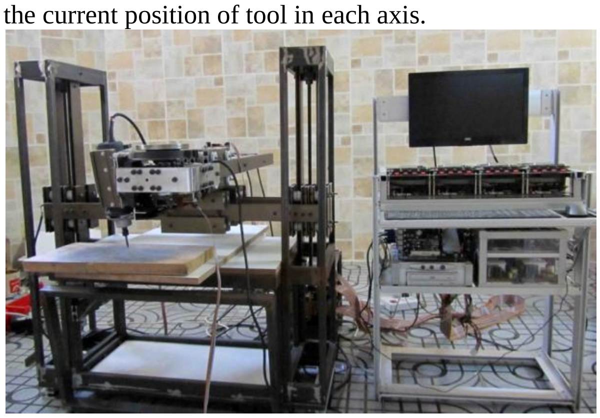

Fig. 2. The developed MAAC connected to a built mechanical part of the CNC machine

Compare and Control unit (CACU): two different data packages entered to CACU: data packages are transmitted from IPCU that determines requested position from NC software in each axis, and data packages are transmitted from APPCU that declares the current position of tool in each axis. CACU compares the requested point with the current position of the tool in each axis and determines the number of movement steps to desire position in each axis and send that to power and command unit (PACU). CACU controls each axis movement and determines the number of movement steps to requested position in a real time mode.
Setting unit (SU): this basic configuration allows operator to change or set all features of controller to optimize the operation performance in a specific operation. Speed, movement steps, accuracy and the other values could be set without changing the NC software values.
Manual control unit (MCU): operator can control the device and move the tool in all available directions in each axis to desire position without taking part of NC software, modify or change the operation during the process in a real time mode.
PACU: incoming transmitted commands from CACU executes in PACU and rotor's rotational direction and motor performance determines via command circuits. There are two different units in a direct connection with PACU, so PACU executes their transmitted commands:
CACU: where the positioning comparison results of requested position from NC software and current position of tool in each axis are determined and transferred to command circuits.
MCU: transmitted commands from MCU are transferred to PACU via MPU and execute directly in a real time mode and take the tool to operator requested position.
Motor position detector unit (MPDU): motor's shaft rotation is the basic element of tool's movement in each axis, rotational movement transforms to linear movement via gearbox and rack and pinions and take the tool to requested position, MPDU recognize the orientation of motor's shaft real time and controls the movement by sending feedback to MPU with an accuracy of 0.1 degrees. In this case controller can prevents any unwanted shaft's rotation or correct it.

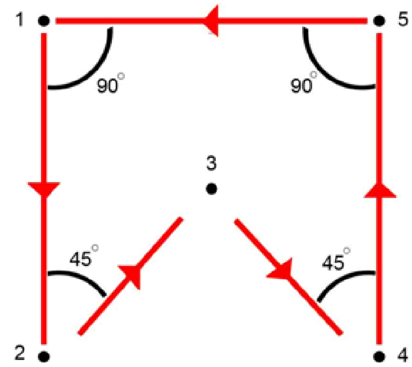

Fig. 3. The designed CAD model for the test

Electronic brake unit (EBU): EBU installed on the motor's location in mechanical part of the device and it has a direct and real time connection with PACU and EBU. EBU blocks the rotor's shaft and does not allow the rotor to rotate in any direction in two cases: when the moving tool reaches to a border and also if any unwanted change going to be happened to shaft's position.
Movement limitation unit (MLU): every CNC machine has a defined range of movement that restricts tool's operation range; MLU determines the dimension limits of device and prevents the tool to get out of these defined limits. MLU has a direct connection with PACU and EBU and if the tool reaches to movement limits MLU stops the movement in desired axis by sending commands to mentioned units.
MMASU: the duty of MMASU is movement changes identification, if any movement happens in each axis MMASU sends a pulse per each movement step to controller so the tool's position is reachable in a real time mode.
After the design and modification of MAAC, it should be compared with the other similar controllers and evaluated, for this purpose MAAC connected to a built mechanical part of a 3 axis CNC machine and the drilling points of a designed CAD model operates for 20 times and the OT on each interval was measured on the manufactured part using a 12-bit timer.
The results will be evaluated in comparison with the results of three similar controllers in same operation. The designed CAD model that operates in the test shows in figure 3, as shown there are 4 drilling points in the corners of a 20 centimeter square and a drilling point in the center of the square, the holes diameter is 1 millimeter.

Table 1. LEAD SHINEST-LS-13 stepper motor specifications

Lead Shine ST-LS-13 Stepper Motor	
Technical code	57HS13
Phase	2
# of Leads	8
Step Angle	1.8 (deg/step)

Holding Torque	1.8 (Nm)
Current/phase	4 (A)
Ambient Temperature	-10 to +50 (C)
Weight	1 (kg)
Holding Torque	1.8 (Nm)
Insulation Resistance	100mΩ min. 500 VDC

Mach3 Motion Card AKZ250 controller, Smooth Stepper WRAP9 tech controller and MC3660 Lead Shine 3axis driver controller which have a wide usage in CNC machinery manufacturing are used in this test. Two kinds of motors are used in this test for evaluating MAAC, LEAD SHINE ST-LS-13 stepper motor with specification in table [1] and ZHENG Gearbox DC motor with specification in table [2].

Table 2. ZHENG Gearbox DC motor specifications

ZHENG GEARBOX DC MOTOR	
Rated Voltage	12 (V)
Torque	9 (Kg.cm)
Maximum Torque	11.6 (kg.cm)
Speed	160 (r/min)
Gear Ratio	59
Shaft Diameter	6 (mm)
Gearbox Diameter	39.75 (mm)
Unload Current	2.1

In the first phase of the experiment all controllers are connected to the mechanical part of 3 axis CNC machine with Lead Shine ST-LS-13 stepper motors and a similar test is operated for 20 times, in the second phase of the experiment only MAAC is connected to the mechanical part of CNC machine with Zheng Gearbox DC motor and similar test is operated for 20 times. Statistical analysis was done with descriptive tests and graphs using MATLAB R2013a (version 8.1.0.604, license number: 724504).

3. RESULT AND DISCUSSION

In this stage, we evaluated and compared the results of 20 times testing of the designed controller with the other three controllers. In the table 3, mean operation time (MOT) for each controller by using stepper motor is summarized. As it is concluded from table 3, the Smooth controller has the minimum MOT during the operation and the Smooth controller MOT is 3.956 seconds.

Table 3. Mean Operation Time (MOT) for three tested controller

Controller	Mx3660	Smooth	Mach3
MOT (seconds)	3.957	3.956	3.958

In the table 4, MOT for MAAC by using stepper motor and DC motor is summarized. As it is concluded from table 4, MAAC's MOT by using stepper motor is 3.956 seconds, also MAAC's MOT by using DC motor is 3.551 seconds. The measured OT of each controller in the tests can be seen in the figure 4.

Table 4. Mean Operation Time (MOT) for MAAC controller

Controller	MAAC with Stepper motor	MAAC with DC motor
MOT (seconds)	3.956	3.551

We observe that the MAAC with a stepper motor has the minimal MOT comparing all the controllers with the stepper motor. However, the MAAC with DC motor has the minimal MOT in the tested complex.

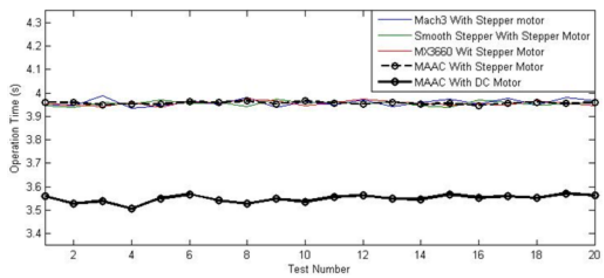

Fig. 4. The measured OT for each controller in tested complex

4. CONCLUSION

In recent years many research have been performed in the field of design, modification and optimization of CNC machines. The designed and built controllers are generally able to control and drive a predetermined particular type of motors but one of the advantages of MAAC is the ability of the device to control and drive all kinds of motor that uses in CNC machinery such as stepper, servo and DC motors. Also by using APPCU and CACU in MAAC, Hydraulic and pneumatic linear movement systems can be driven and used in the manufacturing of CNC machinery. By using of designed CACU, MPDU and EBU in MAAC, the MOT in the same operation reduces in comparison with the other examined controllers. The MOT of MAAC using stepper motor in the test reduces to 3.956 seconds and the MOT of MAAC using DC motor in the test reduces to 3.551 seconds which is less than the other three controllers in the test. So this study shows that DC motor has a better performance in machining speed in comparison with stepper motors in a same machine with similar specifications.

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