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MECHATRONICS APPROACH TO CNC END MILLING STUDY

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ABSTRACT

A mechatronics approach, i.e., developing a mathematical model for the end milling operations on a CNC milling machine to simulate its behavior, is taken up in this paper. The mathematical model of the servomotor controlled XY table, developed elsewhere, is integrated with the proposed model for the end milling operations. Simulations are performed using SIMULINK of MATLAB. An experimental set-up was built to perform end milling operation on an existing XY table. SIMULINK results are validated with the experimental results. Such mathematical models are useful for evaluation of a new design. Hence, the lead time and cost to bring a new design in the market will be drastically reduced.

1 INTRODCUTION

Mechatronics is a concept introduced in Japan in 1980s. Even though people refer to any system having mechanical, electrical, electronics components, for example, washing machine, photocopiers, CNC machines, etc., as mechatronics systems, truly `mechatronics' is a design philosophy. In conventional design approach, components of a system are designed by respective experts. For example, a mechanical engineer designs the mechanical components, whereas the electrical engineer designs the electrical components, and so on. Since every designer leaves certain factor of safety (FOS) due to the ignorance of the other fields, the overall FOS is large and the system becomes bulky and expensive. In mechatronics design approach, the whole system is treated as one by taking care of all the components, be it a mechanical, electrical or electronics. As a result overall factor of safety is small and, hence, the system's size and cost are reduced.

In this paper, the mechatronics approach to the study of end milling in a CNC machine is taken up to aid the process of new design of a CNC machine table. The study requires the model of the machining process. The characteristics of end milling lies in the regular sequence of individual cuts, corresponding to each successive tooth engagements. These cuts many times are strongly overlapped. To predict the instantaneous cutting forces, mechanistic theory (Fuh and Hwang, 1997) is used. The force model developed here takes the feed of table and rpm of cutter as input parameters and gives the instantaneous force as output at different cutter flutes locations. Mechanical transmission elements of the XY table comprising of motor axes and ball screws are also considered. Since stiffness of the mechanical elements plays an important role in accuracy of machined parts they are also taken into account in the mathematical model, whereas the models of the PMBLDC servo motors of the XY table are taken from Kataria and Mehta (2001). Based on these models, simulations are performed using SIMULINK of MATLAB. An attachment for the end milling operation is also designed and fabricated, which is attached to the already available XY table (Chandrasekhar, et al, 2001; Saha et al., 2001) for experimental verifications of some of the simulation results.

This paper is organized as follows: Section 2 presents the experimental set-up whose mathematical model is presented in Section 3. Section 4 presents both the simulation and experimental results. Finally, conclusions are given in Section 5.

2 EXPERIMENTAL SET-UP

The study of proposed end milling operation is assumed to be done in a CNC milling machine. In our study, end milling was carried out on an available XY table. So a frame was designed and fabricated which supports motor and locates the spindle. Figure 1 shows the frame designed and fabricated to carryout the experiments, whereas Fig. 2 shows the photograph of the complete set-up. The spindle of the attachment is designed in such a way that its one end is connected with the AC induction motor shaft providing rotation, whereas the other end is connected to a drilling chuck which is modified to hold the end mill cutter (Kulkarni, 2001). The other components are explained next.

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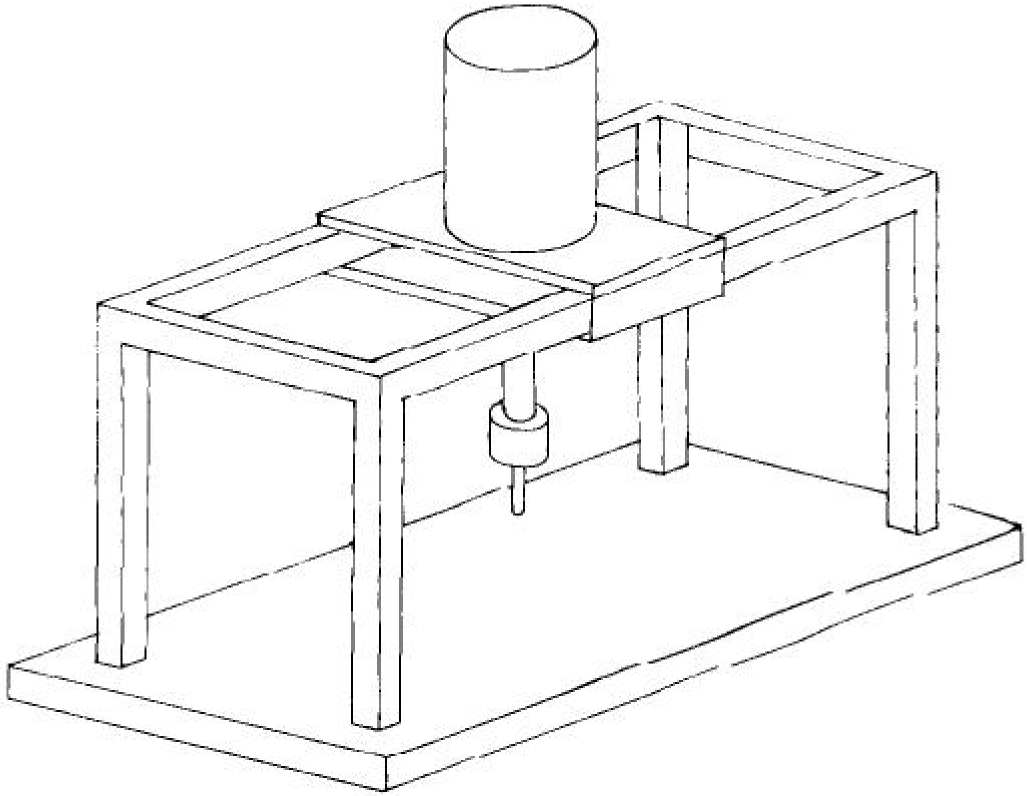

Fig. 1 End milling attachment.

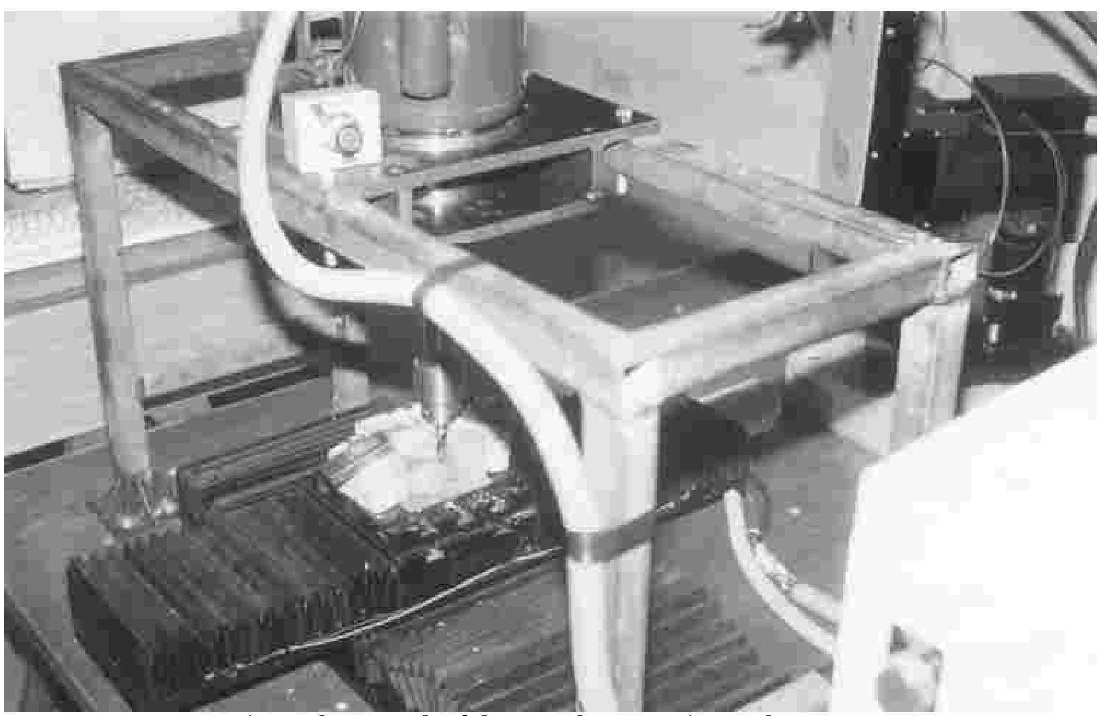

Fig. 2 Photograph of the complete experimental set-up.

2.1 Spindle motor

Power requirements for end milling are done as per the production technology handbook (HMT, 1997). Based on the power to cut Aluminum (Kulkarni, 2001) by an HSS tool, spindle motor is selected as: 220V, 1440RPM, 250W, single-phase AC induction motor.

2.2 Frame

The horizontal link of the frame in the end mill attachment, as shown in Fig. 1, is the critical one as it supports the motor and the spindle against bending forces induced during cutting. This link is designed as simple supported beam. Link cross-section is chosen as: 35mm x 35mm, 3mm thickness, hollow. Detailed calculations are available in Kulkarni (2001).

2.3 Tool holding device

In actual CNC milling machines, draw bar mechanism is used to secure the cutting tool. However, to keep the system simple, here a drilling chuck was modified to serve the purpose of holding the end mill cutter. The drilling chuck of ½ was selected.

2.4 Bearing

Bearing is fixed on the frame which houses the spindle. The forces coming on the spindle are predominantly of bending. So, bearings have to withstand radial forces. Hence, the SKF deep groove ball bearings 6004 are selected.

2.5 Panaterm

The system response was observed by using the software package PANATERM (Minas, 2000), whereas DMCterm is another software was used to communicate with the Galil DMC1822 controller card (Galil, 2000). DMC1822 is a two-axis controller which controls the PMBLDC motors along X and Y axes. Both the software allow online monitoring of the driver, which show errors in terms of the number of pulses, motor RPM, and torque percentage supplied by the motors at any time instant. The positional errors are defined here as the difference between the programmed and achieved positions.

3 SYSTEM MODELLING

The mathematical model of the complete set-up, comprising of the servo controlled XY table, cutting conditions, etc., is presented in this section. The controller of the XY table is mounted on the PCI slot of the PC, which does all the calculations necessary to move the table along a pre-determined path leaving computer processor time free to do other jobs. The software package PANATERM developed by Panasonic facilitates the online monitoring of the servomotors.

The elements of servo system including motor, driver, encoder and the controller are modelled by Kataria and Mehta (2001) and shown in Fig. 3, whereas the complete model is shown in Fig. 4 that takes care of the mechanical elements, cutting forces and stiffness (Kulkarni, 2001).

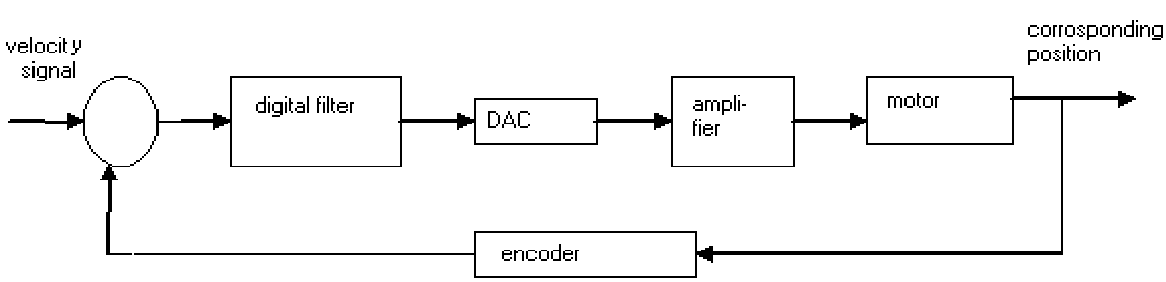

Fig. 3 Functional elements of the controller.

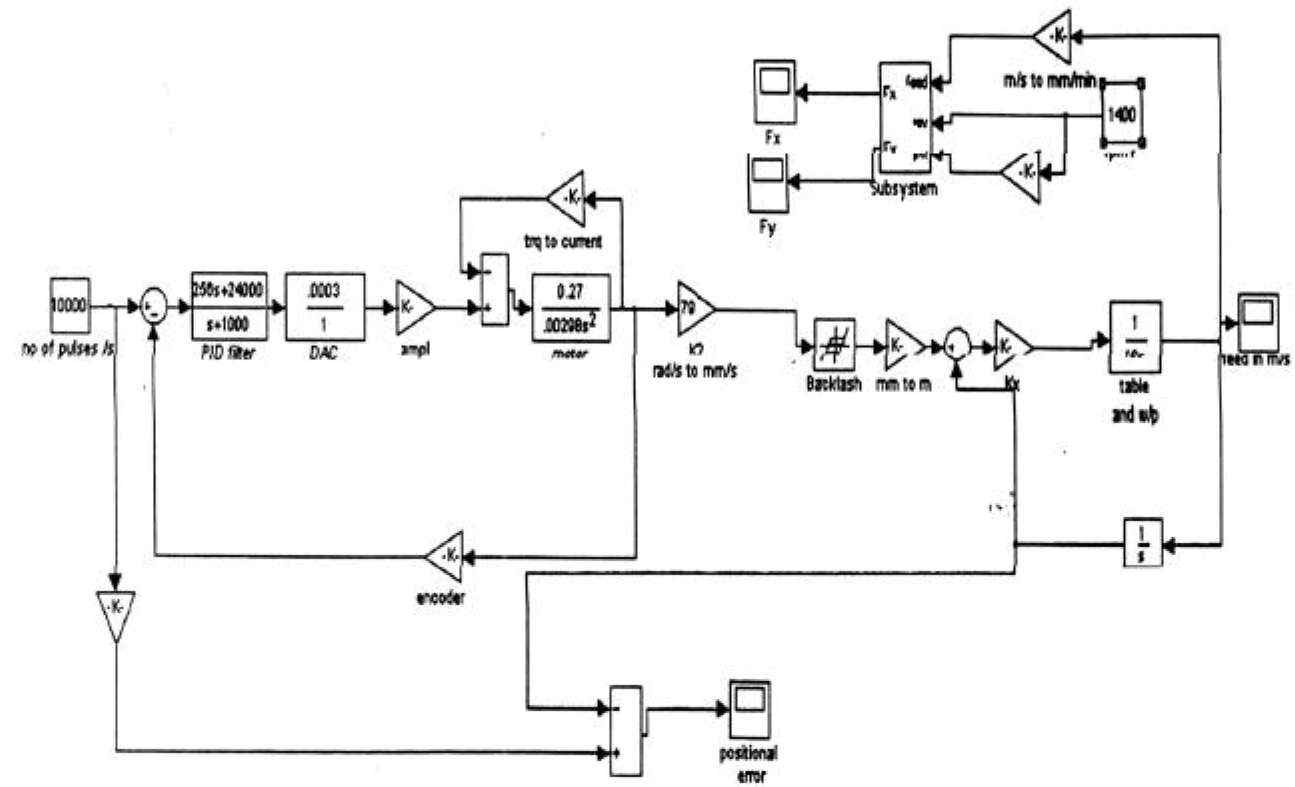

Fig. 4 Complete SIMULINK (in MATLAB) model.

4 RESULTS

Simulations are performed in SIMULINK based on the model shown in Fig. 4 and experiments were conducted using an end milling cutter with the following specifications: HSS tool with straight shank of diameter 12mm; Helix angle of tool 30^0 ; Rake angle of the tool 11^0 . Work materials are considered as Aluminum and Perspex (polymethyl methalcralyte). For experiments, the parameters varied are feed and depth of cut. For the cutting of a circular slot on Perspex block at 300mm/min feed rate with 2mm depth of cut, errors obtained from PANATERM are shown in Fig. 5. Errors were also measured while cutting straight slot but not much variations were observed. So the type of paths may not have much influence on the positional accuracy, whereas the feed rate has. Lowering the feed rate has reduced the variation of errors during straight or circular slots.

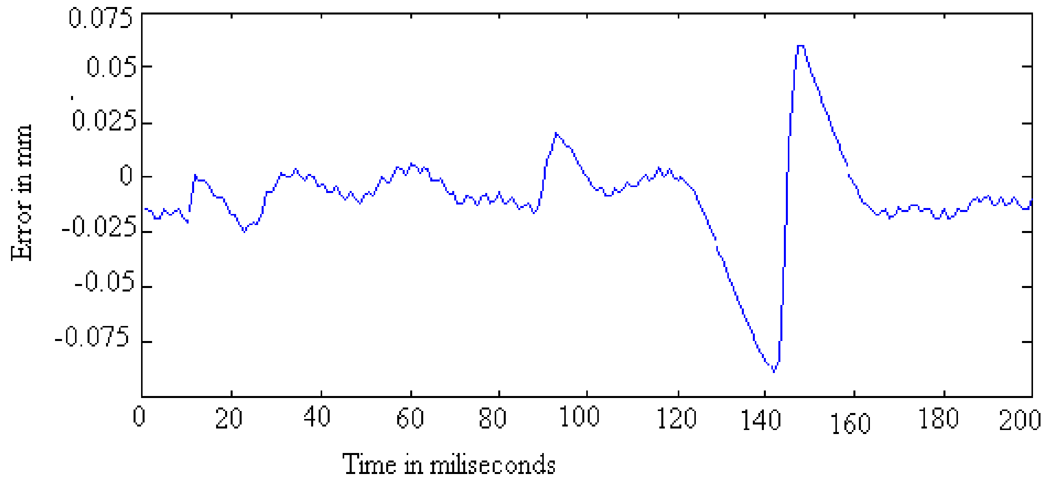

Fig. 5 Positioning errors during circular slot cutting at 300mm/min feed rate at 2mm depth of cut.

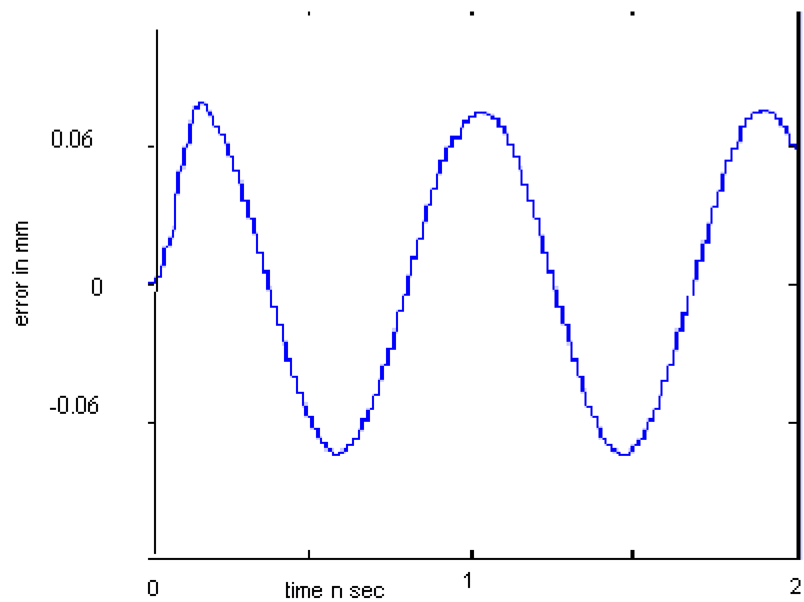

Fig. 6 Positioning errors from SIMULINK with the same conditions as in Fig. 5.

On the hand, errors from the SIMULINK model is shown in Fig. 6, where the cutting conditions remained same as in Fig. 5. Note the range of error variations, which is similar, i.e., +/- .075mm. Hence, the mathematical model represents the a realistic model for the end milling operation on a milling machine.

5 CONCLUSIONS

Mathematical model for the end milling operation is proposed in this paper, which is integrated with an existing SIMULINK model of the servo controlled XY table. An experimental set-up is also built, which is attached to the existing XY table, for the real end milling cutting operations. Positional errors, i.e., the difference between the programmed and achieved positions, for the table are obtained both from SIMULINK simulations and experimental set-up. The results match closely, as shown in Figs. 5 and 6. Hence, such a mathematical model is useful for evaluating the performance of a new design without making a real prototype which is time consuming and expensive. Hence, both the time and investment to bring a new product into the market is reduced drastically. Thus, the mechatronics approach towards the design study is gaining acceptance amongst the designers.

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