A CARRIAGE POSITIONING CONTROL SYSTEM USING A CNC OPEN ARCHITECTURE FOR ACADEMIC PURPOSES

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Abstract. *This paper presents the developing and implementation of a carriage positioning control using an open architecture CNC module to be used as a academic test bench. The system includes the monitoring of crtical variables for safety purposes. It shows the design procedure as well as the main features and possible system aplications. Finally, it presents the experimental results obtained in a test bench.*

Keywords*: Control System, CNC Control Module, Positioning Control, Data acquisition.*

1. Introduction

The shape quality, the tolerance and the surface roughness of a produced part are affected by several factors related to the machine-tool design, among these factors, the positioning accuracy and repeatability of the machine-tool. Due to these facts the positioning system of a machine-tool is one of the most important aspects to be considered. The best accuracy performance that a machine tool can reach is directly related with the positioning system. Therefore, the full understanding of all the aspects involved in the development of a machine-tool positioning system is essential for reaching the optimal solution.

The carriage positioning system was developed to be used in a lathe machine. In this case, the tool is attached to the carriage whose movements are determined by the positioning control system. There are countless options in relation to the structures on a positioning system, and choices should be made depending on the specific objective of the machine tool (Rossi, 1999). In the positioning systems, basic elements are actuators, the slide systems, measurement and control system.

The choice of a CNC module with open architecture was made to facilitate configuration changes and to its utilization in other applications. The end goal is to use the positioning system as a teaching tool in the Mechatronics Laboratory of the Department of Mechanical Engineering of the Federal University of Minas Gerais, Brazil.

In the following sections, it will be shown the main steps in the development of the positioning system, the description of the most important system components and some positioning tests.

2. The Positioning System

The positioning system design procedure includes: the proper choice of the system components, implementation of the right interfacing between electronics and mechanical parts, and the developing of the communication algorithms between the different parts of the system.

2.1. The System Components

- Mechanical Structures: Guides, Transmission and Mechanical Coupling
- Electronics and Control Structures: Encoder, DC Motor Amplifier, DC Motor, CNC Module
- Software: Regulation and Tracking Positioning Control Algorithms and Safety Digital Control.

Figure 1 shows the positioning system main parts: the sliding guides, the re-circulating ball screw and the carriage. The sliding guide restrains the carriage movement to one degree of freedom and the screw transmits the movement to the carriage.

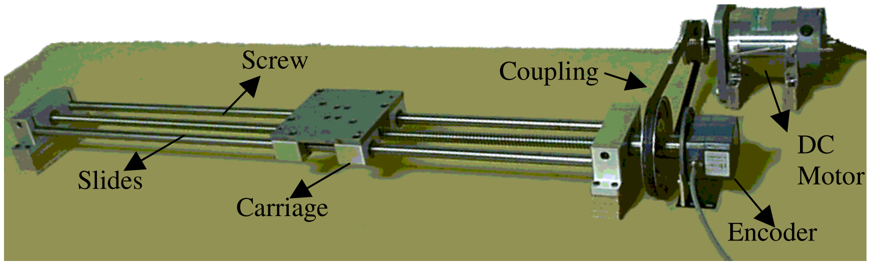


Figure 1 : The Positioning System

The mechanical coupling between the screw, encoder and the DC motor is accomplished through a belt-pulley system. The angular encoder is connected directly to the screw, in this way it doesn't suffer effects of belt sliding. The re-circulating ball screw pitch is 5 mm and the encoder produces 360 pulses per turn, which means that every 360 pulses the screw advances 5 mm. So, the positioning measuring system has a basic resolution of 13.9 micrometer, which by means of interpolation (in the CNC module) turns able to obtain a resolution of 3.4 micrometer. The encoder communicates the screw position to the CNC module.

2.2. The Control Structure

The CNC module is constituted by a DAq system which is capable to control 3 axes (position-velocity) through 3 different encoders. It has 8 digital inputs and 7 digital outputs, besides that, it can simultaneously supervise several machine variables and generate complex trajectories profiles.

Figure 2 presents the positioning system scheme. The analog output is utilized as the positioning set point. The dc-motor amplifier is a PWM (Pulse Wave Modulation) voltage source. The output signals from the encoder are connected to the CNC board through appropriate ports. The CNC digital inputs are utilized to monitoring the front and rear limit switches and emergency signals.

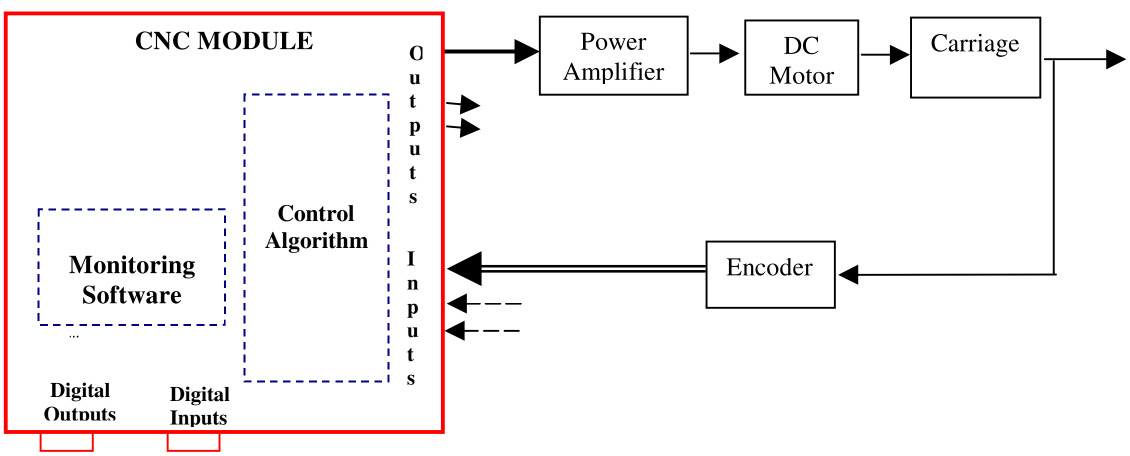


Figure 2 : Schematic Diagram of the Monitoring and Positioning System

To work with a specific application, the CNC module is configured through hardware (jumpers) and software. Some parameters that need to be hardware configured are: the type of encoder signal, the sampling rate, the number of axes that will be controlled and the type of servo amplifier that it will be connected to the motor drive. Besides the jumpers, it is required to configure through software: the initialization variables, the value of these variables and the memory positions to be used. The control loop is constituted by the CNC, the encoder and the motor drive; the communication among them is established using the initialization variables. Since all external devices connected with the CNC microprocessor are memory mapped, the initialization variables must contain the memory addresses that have to be allocated. The encoder needs to be configured specifying the type of signal that will be transmitted, the kind of interpolation to be applied to the digitalized signal and the direction of the movement. The data from the measurements are sent to the CNC to be processed by the control algorithm. The controller type and all control gains need to be defined.

The CNC control board may be seen as being an open architecture module that allows configuring the main input and outputs aspects in agreement with the user needs and the control position algorithm. The CNC module is hosted in a personal computer and processes the position reference through a control algorithm. Some of the main features of the CNC module are:

a) It has the capability to sequentially control up to 3 axes;
b) It accepts signals A/B quadrature type (position feedback coming from encoder) until a frequency of 1 MHz;
c) Process NC part program (motion program) developed in G codes;
d) It collects information from the plant. The limit switches and the emergency alarms send logical signal to the CNC module. The user through a supervisor utility program can to detect any possible faults;
e) It has a friendly user interface that permits the setup of the positioning system operational conditions such as: feed rate, acceleration, stroke and maximum positioning error, the number of axes of a machine, etc

2.3. The Control Algoríthm

Figure 3 presents the block diagram of the positioning control system. The closed-loop includes a control algorithm and an error compensation table. In positioning systems, systematic errors can happen and are detected through experimental tests. The error compensation table is used to correct these errors.

The CNC module receives the encoder positioning signals, computes the positioning error and uses this error to calculate the control signal to be applied to the DC motor amplifier. In this case, the control algorithm was a PD type one, however, due to its open architecture, the systems allows the user to implement any kind of control algorithm (Dorf, 2001).

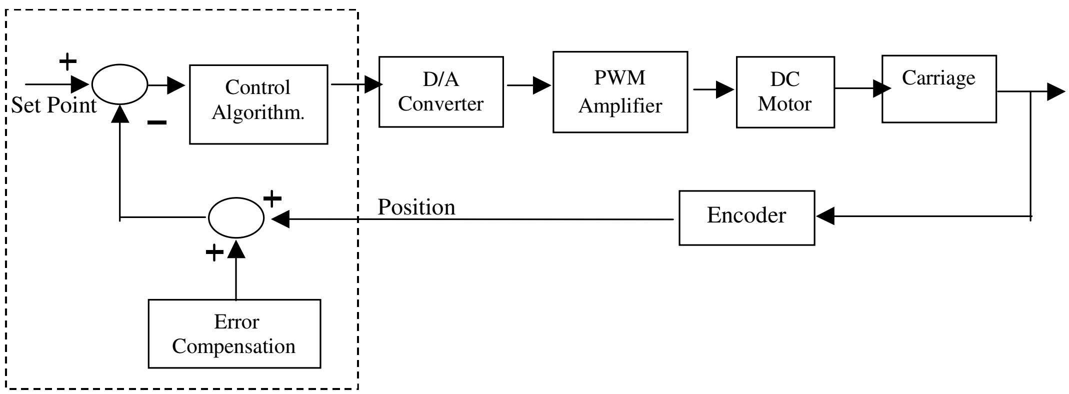


Figure 3 : Positioning Control System

2.4. The Monitoring Program

The CNC digital inputs are connected to 4 limit switches placed on the axes extremes, two of them in each axis end. For safety purposes the protection system was implemented with two security levels. If the first limit switch is activated, the monitoring program will stop the movement and keep the carriage at that position. If for any circumstance the carriage continues moving, a second limit-switch is activated and the monitoring program will shutdown the motor power supply. A similar situation will happen if the emergency master switch is activated. During operations, the monitoring program, created by the user, continuously supervises these signals.

3. The Positioning System Model

In general, a mathematical model of a dynamic system can be obtained from physical equations or from experimental results utilizing parameter estimation techniques (Wellstead 1979). These techniques are based on system measurements obtained from adequate experimental results. The final model is in general a differential equation relating the system outputs with its inputs. Having already obtained the experimental data, the modeling can be performed, in general, following three main steps: a) define of a model structure, b) run the parameter estimation algorithm and c) validate the obtained model.

In this case, it was verified that an acceptable model structure has the form given by the transfer function presented in Eq. (1) :

$$G(s) = \frac{K}{(T_1 s + 1)(T_2 s + 1)} \tag{1}$$

Several parameter estimation algorithms can be applied to determine the model parameter K, T_1 and T_2. In this case, a reasonable model was obtained using the semi-log method (Coughanowr, 1991). Following this technique it was found:

$$G(s) = \frac{1.089}{(0.1051s + 1)(0.043s + 1)} \tag{2}$$

Figure 4 presents a model validation test showing a comparison between the experimental results and the model simulation.

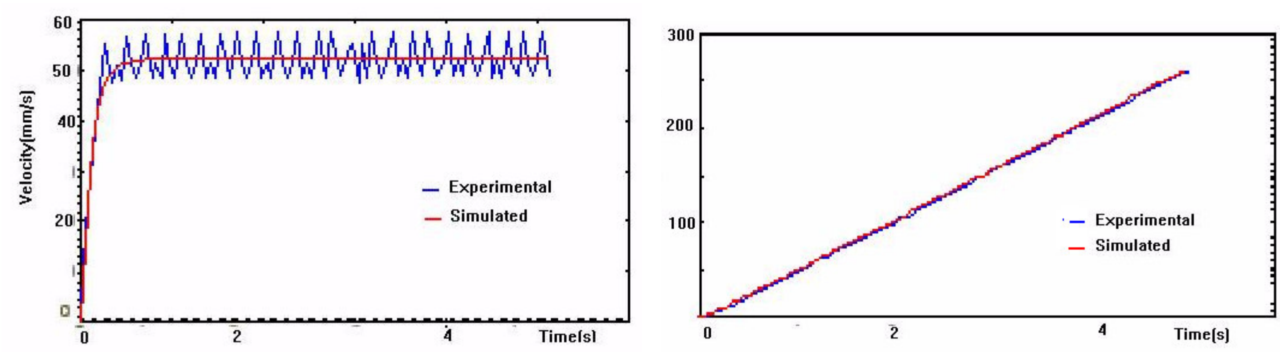


Figure 4 : Model Validation

The oscillation observed in the output variables is a consequence of several factors: irregularities in the rotating components, such as, the re-circulating ball screw and the DC motor; nonlinear friction in the mechanical coupling; measurement noise; etc. These observed problems were left unsolved to be used as challenging tasks for future classroom experiments.

4. Some Experimental Results

In order to assess the positioning system performance, experimental tests can be performed, among them:

a) Assessing the tracking error (difference between actual position and reference position) for a constant speed motion condition;
b) Evaluation of the final positioning error, that is the error when the positioning system stops;
c) The departure error that is de error that occurs at the beginning of the movement;
d) And finally, the reversing error that is the error that happens when there is a change in the displacement.

Figure 5 shows the presence of these errors in the developed positioning system.

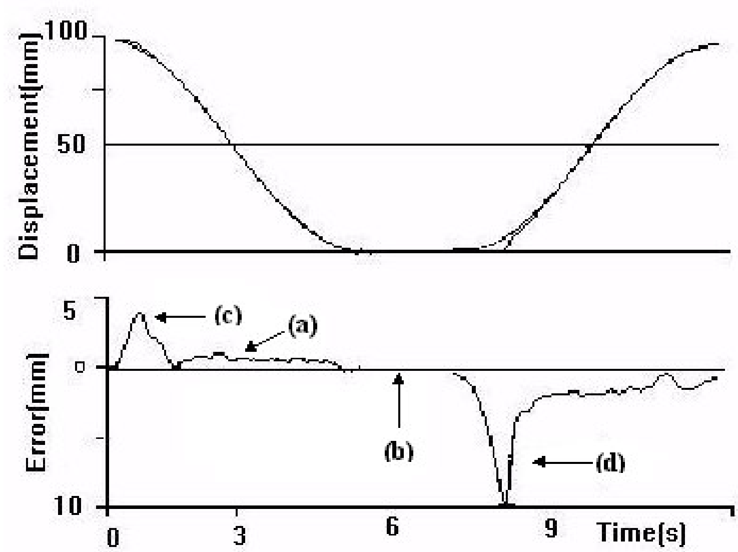
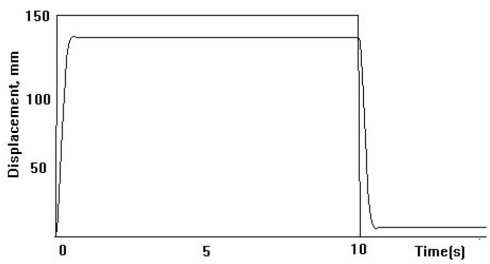
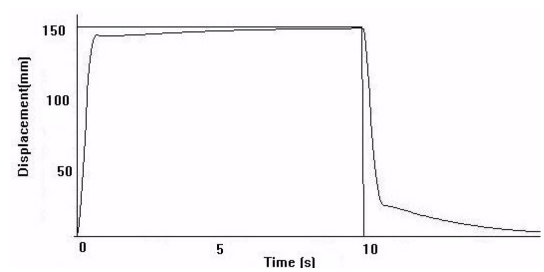


Figure 5 : Positioning Test

Aiming the startup of the positioning system, a PD controller was tuned based on the model from equation (2). The controller parameters were adjusted to obtain a critical dumped system response ($\zeta = 1$). Figure (5a) shows the result of a positioning test with the PD controller, in this case, the system response shows a finite steady state error. Figure (5b), presents the resulting system response after a fine-tuning of the PD controller gains, in this case the steady state error was substantially reduced.



(a)



(b)

Figure 5 : Positioning Test

Figure (6) shows the case in which the steady state error was banished by using a PID control.

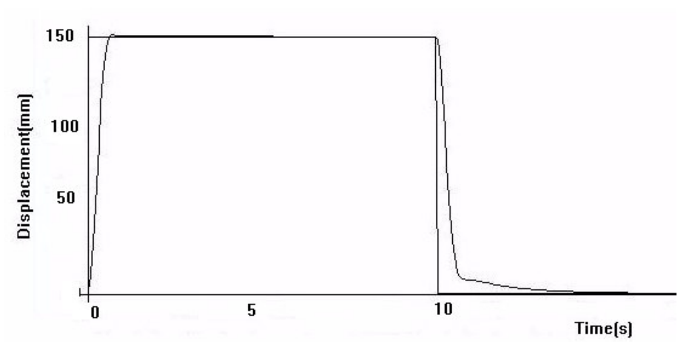


Figure 6 : Positioning Test – PID Control

5. Final Coments

This paper presented a general purpose positioning system. The main objective was to develop a test bench for teaching and academic applications. As it is, it allows performing a great diversity of experimental work. Among them experimental tests can be made to determine the positioning, the tracking, the departure and the reversal errors for many working velocities. Also, new control strategies aiming the minimization of the system errors and the improvement of the system global performance can be used and tested. The system interfaces were designed to allow the easy exchange of the controller such that a regular PID board or a PLC can be included and used as the positioning system controller. Finally, the system permits the analysis of several interesting aspects of the implementation of positioning systems supervision and control showing to be a very powerful teaching tool.

6. References

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