A NOVEL TECHNIQUE FOR CONTROLLING CNC SYSTEMS BY USING ARDUINO

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ABSTRACT

This paper improves the performance of the existing micro Computer Numerical Control (CNC) machines. In this paper, (1) a single axis (vertical axis) CNC machine and (2) a two-axis CNC machine (X-direction and Y-direction) are re-fabricated to improve their robustness and reproducibility. The prototype CNC Machine tool is procured from the manufacturer of CNC Machines for performing the work. The Atmega 2560 microcontroller used in this work is provided with Arduino development board environment for designing the control unit. Three unipolar stepper motors are used for controlling the machine axes. First part contains the work carried out in the design of single axis CNC machine (Z- Axis), and the second part contains the design of a two-axis CNC machine (X-direction and Y-direction). Improvised Stepper motor drivers were designed to improve the robustness and factors related to power dissipation. The traversing time of the drill bit of the drilling machine is considerably reduced by appropriately re-designing to reduce its response time. Sophistication of the twoaxes machine was done to facilitate working in program mode by providing to the use number of ports in the microcontroller. Using the newly designed stepper motor drivers in this CNC machine, the run time operation in program mode of the machine has been enhanced. While the single axis machine is used to drill holes, the two-axis machine moves a platform on a XY-plane (2-Degrees of Freedom) in different geometric patterns/paths.

Keyword *CNC, Arduino, Microcontroller*

1. INTRODUCTION

Computer Numerical Control (CNC) machine is a programmable machine for doing milling, drilling, cutting and shaping on the metals like stainless steel (SS), mild steel (MS) and aluminium. The simplest definition is as the name implies "a process is controlled by numbers". Numerical Control is a system in which the direct insertions of programmed numerical value, Stored on some form of input medium are automatically read and decoded to cause a corresponding function on the machine tool which it is controlling. While the single axis machine is used to drill holes, the two-axis machine moves a platform on a XY-plane (2-Degrees of Freedom) in different geometric patterns/paths. The work carried out is presented in two parts. First part contains the work carried out in the design of single axis CNC machine.The design specifications of the single axis CNC machine, the approach adopted in implementing the modifications is aimed at improving the system's response time. In the modified design of this CNC machine, it is planned to replace LPC 2148 with Arduino UNO processor board for reasons mentioned elsewhere in this paper. Considering the speed while drilling multiple holes, displacement of the drilling motor along with drilling bit and the time consumed in traversing, is found to play a significant role in the design of CNC machine. This traversing time was reduced by appropriate modification in traversing distance to drill each hole. Second part contains the modification of Hardware and Software in respect of the two-axes CNC machine to solve certain problems encountered in earlier machine. Two-axes CNC machine uses two stepper motors for displacements along X and Y directions. As such, modifications in respect of replacement of stepper motor drivers with newly designed stepper motor drivers are incorporated.

The work can be extended for driving more than two axes also. The Software DDA interpolators are designed for generating the control bits for giving motion to the driver cards Coloured LCD and 4 by 4 matrix

keyboard is also interfaced with the controller. The EIA (Electronic Industries Association) part programming codes (G and M-codes) are implemented in developing the algorithm for linear & circular software interpolators . Graphical user interface software is also developed for making control unit interactive & user friendly. Interpreter is also designed for recognizing various machining commands entered as per the EIA international standard format. It serves as a significant step towards low cost automation in the field of CNC machine tool manufacturing. The paper discusses mainly the design & implementation of machine control unit using Arduino platform

2. DESIGN & DEVELOPMENT OF MACHINE CONTROL UNIT

Control Unit

The Present work includes design & development of software DDA interpolator both linear & circular, G & M codes interpreter (G00, G01, G02, G03, M30), interfacing of graphical LCD (480 by 320 pixels) & 4 by 4 keyboard with Atmega 2560 microcontroller (Arduino development board) & design of driver card for unipolar stepper motors. The matrix keyboard is used to enter commands for controlling the CNC machine tool. The execution effect can be visualized on the graphical LCD. The graphical LCD display programming codes, command menu, real time as well as simulated machining path & real time counters for motion indication. The control unit with Atmega 2560 microcontroller and its interfacing with required peripherals is shown in Figure 1. The Arduino environment is created and all compatible devices are integrated in the designed system.

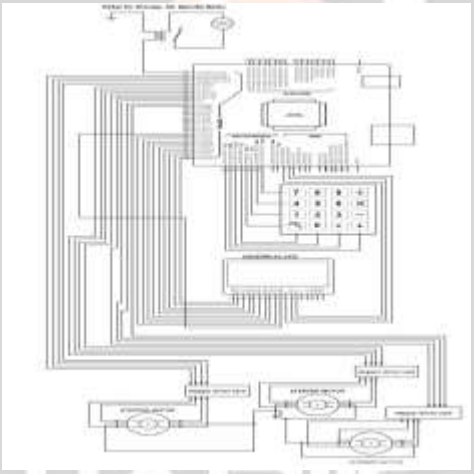

Fig. 1. Machine Control Unit

Interpreter

The interpreter is designed to establish the user interface between operator and machine. The interpreter's role is very important in implementing the command issued by the operator and generating the desired response. The interpreter is designed to show graphically the tool path as the machining takes place in real mode as well as the virtual mode. One special key is defined as HOME key. By entering this key machine tool is brought to its machine Zero position in the XY plane. The tool movement is shown on the graphical LCD by the X-counter and Y-counter for indicating the tool motion in X and Y direction. The counters accurately display tool movement on the machine table up to the resolution of the machine tool, 0.025mm. The Interpreter plays very important role in providing the user friendly interface and interpreting the G & M codes. It is designed to perform as under

Stepper Motor

A stepper motor is a brushless, synchronous electric motor that converts digital pulses in to mechanical shaft rotation. Every revolution of the stepper motor is divided into a discrete number of steps, in many cases 200 steps, and the motor must be sent a separate pulse for each step. The stepper motor can only take one step at a time and each step is the same size. Since each pulse causes the motor to rotate a precise angle, typically 1.8°, the motor's position can be controlled without any feedback mechanism. As the digital pulses increase in frequency, the step movement changes into continuous rotation, with the speed of rotation directly proportional to the frequency of the pulses. Step motors are used every day in both industrial and commercial applications because of their low cost,

high reliability, high torque at low speeds and a simple, rugged construction that operates in almost any environment.

Selection criteria of Stepper Motor

While selecting a stepper motor for a particular application various factors are to be considered. Starting torque (N – m)

- Maximum speed (steps/second)
- Duty cycle
- Required power
- Load inertia
- Speed control
- Reversible motor
- Time to accelerate, decelerate
- Size and weight consideration.

Stepper Motor Operation

DC brushed motors rotate continuously when voltage is applied to their terminals. The stepper motor is known by its important property to convert a train of input pulses (typically square wave pulses) into a precisely defined increment in the shaft position. Each pulse moves the shaft through a fixed angle. Stepper motors effectively have multiple "toothed" electromagnets arranged around a central gear-shaped piece of iron. The electromagnets are energized by an external control circuit, such as a microcontroller. To make the motor shaft turn, first, one electromagnet is given power, which magnetically attracts the gear's teeth. When the gear's teeth are aligned to the first electromagnet, they are slightly offset from the next electromagnet. This means that when the next electromagnet is turned on and the first is turned off, the gear rotates slightly to align with the next one. From there the process is repeated. Each of those rotations is called a "step", with an integer number of steps making a full rotation. In that way, the motor can be turned by a precise angle.

DDA Concept

For interpolating from one co-ordinate to another the DDA concept is incorporated. The DDA concept is highlighted in Figure 2. The software DDA simulates the working of hardware DDA, however the logic is designed in such a way that it would be very simple for the programmer to interact with the controller using programming codes.

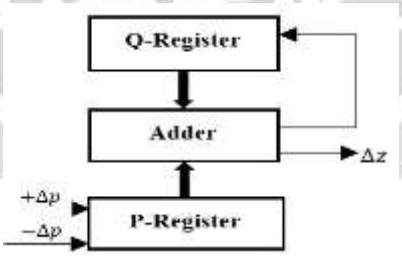

Fig. 2. Digital Differential Analyzer

The DDA as shown in Figure 2, consists of two n-bit registers, P & Q and one binary adder. During each integration the new value of register P is obtained according to Equation 1, in which ΔP is either 0 or 1. The integration is performed according to Equation 2 and is executed with reference to the binary adder which adds the contents of the P & Q register at each iteration. The overflows of the adder are the output increment ΔZ, which are also called control pulses.

$$Pk=Pk\text{-}1 + Pk \qquad (1)$$

$$Qk=Qk-1 +Pk \quad (2)$$

The DDA integrator operates in an iterative mode at a frequency (f) provided by the external clock. The output frequency (fo) of the overflow pulses obtained is proportional to the iteration frequency (f) and the content of register P and inversely proportional to 2n, where n is the size of DDA registers. The number n is also called resolution of the integration process. The control bits generated by the DDA interpolator as explained above, would be used to provide motion to the machine slides in X and Y direction, using unipolar stepper motors. The driver cards are used to provide rotational motion to the motors in steps. Driver card is interfaced directly with the stepper motor on one side & microcontroller on other side. Each control bit actuate stepper motor to rotate by a step of 1.8 or 0.9 degrees in the required direction. The ball screw in turn would rotate by that amount and provides motion to the machine slide by 1 BLU (Basic Length Unit), which is also termed as resolution of the machine tool. The velocity of the slide depends on frequency of generation of control bits by the interpolator.

Unipolar Stepper Motor Driver Card

The Driver card circuit designed for running stepper motor is shown in Figure 3. One of the most significant advantages of a stepper motor is its ability to be controlled in an open loop. The use of stepper motors eliminates the need for establishing feedback loop and the accurate & reliable control can be achieved. Design of the driver card for unipolar stepper motor also becomes relatively easier in comparison to bipolar. For the present work drivers are designed for all the three axes motion. X-Y table is carrying work piece to be machined and it is interpolated, however the Z-axis motion is imparted to the spindle carrying cutting tool. The components used in designing the driver card are BC547 NPN Transistors (4 Nos.), 5K Resistors (4 Nos.), Light Emitting Diodes (4 Nos.) and 2N3055 Power Transistors (4 Nos.).

The driver card control the current required for driving the stepper motor. The power transistor 2N3055 is capable of carrying high current passing through it. The four outputs

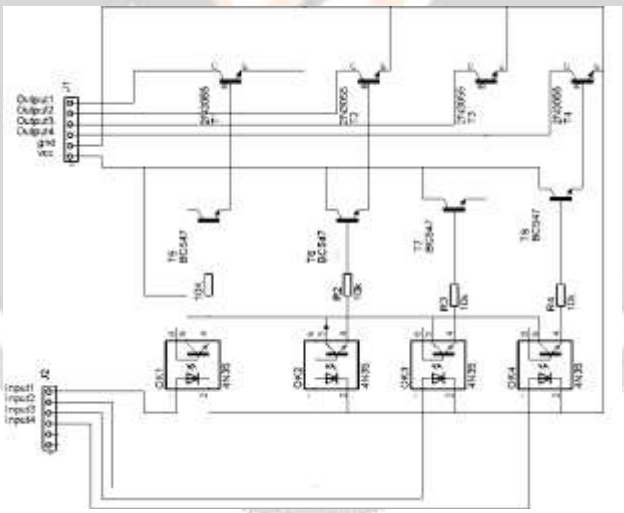

Fig. 3. Driver Card Circuit

from microcontroller are connected to the four BC547 NPN Transistors via 10K Resistors. The BC547 Transistor is used to trigger Power transistor when its input pin becomes high. The emitter of the BC547 is connected to the base of the power transistor. When the base of the power transistor is triggered by the BC547, its operating point goes in the saturation region and allows current to pass through it as it behaves as a closed switch. The motor leads are connected with the power transistor while the emitter of the power transistor is grounded. Thus when the input becomes high its corresponding power transistor enter in to saturation and energize the winding of the stepper motor.

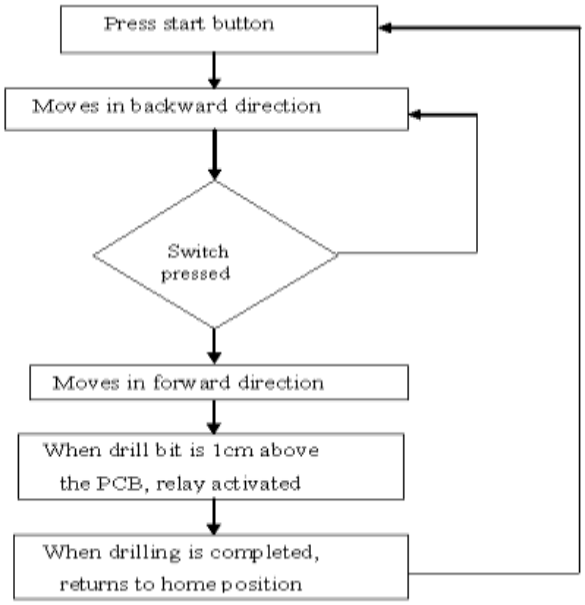

Fig 4. Flow chart for Single axis micro CNC Machine

A DC Motor relies on the facts that like magnet poles repel and unlike magnetic poles attract each other. A coil of wire with a current running through it generates an electromagnetic field aligned with the centre of the coil. By switching the current on or off in a coil its magnetic field can be switched on or off or by switching the direction of the current in the coil the direction of the generated magnetic field can be switched 180°.

Fig 5. Mechanical part of the micro CNC Machine

After re-fabrication of mechanical gadget, the lead screw is connected to the bipolar stepper motor and dual H-bridge driver (L297 and L298) connected with a arduino UNO (AT mega 328p) board. The final single axis micro CNC machine for displacements along linear axis in front view and back view

CONCLUSION

In the current trend of modernization in manufacturing industries, use of CNC machine tool is increasing exponentially. Without its application it is going to become very difficult for the manufacturing industries to grow and survive. In the core of the CNC machine working, the role of DDA interpolator is very significant. The paper focuses mainly on study of DDA and designing the software DDA interpolators (linear and circular). Software DDA interpolator is the simulation of hardware interpolator. This project has definitely touched the core concept of working of CNC machine tool and successfully incorporated interpreter for decoding the EIA machining codes as per the international standard of part programming. The CNC milling machine is procured from CNC machine tool

manufacturer and experiments are carried out for interpolating the machine tool in two dimensions (X and Y). During machining large amount of torque and power is required and therefore AC servo motors are required as actuators. For economizing the work, unipolar stepper motors are selected for driving the X, Y and Z axes & driver cards are designed accordingly. As the stepper motors are having low capacity of load carrying, the machining is demonstrated using engraving tools with light cut using low depth of cut. The machine control unit designed is capable of actuating all types of CNC machine tools with required modifications in hardware & software, as fundamentally the interpolation is the common phenomenon. The project work establishes the possibility of economizing the high cost of automation. The present work would be very encouraging for Training & Research institutes, as the system is open & very transparent for study & research purpose. The electronic control unit is operated with open loop system using unipolar stepper motors fitted on the ball screws of CNC machine tool for performing two dimensional interpolation in XY plane. The linear as well as circular interpolation and graphical simulation on LCD screen are carried out on CNC machine tool. The working of control unit is tested by making actual machining cuts using engraving tool on the CNC machine and the interpolators are found to be working up to the desired level of performance with the resolution of 0.025mm.

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