DESIGN AND IMPLEMENTATION OF MINI SAUDI ARDUINO CNC

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ABSTRACT

In this paper, design and implementation of miniArduino CNC have been developed in the product design specification (PDS) as capstone project. The machine was designed to provide 3-Axis control, allowing for X/Y Axis control and Z Axis plunge. The actual external dimensions of the machine are 500mm x 403mm x 75mm, the maximum work piece size is 400mm x 280mm x 5mm. and net weight is 5 kg.

The programming was done on a G-code microcontroller using Arduino programming. The CNC shield was also used. The signals were sent to the microcontroller and thus accurately controlled, engraved or written on the board. In today's world, this type of machine has many applications in the industry.

KEYWORDS: Mini CNC, Arduino, Design, Simulation

Received: Jun 01, 2020; **Accepted:** Jun 20, 2020; **Published:** Jul 09, 2020; **Paper Id.:** IJMPERDJUN2020254

INTRODUCTION

In order to meet the huge demand of manufacturing complicated components with high accuracy and large quantities, sophisticated technological equipment and machinery have been developed. Production of these components calls for machine tools which can be set up fairly rapidly without much attention. The design and construction of Computer Numerically Controlled (CNC) machines differs greatly from that of conventional machine tools. This difference arises from the requirements of higher performance levels. The CNC machines often utilize several of mechatronics elements that have been developed over years. However, the quality and reliability of these machines depends on some of machine elements and subsystems of the machines. There are some of the important constituents parts and aspects of CNC machines to be considered in their designing, for example Machine structure, Guideways, Feed drives, Spindle and Spindle bearings, Measuring systems, Controls, Software and Operator interface, Gauging, Tool monitoring. The control of a machine tool by means of stored information through the computer is known as Computer Numerically Controlled. The information stored in the computer can be read by automatic means and converted into electrical signals, which operate the electrically controlled servo systems. Electrically controlled servo systems permits the slides of a machine tool to be driven simultaneously and at the appropriate and direction so that complex shapes can be cut, often with a single operation and without the need to reorient the work piece. CNC can be applied to milling machines, lathe machines, grinding machines, boring machines, flame cutters drilling machines etc. [1]

System Model

The key essential characteristics of a Mechatronics engineer are a balance between two skills; Modeling/Analysis skills and Experimentation/Hardware implementation skills. Modeling, simulation, analysis and evaluation processes in Mechatronics system design consists of two levels; (a) Subsystems modeling levels, (b) Overall system

Modeling levels, with various sub-system models interacting similar to real situation. All engineering subsystems should be included in overall system model: mechanical, electrical and electronic components, a model is a simplified representation of a system at some particular point in time or space intended to promote understanding of the real system. Mathematical Modeling: a process of representing the behavior of a real system by a collection of mathematical equations and/or logic. Simulation is the process of solving the model i.e. solving mathematical equations and/or logic equations; simulation generally refers to a computerized version of the model which is run over time to study the implications of the defined interactions. The Permanent Magnet Direct Current PMDC, motor is an example of electromechanical systems with electrical and mechanical components, a simplified representation of PMDC motor's two components are shown in Fig. 4.1 Based on the Newton's law combined with the Kirchhoff's law, the differential equations describing characteristics of PMDC motor can be derived [4].

Mathematical Modeling and Simulation of PMDC Motor

Applying a voltage to motor coils, produces a torque in the armature. The torque developed by the motor, T_m , is related to the armature current, I_a , by a torque constant K_t , and given by Eq. (1):

$$\text{Motor Torque} = T_m = K_t \cdot I_a \quad (1)$$

The EMF is related to the motor shaft angular speed, ω_m , by Eq. (2):

$$e_a(t) = K_b \frac{d\theta_m(t)}{dt} = K_b \omega_m \quad (2)$$

Applying Kirchhoff's law gives:

$$\sum V = V_{in} - V_R - V_L - EMF = 0$$

$$V_R = R \cdot I(t)$$

$$V_L = L_a \frac{di(t)}{dt}$$

$$EMF = e_a(t) = K_b \frac{d\theta_m(t)}{dt} = K_b \omega_m \quad (3)$$

$$V_{in} = R_a \cdot I_a(t) + L_a \left(\frac{dI_a(t)}{dt} \right) + K_b \omega_m \quad (4)$$

$$(L_a s + R_a) I_a(s) = V_{in}(s) - K_b \omega_m$$

$$I_a(s) = \frac{V_{in}(s) - K_b \omega_m}{(L_a s + R_a)}$$

$$[V_{in}(s) - K_b \omega_m] \cdot \frac{1}{(L_a s + R_a)} = I_a(s) \quad (5)$$

The torque, developed by motor, produces an angular velocity, $\omega = d\theta/dt$, according to the inertia J and damping friction, b , of the motor and load. Performing the energy balance on the DC motor system; the sum of the torques must equal zero, we have:

$$\sum T = J \cdot \alpha = J \cdot \frac{d^2 \theta}{dt^2}$$

$$T_e - T_a - T_\omega - T_{EMF} = 0 \quad (6)$$

Substituting the by Eq. (7) in Eq. (6):

$$T_e = K_t * I_a$$

$$T_a = J_m \cdot \frac{d^2 \theta}{dt^2} \quad (7)$$

$$T_\omega = b_m \cdot \frac{d\theta}{dt}$$

$$K_t * I_a - T_{Load} - J_m \left(\frac{d^2 \theta}{dt^2} \right) - b_m \left(\frac{d\theta}{dt} \right) \quad (8)$$

Taking Laplace transform and rearranging, gives Eq.(9) :

$$K_t * I_a(s) - J_m * s\omega(s) - b_m * \omega(s) = 0$$

$$K_t I_a(s) = (J_m s + b_m) \omega(s)$$

$$K_t I_a(s) = (J_m s + b_m) \omega(s)$$

$$\frac{K_t I_a(s)}{(J_m s + b_m)} = \omega(s) \quad (9)$$

$$I_a(s) * K_t * \frac{1}{(J_m s + b_m)} = \omega(s)$$

Substitute the value of I(s) in Eq. (9) describing PMDC mechanical characteristics, this gives Eq.(10):

$$K_t \left[\frac{1}{(L_a s + R_a)} \right] [V_{in}(s) - K_b \omega(s)] = J_m s \omega + b_m \omega \quad (10)$$

Rearranging (10), we obtain Eqa.(11):

$$G_{speed}(s) = \frac{\omega(s)}{V_{in}(s)} = \frac{K_t}{[(L_a J_m) s^2 + (R_a J_m + b_m L_a) s + (R_a b_m + K_t K_b)]} \quad (11)$$

Mathematical Modeling of Electric Part of PMDC Motor

Applying a voltage to motor coils, produces a torque in the armature. The torque developed by the motor, T_m , is related to the armature current, I_a , by a torque constant K_t , and given by Eq. (12)

$$\text{Motor Torque} = T_m = K_t * I_a \quad (12)$$

The back electromotive force, EMF voltage, e_a is induced by the rotation of the armature windings in the fixed magnetic. The EMF is related to the motor shaft angular speed, ω_m , by a linear relation given by Eq. (13):

$$e_a(t) = K_b \frac{d\theta_m(t)}{dt} = K_b \omega_m \quad (13)$$

Applying Kirchhoff's law around the electrical loop by summing voltages throughout the R-L circuit gives:

$$\sum V = V_{in} - V_R - V_L - EMF = 0 \quad (14)$$

Applying Ohm's law, substituting, values of V_R , V_L , V_{EMF} given by Eq.(15), rearranging and taking Laplace transform, we get Eqs. (13-14) that describes the electrical characteristics of DC motor:

$$\begin{aligned} V_R &= R \cdot I(t) \\ V_L &= L_a \frac{di(t)}{dt} \\ EMF &= e_a(t) = K_b \frac{d\theta_m(t)}{dt} = K_b \omega_m \end{aligned} \quad (15)$$

$$V_{in} = R_a \cdot I_a(t) + L_a \left(\frac{dI_a(t)}{dt} \right) + K_b \omega_m$$

$$I_a(s) = \frac{V_{in}(s) - K_b \omega_m}{(L_a s + R_a)}$$

$$[V_{in}(s) - K_b \omega_m] \cdot \frac{1}{(L_a s + R_a)} = I_a(s)$$

$$(L_a s + R_a) \underline{I_a}(s) = V_{in}(s) - K_b \underline{\omega_m} \quad (16)$$

Mathematical Model of Mechanical Part of PMDC Motor

The torque, developed by motor, produces an angular velocity, $\omega = d\theta/dt$, according to the inertia J and damping friction, b , of the motor and load. Performing the energy balance on the DC motor system; the sum of the torques must equal zero, we have:

$$\sum T = J \cdot \alpha = J \cdot \frac{d^2\theta}{dt^2}$$

$$T_e - T_a - T_\omega - T_{EMF} = 0 \quad (17)$$

Substituting the below values given by Eq.(16) in Eq.(17), without load attached, where the change in T_{motor} is zero gives Eq.(4.8):

$$T_e = K_t \cdot I_a$$

$$T_a = J_m \cdot \frac{d^2\theta}{dt^2}$$

$$T_\omega = b_m \cdot \frac{d\theta}{dt}$$

$$K_t \cdot I_a - T_{Load} - J_m \left(\frac{d^2\theta}{dt^2} \right) - b_m \left(\frac{d\theta}{dt} \right) = 0 \quad (18)$$

Taking Laplace transform and rearranging, gives Eq.(18) describing mechanical characteristics of PMDC motor:

$$K_t \cdot \underline{I_a}(s) - J_m \cdot s \omega(s) - b_m \cdot \omega(s) = 0$$

$$\underline{I_a}(s) \cdot K_t \cdot \frac{1}{(J_m s + b_m)} = \omega(s)$$

$$K_t \underline{I_a}(s) = (J_m s + b_m) \omega(s) \quad (19)$$

The electrical and mechanical PMDC motor two components are coupled to each other through an algebraic torque equation given by Eq.(19). To derive the PMDC motor transfer function, we need to rearrange equation describing electrical characteristics of PMDC, such that we have only current $I(s)$ on the right side, then substitute this value of $I(s)$ in Eq.(19) describing PMDC mechanical characteristics, this gives Eq.(20):

$$K_t \left[\frac{1}{(L_a s + R_a)} \right] [V_{in}(s)] = J_m s \omega + b_m \omega \quad (20)$$

Rearranging (4.10), we obtain the PMDC motor open loop transfer function without any load attached relating the input voltage, $V_{in}(s)$, to the angular velocity, $\omega(s)$, given by Eq.(21), this equation shows that the DC motor is a second order system. [3]

$$G_{speed}(s) = \frac{\omega(s)}{V_{in}(s)} = \frac{K_t}{\left\{ \left[(L_a s + R_a) (J_m s + b_m) + K_t K_b \right] \right\}} \quad W$$

(21)

SIMULATION RESULTS

We have noticed from Fig 2, that the system of the second order system (Under damped). These values are required by add controller with values $P=0.5$, $I=50$, $D=1.2$, settling time < 1 sec, steady-state error $< 1\%$, $K_{DC} = 3.333$, so we need to add a controller. The motor reaches steady state value of 1 rad/s in 0.75 s, with very small overshoot the system response is very fast[2].

Figure 1: Simulink Model of the System

Figure 2: PID Tuning For DC Motor System

Implementation of Hardware

- Choose the structure material, The choice was made on a square aluminum section with a thickness of 2 mm
- Design drawing on the Solid Work package

Figure 3: Final Design by Solidworks

- Install electronic parts by Connect 3 stepper motors and 1 spindle motor to Arduino and from Arduino to power supply
- Writing Code (Saudi Arabia), using G-code

Figure 4: Applied Final Design

CONCLUSIONS

In this paper, it was designed and applied the required engineering expertise to produce a functional mini CNC machine at Taif University. Prototype testing has gone well and the team has proven that our design was feasible and that the electrical and mechanical design selections were appropriate. The prototype cost is under the target cost and feasible to be duplicated other teaching institutions.

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