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Research Article

Study on the design and manufacturing for the five-axis CNC machine

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ABSTRACT

The advent of technology has led to a growing demand for automation compact machines. In the past, large, heavy machines were the norm. However, these machines were often not practical for small businesses or startups, as they were expensive to purchase, maintain, and operate. They were also not portable, making it difficult to move them from one location to another. In recent years, there has been a shift towards more compact and portable machines. These machines are still capable of performing complex machining tasks, but they are much smaller and easier to use. This makes them ideal for small businesses and startups, as well as for home use. One of the most important benefits of compact CNC machines is their affordability. These machines are often much cheaper than traditional large machines. This makes them a more viable option for small businesses and startups, which may not have the budget for a large, expensive machine. Another benefit of compact machines is their portability. These machines are often small enough to be easily transported. This makes them ideal for businesses that need to move their machines from one location to another. It also makes them a good option for home use, as they can be easily stored in a garage or workshop. In addition to being affordable and portable, compact machines are also often very versatile. These machines can often be used for a variety of machining tasks, which makes them a good investment for businesses that need to be able to handle a variety of projects. Overall, compact CNC machines offer several advantages over traditional large CNC machines. They are more affordable, portable, and versatile. This makes them a good option for small businesses, startups, and home users.

Key words: CNC machine, Automation, Manufacturing, Machining, Portable

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INTRODUCTION

CNC machines are a type of automated machine tool that can be programmed to perform complex tasks with great precision. They have been used in manufacturing for many years, and their capabilities have continued to improve over time.

One of the most advanced types of CNC machines is the 5-axis CNC machine. These machines can remove materials from a workpiece along five axes, which allows them to machine complex 3D shapes that would be difficult or impossible to machine on a 3-axis CNC machine.

The Vietnamese machine tools industry is growing rapidly, but there are two main challenges: the high cost of imported machine tools and the lack of skilled machinists. To address these challenges, Vietnam needs to develop a domestic manufacturing industry for 5-axis CNC machine tools and invest in skill development programs for machinists. By addressing these challenges, Vietnam can position itself as a leader in the global machining market.

In this study, we researched and manufactured a 5-axis CNC machine using knowledge from a variety of subjects, including soft skills, engineering, mechanical drawing, physics, materials science, electrical engineering, and CAM/CAM. The machine was designed to be simple, easy to use, repair, and replace. Old components were used from scrap yards to make the machine more affordable.

METHODS AND IMPLEMENTATION

Operation Procedure of CNC Machine

The simplified operation procedure of CNC machines is presented in Figure 1. First, engineering drawings are prepared using CAD software. Then, a CNC program is written or composed based on the engineering drawings. This program includes geometrical and technical information, such as the position of the tool movement and cutting direction. The technical information also includes the choice of tools, rotational speed, and direction, cutting speed, etc. Finally, the CNC program is loaded into the machine control, the machine is started, and the program is run. The machining process is monitored, and adjustments are made as needed.

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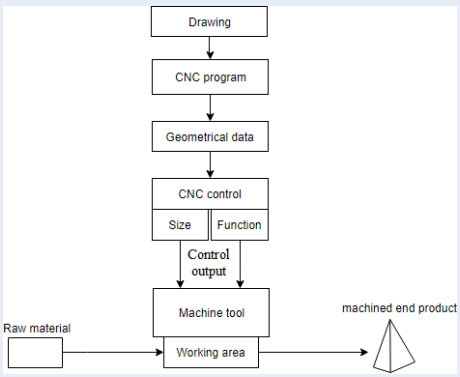

Figure 1: Simplified operation procedures of CNC machine [1]

CNC Machine Analysis

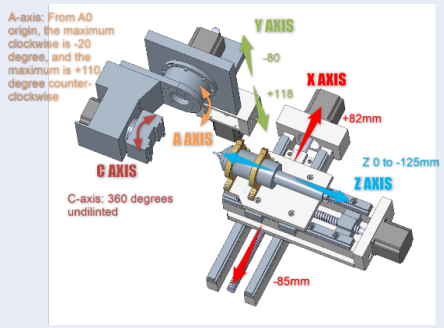

Figure 2: The stroke of 5 axis [2]

The shaft is a critical component of a 5-axis CNC machine. It is responsible for holding other parts in place and ensuring that the machine runs smoothly. The dimensions of the shaft should be approximately 800mm × 400 mm to ensure that the machine has the necessary working capacity while still being compact enough for a laboratory environment. The preliminary design of the shaft will focus on the X, Y, and Z axes which is illustrated in Figure 2, as these axes will withstand the most load during machining [3].

Integral motor spindles and separate motor spindles are two types of spindles used in CNC machines. Integral motor spindles have an inbuilt motor that can reach speeds of up to 50,000 RPM, making them ideal for high-speed applications. However, they can burn out quickly. Separate motor spindles have a separate motor that is connected to the spindle, making them more powerful and durable. However, they are not as fast as integral motor spindles.

The type of spindle that is best for a particular application will depend on the specific requirements of the application. For example, if the application requires high speeds, then an integral motor spindle would be a good choice. However, if the application requires more power and durability, then a separate motor spindle would be a better choice (Figure 3). The motor spindle is mouted on a cover support which is shown in Figure 4.

Figure 3: The Nakanishi NR50-5100 ATC spindle

We have the formula to calculate Cutting Speed (vc):

$$v_c = \frac{\pi \times D_c \times n}{1000}$$

Where:

v_c: Cutting Speed (m/min)

$\pi = 3.14$

D_c: Cutter Diameter (mm), D_c = 10 mm

n: Spindle Speed (rpm), n = 24000 rpm

Finally, we have the maximum cutting speed is:

$$v_c = \frac{\pi \times 10 \times 24000}{1000} \approx 754\ (mm/min)$$

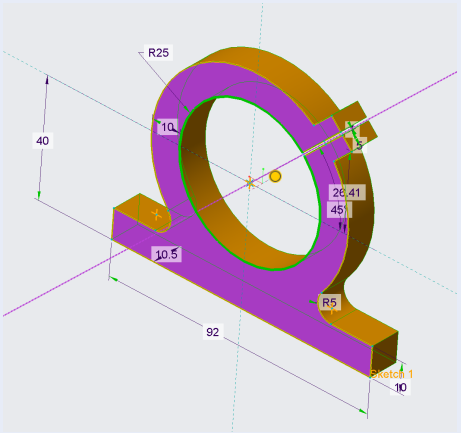

Figure 4: Preliminary design of the Spindle Cover Support

Electric motors are more efficient, lighter, and cheaper than internal combustion engines. They can also provide rapid and consistent torque at any speed, run on renewable energy, and emit no carbon into

the atmosphere. These benefits make electric motors a versatile and efficient way to convert electrical energy into mechanical energy. They are used in a wide variety of applications and are becoming increasingly popular to reduce emissions and improve efficiency. Stepper motors (Figure 5) were used in this machine with their chracteristics in Table 1.

Table 1: Motor characteristics

Type	TH Geared Type
Shaft type	Single Shaft
Maximum Holding Torque	1.25 Nm
Gear Ratio	3:6
Resolution Setting 1000 P/R	0.10/Pulse
Power Supply Input Voltage	24VDC
Power Supply Input Current	3.7A
Frame Size	60 mm
Speed Range	0~500 r/min

Figure 5: A VEXTA stepper motor

The height of the Z-axis is 770mm, and to ensure many safe factors, choose the linear guide with model TBI TRS-V with the height is 25mm and the rail length is 460 mm which is described in Figure 6.

Figure 6: TBI TRS-V linearguides

Ball screws are a type of mechanical device that converts rotary motion into linear motion which is descried in Table **??** and Table 3. They are more efficient than traditional sliding screws, requiring one-third or less driving torque. This makes them ideal for applications where power consumption is a concern.

The workable dimension of a ball crew drive is about 450 mm, choose the rolled ball screw lineup with the characteristics:

Table 2: The Z-axis ball crew drive characteristics

Type	Existing product compact nut accuracy grade C7
Standard type	THK
Shaft diameter	20 mm
Lead	10
Shaft length	450 mm
Young's modulus	2.06×105 N/mm^2
Coefficient	1

Safety calculation:

Allowable axial load (P):

$P = \frac{n\pi^2 EI}{l^2}\alpha = m\frac{d^4}{l^2}$

Where:

(P): Allowable axial load (N)

l: Distance between points of buckling load (mm), (I = 450 mm) E: Young's Modulus (2.06×10^5N/mm^2)

I: Min. Geometrical Moment of inertia of across root area (mm^4)

$I = \frac{\pi}{64}d^4$

d: Thread root diameter (mm), (d = 20 mm) n: Coefficient of the ball crew drive, n = 1 α: Safety factor = 0.5

The allowable axial load:

$(P) = \frac{1\times\pi^2\times2.06\times10^5\times\frac{\pi}{64}\times20^4}{450^2}\times0.5 = 3900\ (N)$

Compared the allowable axial load (P) to Z-axis table load, the (P) > P (3900N > 600N) –> The safety condition is accepted.

RESULTS

We successfully completed the thesis on designing and manufacturing a 5-axis CNC milling machine. We researched the principles of the machine, found the needed components, analyzed the equipment, used 3D design software to build models, set up the control system, manufactured the machine, and found places to buy embryos to test the machine.

Table 3: The X, Y-axis ball crew drive characteristics

Type	Existing product compact nut accuracy grade C7
Standard type	THK
Shaft diameter	12 mm
Lead	4
Shaft length	350 mm
Young's modulus	2.06 × 105 N/mm^2
Coefficient	1

CONCLUSION AND DISCUSSION

In this study, we successfully designed and manufactured a 5-axis CNC milling machine (Figure 7). The project involved researching the machine's principles, sourcing components, analyzing equipment, developing 3D models, setting up the control system, and manufacturing the machine. We also identified sources for materials to test the machine.

The successful design and manufacturing of the 5-axis CNC milling machine in this study not only demonstrates the practical application of complex mechanical principles but also opens up several important avenues for discussion. This process involved extensive research into the machine's operational principles and careful selection of suitable components. Crucially, the development of 3D models proved instrumental in visualizing and optimizing the design before moving to the manufacturing phase. The successful implementation of the control system highlights the effective integration between hardware and software, which is paramount for a sophisticated 5-axis CNC machine. Furthermore, identifying reliable material sources for testing ensures that future performance evaluations of the machine can be conducted systematically and dependably. These outcomes lay a solid foundation for subsequent research focused on optimizing machining performance, precision, and the machine's applicability in industries requiring high complexity.

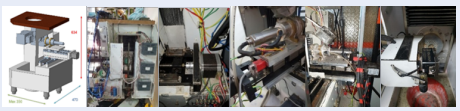

Figure 7: The 5-axisCNC milling machine

LIST OF ACRONYMS

CNC - Computer Numerical Control
CAD - Computer-Aided Design
CAM - Computer-Aided Manufacturing
RPM - Revolutions Per Minute
ATC - Automatic Tool Changer

CONFLICT OF INTERESTS

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

The author contributed 100% to this work.

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Bài nghiên cứu

Nghiên cứu thiết kế và chế tạo máy phay CNC 5 trục

Nguyễn Hải Đăng*

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TÓM TẮT

Sự ra đời của công nghệ đã dẫn đến nhu cầu ngày càng tăng về các loại máy tự động hóa nhỏ gọn. Trước đây, máy móc cồng kềnh và hạng nặng là chuẩn mực phổ biến. Tuy nhiên, những cỗ máy này thường không khả thi đối với các doanh nghiệp nhỏ hoặc các công ty khởi nghiệp vì chúng có chi phí cao khi mua, bảo trì và vận hành. Chúng cũng không có tính di động, khiến việc di chuyển chúng từ địa điểm này sang địa điểm khác rất khó khăn. Trong những năm gần đây, đã có sự chuyển dịch sang các loại máy nhỏ gọn và di động hơn. Những cỗ máy này vẫn có khả năng thực hiện các tác vụ gia công phức tạp, nhưng chúng nhỏ hơn và dễ sử dụng hơn rất nhiều. Điều này khiến chúng trở nên lý tưởng cho các doanh nghiệp nhỏ và công ty khởi nghiệp, cũng như để sử dụng tại gia. Một trong những lợi ích quan trọng nhất của máy CNC nhỏ gọn chi phí thấp. Những máy này thường rẻ hơn nhiều so với các máy lớn truyền thống. Điều này khiến chúng trở thành một lựa chọn khả thi hơn cho các doanh nghiệp nhỏ và công ty khởi nghiệp, những nơi có thể không có ngân sách cho một cỗ máy lớn và đắt tiền. Một lợi ích khác của máy móc nhỏ gọn là tính di động của chúng. Những máy này thường đủ nhỏ để có thể vận chuyển dễ dàng. Điều này khiến chúng trở nên lý tưởng cho các doanh doanh nghiệp cần di chuyển máy móc từ địa điểm này sang địa điểm khác. Nó cũng khiến chúng trở thành một lựa chọn tốt cho việc sử dụng tại gia, vì chúng có thể được cất giữ dễ dàng trong nhà xe hoặc xưởng làm việc. Ngoài việc có giá cả phải chăng và di động, máy móc nhỏ gọn cũng thường rất đa năng. Những máy này thường có thể được sử dụng cho nhiều tác vụ gia công khác nhau, điều này khiến chúng trở thành một khoản đầu tư tốt cho các doanh nghiệp cần khả năng xử lý nhiều dự án đa dạng. Nhìn chung, máy CNC nhỏ gọn mang lại nhiều ưu điểm so với máy CNC lớn truyền thống. Chúng có giá cả phải chăng hơn, di động hơn và đa năng hơn. Điều này khiến chúng trở thành một lựa chọn tốt cho các doanh nghiệp nhỏ, công ty khởi nghiệp và người dùng gia đình.

Từ khoá: CNC, máy móc, tự động hóa, chế tạo, gia công, nhỏ gọn

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