DESIGN AND FABRICATION OF LOW-COST MINI 3-AXIS CNC MILLING MACHINE FOR TRAINING APPLICATIONS IN VIETNAM

THIẾT KẾ VÀ CHẾ TẠO MÁY PHAY CNC 3 TRỤC MINI CHI PHÍ THẤP ỨNG DỤNG TRONG ĐÀO TẠO TẠI VIỆT NAM

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ABSTRACT

Computer Numerical Control (CNC) machines have been widely used in the mechanical manufacturing due to the complex machining ability, advantages such as high-speed, extreme accuracy, easy used interface, and high rate of automation. Nowadays, the CNC milling and lathe training courses are becoming as the primary subjects of mechanical engineering program at the university in Vietnam. In fact, few mechanical departments at the universities are equipped with CNC machine because of the high investment costs. The aim of this article is to develop a low-cost mini 3-axis CNC milling machine that can be used in training course at the university. The 3-axis CNC milling machine is designed based on the stepper motor and ball-screw mechanism. By using the Mach 3 program, this machine is controlled via a computer. To fabricate a part, the manufacturing process is conducted following 3 steps. First, a part is designed by a computer aided design (CAD) software. Second, the toolpath is generated and exported to the G-code program by a computer aided manufacturing (CAM) software. Third, the G-code program is imported to the CNC machine for fabrication. The 3-axis CNC milling machine is assembly and validated by manufacturing some parts. The tolerance ranges of -0.15 to +0.15 mm demonstrate this 3-axis CNC milling machine can be used as an equipment in mechanical and mechanic training courses at the Vietnamese university.

Keywords: *Computer Numerical Control (CNC); 3-axis CNC milling; Mechanical engineering; Mechanical processing; Training course.*

TÓM TẮT

Máy công cụ điều khiển số CNC được sử dụng rộng rãi trong sản xuất cơ khí nhờ khả năng gia công chi tiết phức tạp, các ưu điểm như tốc độ cao, độ chính xác rất cao, giao diện dễ sử dụng và tỷ lệ tự động hóa cao. Hiện nay, các học phần đào tạo phay và tiện CNC đang trở thành môn học chính trong chương trình kỹ thuật cơ khí tại các trường đại học tại Việt Nam. Trên thực tế, rất ít các trường đại học được trang bị máy công cụ CNC do chi phí đầu tư cao. Mục tiêu của bài báo này là phát triển một máy phay CNC 3 trục mini chi phí thấp có thể được sử dụng trong đào tạo tại trường đại học. Máy phay CNC 3 trục được thiết kế dựa trên động cơ bước và bộ truyền động vít ☞

me bi. Sử dụng phần mềm điều khiển Mach 3 để điều khiển máy CNC qua máy tính. Quy trình chế tạo, sản xuất một chi tiết trên máy phay CNC được thực hiện theo 3 bước. Đầu tiên, chi tiết được thiết kế bằng phần mềm CAD. Thứ hai, đường chạy dao được tạo ra và xuất sang mã G-Code bằng phần mềm CAM. Thứ ba, chương trình mã G-Code được nhập vào máy CNC để gia công. Máy phay CNC 3 trục được chế tạo và kiểm tra độ chính xác bằng cách gia công một số chi tiết. Sai số sau quá trình thử nghiệm đạt từ -0,15 đến +0,15 mm, máy phay CNC 3 trục được chế tạo có thể được sử dụng làm mô hình thiết bị đào tạo ngành cơ khí tại các trường đại học Việt Nam.

Từ khóa: *Điều khiển số bằng máy tính (CNC); Máy phay CNC 3 trục; Kỹ thuật cơ khí; Gia công cơ khí; Đào tạo.*

1. INTRODUCTION

Nowadays, Computer Numerical Control (CNC) machines have been widely used in industrial manufacturing. Using specific alphanumeric codes generated by Computer Aided Manufacturing (CAM) program, CNC machines provide a mechanical product with complex shape and high accuracy [1-4]. CNC machines have become common in the factory due to its capabilities of high-speed and automation. There are several kinds of CNC machine such as: lathe, milling, grinding that have been used in almost manufacturing industries for machining metal, wood, fabric, glass and plastics [5, 6].

Recently, CNC technology is applied to mechanical training course in the university, especially turning and milling CNC machines. Due to the cost-prohibitive of commercial CNC machine, development of low-cost CNC machine is essential research in the university. There are several researches that focus on designing CNC machine with small size and light weight [7-12]. Technically, to fabricate a part, a G-code file generated by CAM program is transferred to CNC machine through LAN or USB port [13, 14]. Using a Computer Aided Design (CAD), a part is created and exported to 2-dimensional (2D) or 3D drawing that is imported to CAM program. At this step, a suitable operation is chosen and the tool and cutting parameters are setup to optimize the tooth path and export to the standard file which is used to fabricate this part by CNC machine.

The aim of this study is to design and fabricate a low-cost 3-axis milling CNC machine that is used for training at the mechanical university in Vietnam. Three linear motions were developed based on stepper motor and ball-screw mechanism. All mechanical components were mounted on the compact frame with dimension of 855 × 620 × 620 mm along the X-, Y-, and Z-axes, respectively. The machine was controlled by a printed circuit board (PCB) that is integrated into electric box. The Mach 3 software was used to interface between a computer with the CNC machine to fabricate a part. Finally, some samples were manufactured with tolerance of ±0.15 mm that validate the capabilities of the machine. The price of this machine was estimated of $ 365. These results demonstrate the potential application of this machine in education in Vietnamese university.

2. METHODS

2.1. Mechanical design of CNC milling machine

The CNC machine is designed based on some criterias such as low price and full training features, creating a compact design, movable spindle, fixed milling table is shown in the Figure 1. Select equipment and components that are mainly available domestically to facilitate design, manufacturing and testing is shown in the Table 1. The structure of the CNC machine consists of the mechanical, drive, measuring, and control systems.

Table 1. Design specifications of CNC milling machine

No.	Specifications	Value
1	Machining material	Plastic, non-ferrous metals
2	Machine size	854.5×619×623(mm×mm×mm)
3	Working size	410×300×50(mm×mm×mm)
4	Main spindle speed (Maximum)	12000 RPM
5	Spindle power (Maximum)	500W
6	Maximum speed along X, Y, Z axes	500, 300, 500 mm/min

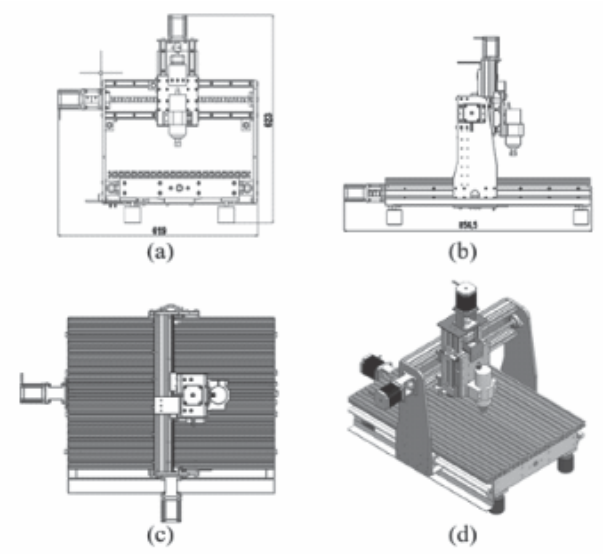

Figure 1. The mechanical design of mini CNC milling machine: (a) front view, (b) left view, (c) top view, (d) isometric view

The calculations to select the motor are performed on the X-, Y- and Z-axes, respectively. Based on the calculation results, the mechanical components were selected as following:

- Ball screw has pitch: h = 20mm;
- We choose the sliding friction coefficient between steel and cast iron: $\mu = 0.12$;
- Gravitational acceleration: $g = 10$ m/s²;
- X-axis moving mass: Mx = 9.256 kg;
- Axial tilt angle: $\alpha = 0°$;
- Because the motor drives directly to the ball screw shaft through the coupling, the transmission ratio: i = 1;
- Machine efficiency: $\eta = 0.9$;
- Maximum axial force: Fmx = 99.141(N) = 9.914 (kgf);
- Maximum rotation speed of the engine: S = 1200 rpm.

2.2. Electrical design of CNC milling machine

Using Mach3 software on the computer, CNC milling machine is controlled via a printed circuit board. The machining process is monitored on a computer screen. The CNC control circuit will control the operation of 4 motors: X-axis motor, Y-axis motor, X-axis ☞

motor through Driver Step DM542 and control on and off the milling motor. Stepper motors drive lead screws to control machine operation. When working beyond the travel limit, the corresponding sensor in the 3 axes X, Y, Z will signal the machine to stop operating, the user needs to reset it to complete the machining process. During operation, if an unsafe point is detected, the user can press the emergency stop button (ESTOP) is shown in the Figure 2. Calculations on motor parameters are performed on all 4 motors: x-axis motor, Y-axis motor, Z-axis motor, milling motor to ensure the CNC machine operates with enough capacity and necessary cutting force for machining on metal materials.

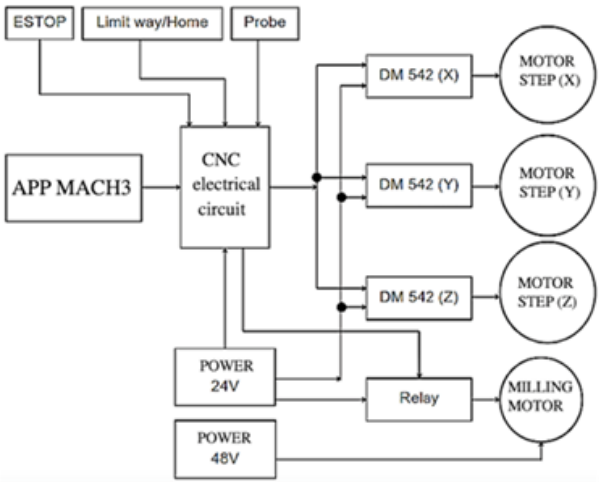

Figure 2. Electrical wiring diagram of CNC machine

3. RESULTS

3.1. Fabrication and assembly of CNC milling machine

The total cost of the CNC machine is about $ 365. The cost to manufacture the machine is low but it brings high value to its machining capabilities. Here, let's use Mach3Mill Gcode CAD/CAM software to set up a tool testing process on the created CNC milling machine. The final stage is to install and connect the electronic components to the keyboard to be able to control and operate the CNC machine accurately and precisely. The machine is controlled and operates smoothly via the CNC electrical circuit controller. The manufactured mini CNC milling machine is shown in the Figure 3.

Figure 3. The real assembly of mini CNC milling machine

3.2. Experimental results

To check the accuracy of the product after machining, samples were machined and measured. Here, processing is carried out on 3 types of materials: Plastic, aluminum and wood.

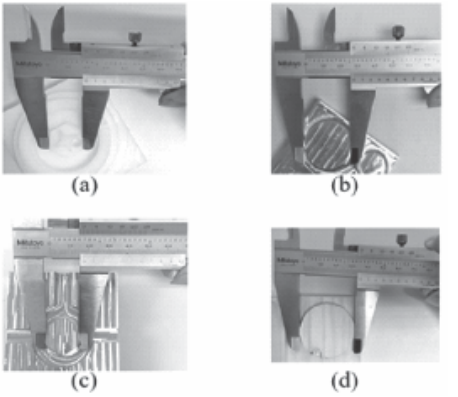

Figure 4. Some mechanical parts fabricated by mini CNC milling machine

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After machining, the part is measured and checked for dimensions is shown in the Figure 4. Measure each size 4 times and the error of that size will be calculated as the average of 4 measurements is shown in the Table. 2.

Table 2. Measurement results

Material	Fig.	Design dimensions (mm)/Actual measurement (mm)				Average error (mm)
Plastic	4(a)	20				
		19.90	19.92	19.92	19.90	0.09
Aluminum	4(b)	28				
		28.10	28.10	28.10	28.10	0.1
	4(c)	20				
		20.00	20.00	20.10	20.10	0.05
Wood	4(d)	36				
		35.90	35.90	35.90	35.90	0.1

For plastic material details, through the testing process, it was found that the smallest error of this material is 0.015 mm and the largest is 0.115 mm.

For aluminum material, the smallest error of this material is 0.008 mm and the largest error is 0.15 mm.

For wood material, the smallest error of this material is 0.01 mm and the largest error is 0.1 mm.

4. DISCUSSION AND CONCLUSION

This study focuses on development of a low-cost 3-axis milling CNC machine that is used for education in Vietnam. This machine is designed, fabricated and setup to manufacture some samples with tolerance of ±0.15 mm that can be acceptable for education purpose. The tolerance is depended on the accuracy of stepper motor, ball-screw mechanism. To improve the tolerance of machine, the linear encoder can be used to trigger the position of the cutting tool in manufacturing process. However, the cost of linear encoder is high, thereby increasing the price of machine.

The main objectives of this study can be summary as bellow:

• The machine is developed by exploited the stepper motor and ball-screw mechanism.
• The spindle motor is selected following the power calculation.
• The linear guideways are used to support the linear motion along x-, y-, and z-axes.
• All mechanical components are mounted on the gantry that is setup from aluminum frame.
• A PCB and the Mach 3 software are used to control the machine via a computer.
• The cost of machine is estimated of $ 365.

These results demonstrate that the 3-axis milling CNC machine is suitable for education in Vietnamese university.❖

References:

[1]. S.M. Ali, H. Mohsin, "*Design and fabrication of 3-axes mini CNC milling machine*". In: IOP Conference Series: Materials Science and Engineering, IOP Publishing, 2021, pp. 012005.

[2]. M.P.N. Patel, M.S.D. Pavagadhi, S.G. Acharya, "*Design and development of portable 3-Axis CNC router machine*". International Research Journal of Engineering and Technology (IRJET), 6 (2019) 1-452.

[3]. P.W. Lin, "*Design and Fabrication of a Small-scale CNC Milling Machine*". International Journal of Scientific & Engineering Research, 9 (2018) 1204-1209.

[4]. K. Bangse, A. Wibolo, I. Wiryanta, "*Design and fabrication of a CNC router machine for wood engraving*". In: Journal of Physics: Conference Series, IOP Publishing, 2020, pp. 012094.

[5]. R. Ginting, S. Hadiyoso, S. Aulia, "*Implementation 3-axis CNC router for small scale industry*". International Journal of Applied Engineering Research, 12 (2017) 6553-6558.

[6]. G. Jodh, P. Sirsat, N. Kakde, S. Lutade, "*Design of low cost CNC drilling machine*". International Journal of Engineering Research and General Science, 2 (2014) 189-196.

[7]. S.V. Deshpande, P. Karthik, N. Kumar, V. Kumar, K. Badrinaryan, "*Design and fabrication of 3-axis CNC Milling machine*". International Journal of Engineering Research and General Science, 6 (2018) 34-38.

[8]. D. Dey, S. Mondal, A.K. Barik, "*3-Axis CNC Router Modifiable to 3D Printer*". International Journal of Innovative Research in Science, Engineering and Technology, 5 (2016) 16983-16990.

[9]. N.H.B. Ambrizal, A. Farooqi, O.I. Alsultan, N.B. Yusoff, "*Design and development of CNC robotic machine integrate-able with Nd-Yag laser device*". Procedia engineering, 184 (2017) 145-155.

[10]. Đường K. Sơn, H. M. Vũ, và Đặng H. Bảo, "*Thiết kế chế tạo máy phay CNC 3 trục*". Tạp chí khoa học Trường Quốc tế Hồng Bàng, vol 26, tr 163-170,11 (2023).

[11]. Nguyễn Thị Thu Trang, Phạm Thanh Cường, Tống Ngọc Tuấn, Ngô Đăng Huỳnh, Nguyễn Hữu Hưởng, "*Thiết kế và chế tạo mô hình máy phay CNC 3 trục*". Tạp chí Khoa học Nông nghiệp Việt Nam, tr 1005-1016, 01 (2019).

[12]. Hoàng Thế Phương, "*Nghiên cứu, thiết kế, chế tạo máy CNC phay mạch in phục vụ công tác đào tạo*". Tạp Chí điện tử Khoa học và Công nghệ Giao thông, 3(1), 35-44, (2023)

[13]. M. Kovjanic, A. Kecman, N. Brdar, M. Stojcic, G. Globocki-Lakic, "*Design of laboratory 3-axis CNC milling machine by modular approach labros 100s*". ACTA Technica Corviniensis-Bulletin of Engineering, 7 (2014).

[14]. C. Manjunatha, K. Manjunath, P. Suresha, "*Design & Development of Portable Milling Machine*". International Journal of Innovations in Engineering Research and Technology (2015), 1-6.