Design and Manufacturing of Mini CNC Vertical Machining Center for Educational Purposes and Obtaining Optimum Spindle Speed based on Machine Vibration

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Abstract

Mini vertical CNC machine which has three-axis, low price and similar to modern CNC machines has been designed and manufactured at Kocaeli University Mechatronic Engineering Sensor Laboratory. After manufacturing of mini CNC machine, vibrations that are critical in machining are measured to obtain optimum spindle speed according to different spindle speeds and different milling depths. The CNC machine which has step motor controlled X, Y and Z axes could perform engraving, scratching and drilling processes. The system has Mach3 interface in order to process data of engraving, scratching and drilling which are output of design programs (CAD-CAM) and it transmits those processes to the control unit by using USB data line.

Key words: G and M Codes, Mach3, Mini CNC, Vibration.

1. Introduction

Computer Numeric Control (CNC) is the automation of machines that are processed by programmed commands. In CNC systems, component design and manufacture is performed by using computer aided design (CAD) and computer aided manufacturing (CAM) programs. The programs produce a computer file that is interpreted to extract the commands needed to operate a particular machine via a post processor, and then loaded into the CNC machines for production.

Machining vibrations result of the relative movement between the work piece and the cutting tool. The vibrations create waves on the machined surface. This affects machining processes, tool life and surface quality.

2. Mini Vertical CNC Machine Design and Manufacturing

Mini vertical CNC machine has three main sections; mechanic hardware, electric-electronic hardware and software.

2.1. Mechanical Design

Mini CNC is constructed by 50x50x5 mm square profiles as shown Figure 1. It was designed as closed structure with 2 sliding doors and 4 transparent windows in order to observe machining process. (Figure 2.)

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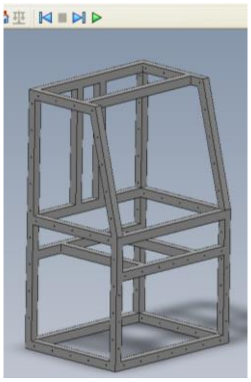


Figure 1. Construction (50x50x5 mm profiles)

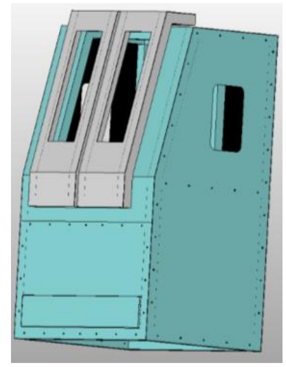


Figure 2. Mini CNC machine Structure

2.1.1. X, Y and Z Axes Mechanisms

Three axes mini vertical CNC machine has worm shaft mechanisms for X, Y and Z direction motions. For X and Y direction motion, combined mechanism was selected as shown Figure 3. For Z direction motion, the mechanism that has spindle motor and step motor connections was used as shown Figure 4.

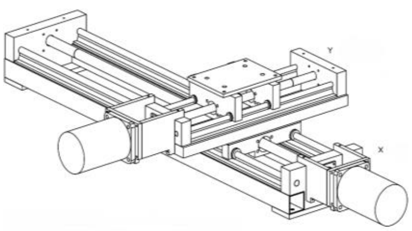


Figure 3. X and Y axes worm shaft mechanism

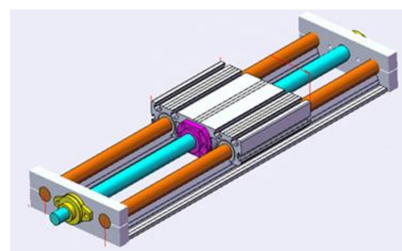


Figure 4. Z axes mechanism

2.2. Electrical-Electronic Design

Hybrid type step motors were selected in order to control X, Y and Z axes motion as shown Figure 5. These step motors could be controlled micro stepping technique.
For step motor controller, control cards which have micro stepping control specification were used. (Figure 6)

Figure 5. Step motor for X,Y,Z axes motion card

Figure 6. Step motor controller

Spindle motor was selected high frequency induction motor which has 0,75kW, 300Hz and 18.000 rev/min. specifications. (Figure 7)
Induction motors can be controlled by inverters and Fuji-Frenic inverter was used for mini CNC machine as shown Figure 8.

Figure 7. Spindle motor controller

Figure 8. Spindle motor

In order to control all system (step motors, spindle motor), USB controlled mach3 controller board, widely used in CNC machines, was selected. (Figure 9)
All electric-electronic system were assembled in panel which is located rear side of mini CNC machine. (Figure 10)

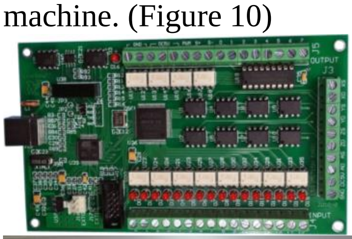


Figure 9. 3 axes USB controller board

Figure 10. Mini CNC vertical machine control panel

2.3. Mini CNC Vertical Machine center

Machine structure was produced according to required processes which are welding, laser cutting

and painting. X, Y, Z mechanisms were assembled on mechanic structure with different types of nuts and bolts.
After assembly of electric-electronic panel, mini CNC vertical machine is ready to manufacture components. (Figure 11)

Figure 11. Mini CNC vertical machining center

3. CNC Machine Control and Sample Part Production

To manufacture components at CNC machines, design and manufacturing softwares (CAD-CAM) are necessary. After getting required output from manufacturing program, it must be converted to CNC machine control software (Mach3). (Figure 12)

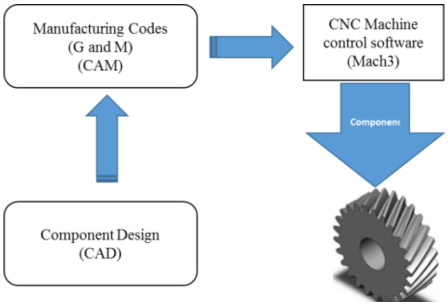


Figure 12. CNC Machining process cycle

Mini CNC vertical machine is controlled by Mach3 program which is widely used at industry. Mach3 program can process regarding to G and M codes which are output of CAM program. It is very rich in features and provides a great value to those needing a CNC control package. Mach3 works on most Windows PC's to control the motion of motors (stepper & servo) by processing G-Code. (Figure 13)

Table 1. Some G codes

Code	Description
G00	Rapid positioning
G01	Linear interpolation
G02	Circular interpolation, clockwise
G03	Circular interpolation, counterclockwise
G04	Dwell

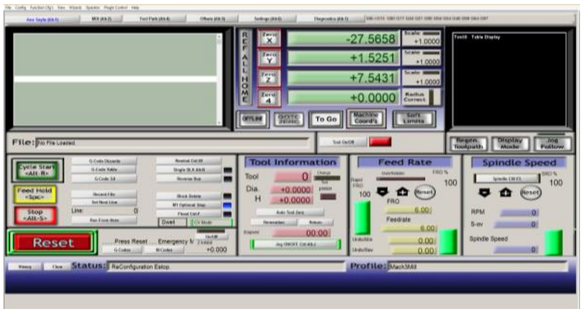


Figure 13. Mach3 program interface

Adjustment of X, Y, Z axes movement was done by Mach3 control software and some parts were produced in order to test designed and manufactured mini CNC vertical machine. There are many types of tools for different materials production. Sample printed circuit board (PCB) part was produced by PCB engraving tools. (Figure 14-15)

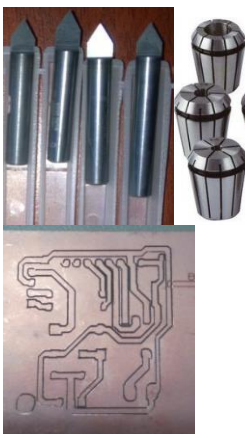


Figure 14. Tools for PCB engraving

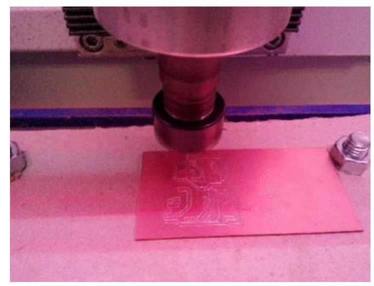


Figure 15. Sample PCB production

4. Machine Tool Vibrations and Obtaining Optimum Spindle Speed

Increasing competition on manufacturing market, it is necessary to perform high speed machining and to remove maximum chip thickness on material. In order to provide this necessities, vibration and precision of machines must be controlled precisely. Effects of vibration must be minimized on machine to have maximum precision on machining process. Machine tools experience both forced and self-excited vibrations during machining operations.

In this study, it was aimed to obtain optimum spindle speed regarding to vibrations on machining. To achieve this, test data were selected as below Table 2.

Table 2. Test conditions

Test No.	Feed Rate	Cutting Depth	Spindle Speed
1	100 mm/min.	1mm	6.000 rev/min
			9.000 rev/min

			12.000 rev/min
			15.000 rev/min
			18.000 rev/min
			6.000 rev/min
			9.000 rev/min
2	100 mm/min.	2mm	12.000 rev/min
			15.000 rev/min
			18.000 rev/min
			6.000 rev/min
			9.000 rev/min
3	100 mm/min.	3mm	12.000 rev/min
			15.000 rev/min
			18.000 rev/min

Spindle speed is able to be adjusted by potentiometer according to defined test parameters. Tests measurements were gathered by Matlab® software.

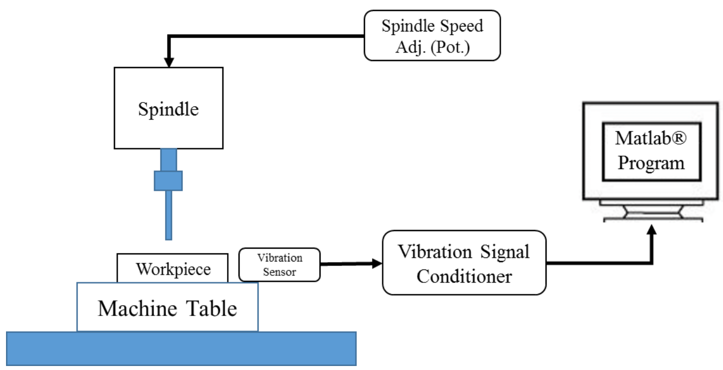


Figure 16. Test schematic

Wood material work piece was selected for testing and PCB 607A11 type accelerometer was used for measurement.

Figure 17. Wood material test

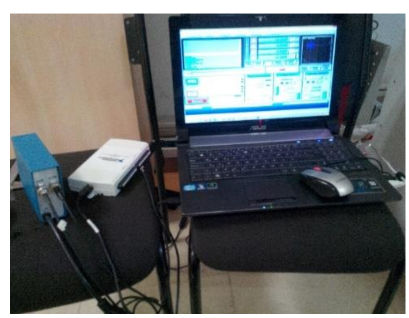


Figure 18. Vibration measurement system

Vibration accelerations were measured as 1.000 times sampling in a second.

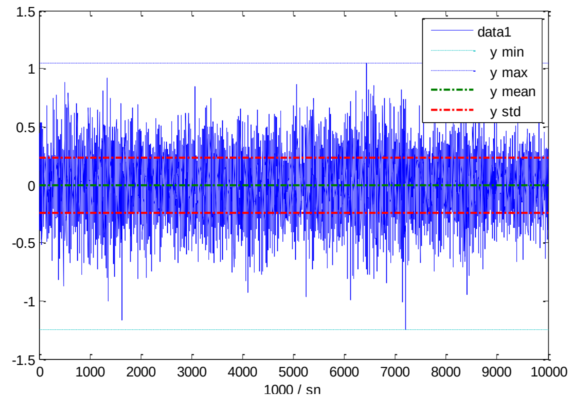
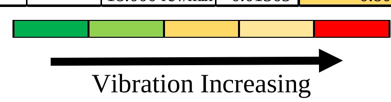


Figure 19. Matlab graphic of 1mm 6.000 rev/min.

Regarding to defined test conditions, 15 results have been collected and analyzed. As shown below result table, 3 different cutting depth results data are similar in aspects of vibration magnitudes.

Table 3. Vibration test results

Feed Rate	Cutting Depth	Spindle Speed	Vibration	
			Avarage	Standart Deviation = RMS
100 mm/min.	1mm	6.000 rev/min	-0.003266	0.2387
		9.000 rev/min	-0.009102	0.327
		12.000 rev/min	-0.01188	0.3702
		15.000 rev/min	-0.01613	0.5617
		18.000 rev/min	-0.01952	0.6659
100 mm/min.	2mm	6.000 rev/min	-0.02616	0.431
		9.000 rev/min	-0.02041	0.549
		12.000 rev/min	-0.02312	0.5753
		15.000 rev/min	-0.02927	1.163
		18.000 rev/min	-0.01799	0.9365
100 mm/min.	3mm	6.000 rev/min	-0.02618	0.3464
		9.000 rev/min	-0.01197	0.4968
		12.000 rev/min	-0.01275	1.184
		15.000 rev/min	-0.03232	1.184
		18.000 rev/min	-0.01365	0.8057



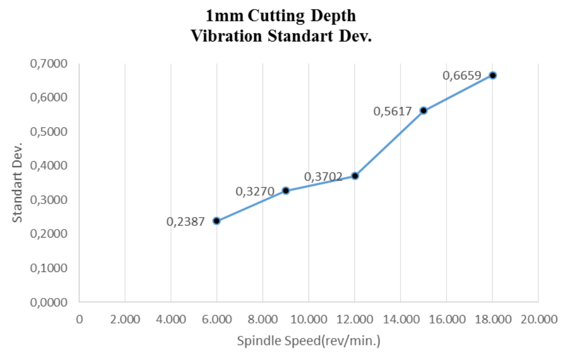


Figure 20. 1mm cutting depth vibration result acc. to different spindle speeds

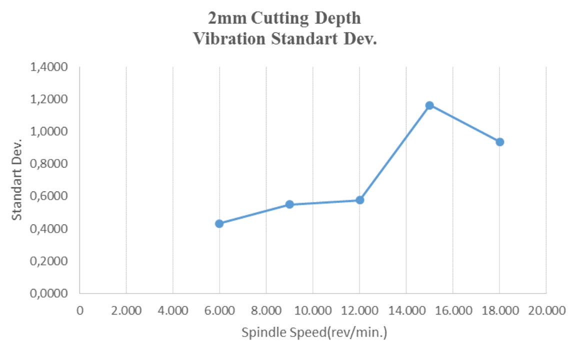


Figure 21. 2mm cutting depth vibration result acc. to different spindle speeds

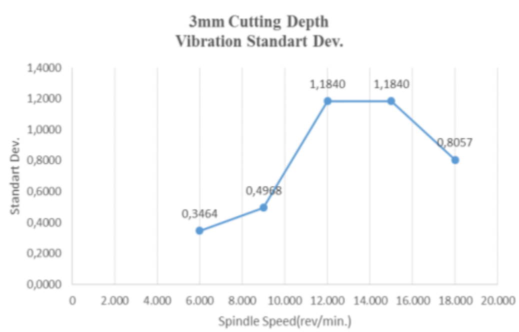


Figure 22. 3mm cutting depth vibration result acc. to different spindle speeds

5. Conclusions

This study presents design and manufacturing of mini CNC vertical machining center and optimum spindle speed obtaining according to vibration on machining process. Design of Mini CNC machine was inspired from modern CNC machines and it has closed structure and sliding doors. Material chips are not moving outside of machine due to its chips drawer and machine operation can be observed on process by transparent windows. X, Y, Z direction movements were performed by step motors which has micro stepping control. Main control of machine was done by USB controlled mach3 control board. Depending of this control board, mach3 software was operated as machine control.

According to vibration test results for 1mm, 2mm, 3mm cutting depths at same feed rate (100 mm/min.), optimum spindle speeds are 6.000 rev/min. and 9.000 rev/min. for good surface quality. Results were combined as graphical in order to show vibration rates. Above 3 graphs (Figure 20-22) shows spindle speed and vibration magnitude change. These graphs can lead the operator to select optimum spindle speed according to process of material. For example, if surface quality is important for component, operator should select 6.000 rev/min spindle speed.

Acknowledgment

This research has been implemented at Sensor Laboratory, Mechatronics Engineering Department of Kocaeli University. The authors thanks to Sensor Laboratory Research and Development group for their contributions. The research was partially supported by Kocaeli University Scientific Research Projects Unit.

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