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Research Article

Proposing a solution to reduce heat for control cabinet of self-made CNC milling machine

Hung NGUYEN-QUOC[1,2,*], Toan PHAM-BAO[1,2], Luan VUONG-CONG[1,2], Nhi NGO-KIEU[1,2]

ABSTRACT

Today, CNC milling machines appear in almost all areas of production and are widely used in industries. Besides, the CNC controller using LinuxCNC software (LinuxCNC controller) is considered to be quite cheap in price and compact in size. Therefore, it can be widely used to serve the needs of self-manufacturing CNC machines and meet the tastes of the Vietnamese market. During operation, there are many factors that affect the operation of the controller such as temperature and humidity inside the cabinet, Electromagnetic Compatibility (EMC), vibration...etc. Continuous operation for a long time, the release of a large amount of heat due to electrical equipment inside the control cabinet is unavoidable. High ambient temperature inside the control cabinet can affect the stability and responsiveness of the electrical equipment, thereby reducing the accuracy of the CNC machine. The investigation based on experimental measurements will give the best estimates for the cooling option of the switchboard. But such things will take a lot of time, effort and money. By the way, Ansys CFX simulation software is considered a reliable solution to support experimental survey methods. In this paper, first of all, the authors have designed and modeled the electrical cabinet cover and the equipment inside the control cabinet into a 3D model. Then, the authors applied Ansys CFX software to simulate the temperature change inside the control cabinet after applying the cooling methods. The authors propose a solution to limit the high ambient temperature inside the control cabinet and based on the simulation results to evaluate the effectiveness, then select the appropriate method. For small-scale workshops without cooling systems, this survey method can be the right solution. To evaluate the effectiveness of the proposed method to reduce heat, the authors measured and evaluated the position tracking error of the CNC milling machine. Besides, some products have been processed to compare and evaluate the quality. Finally, based on the results obtained in the paper, some conclusions are drawn to verify the effectiveness of this research method.

Key words: CNC milling machine, LinuxCNC controller, the control cabinet temperature, Ansys CFX

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INTRODUCTION

Today, many companies in the world manufacture and supply control systems for CNC milling machines. The control systems are produced with different architectures, interfaces and partly based on the individual standards of each company in different countries. The development of a multiprotocol CNC system that allows solving this problem has been presented [1] using various peripheral devices. Control systems of CNC milling machine can be divided into closed systems and open systems generally based on an industrial PC (IPC). The CNC control system with open-source LinuxCNC software based on PC can be easily adapted to different configuration machines. The integration of equipment from different manufacturers into a LinuxCNC controller system is made easy and ensures operational reliability [2]. In addition, some users understand the openness of the control software, thereby creating personalized screen interfaces for convenient operation. In practice, commercial systems offer limited openness, as they are oriented towards a closed-loop control solution from CNC milling machines, drive systems, and automated electrical devices. Therefore, the authors are particularly interested in the research and development of a PC-based LinuxCNC controller.

During operation, the electrical components in the CNC control cabinet will generate heat, causing the ambient temperature to rise. This heat is transferred to the ambient inside the cabinet through convection heat exchange processes. In a control cabinet, there are often many electronic devices operating at the same time under different capacities, from which the temperature generated in each device is also different. It is very difficult and important to ensure the ambient temperature of the control cabinet and the internal electrical components. The consequences of

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overheating for electrical equipment are mainly reduced performance of the equipment. In particular, like transistors, the higher the temperature, the more time it takes to activate the threshold voltage, the more it affects the response time. In addition, the increase in temperature causes the internal resistance to increase, which degrades the quality of the device or causes damage. For electrical wires, when the temperature increases, the wire will lose its elasticity and strength, even causing the sheath to melt. The most serious and least noticeable consequence is overheating, which reduces the life of the equipment. For solving this problem, many solutions have been proposed to reduce temperature and ventilate the airflow in the control cabinet. In particular, the design and arrangement of equipment in the electrical cabinet (Figure 1) contributes significantly to air conditioning and has been recommended by equipment manufacturers[3].

The authors have experimentally investigated the control cabinet overheating phenomenon during long-term operating when the ambient temperature of the control cabinet increases. In which heat-generating sources are identified as AC-DC or UPS power supply, inverter, AC Servo driver, Programmable Logic Controller PLC, and HMI, Motion Control Unit (MCU) and Break outboard (BoB). The overheating process in the control cabinet is developed from two stages. The first stage is heat generation in electronic components of electrical devices. Starting from the moment when the power is turned on and the load is active, the temperature of the devices changes rapidly from 295 °K to more than 313 °K. The next stage is convection heat exchange and thermal resonance inside the control cabinet. The environment temperature inside the cabinet is much higher than the temperature outside, and the pressure difference is generated. In addition, the ambient temperature inside the cabinet is not radiated to the outside, which causes the device's temperature to increase even more due to reverse absorption. This process is repeated continuously during long-term operation, causing the device's temperature to increase significantly from 313 °K to over 323 °K. Long-term working under high ambient temperatures conditions can affect the performance as well as reducing the life of the electronic devices (Figure 2)[4].

With the increasingly modern development of science and technology, electrical equipment is manufactured for the purpose of long-term service with high durability and ability to withstand the harshness of the external environment. In addition, the high temperature inside the electrical cabinet is said to be the main cause that directly affects the performance and working ability of control devices and actuators. Programmable logic controllers (PLCs), drivers, and electronic components are particularly erratic with heat. Operating under high ambient temperature conditions makes these devices noisy, leading to erroneous control signals for the drive system. Some studies have shown that the unstable operation of control devices such as drivers and inverters will cause power loss or abnormally high voltage and current of electric motors. Thereby, causing the electric motor to generate high heat, causing incorrect operation[5,6]. Therefore, in this paper, the objective is to study the feasibility of some solutions to reduce the temperature inside the control cabinet to apply to the self-manufacturing of the controller. First, the author's team has successfully designed and manufactured a CNC controller for milling machines. The operability and performance of the controller are evaluated through actual tests. Theories of dynamic error, position error and position tracking error related to the control system are also mentioned in this paper to apply experimental measurements and evaluate the precise operation of the controller. During operation, the heat emitted from electrical components inside the control cabinet is significant and needs to be controlled to avoid thermal resonance. On the basis of the control cabinet design theory, electrical equipment is modeled into 3D CAD drawings and logically arranged into the control cabinet. Then, the authors simulate and analyze the ambient temperature inside the control cabinet using Ansys CFX software combined with experimental measurements. From the simulation results, the author's team proposes heat reduction options for the simulation, from which it is possible to choose a method suitable for actual conditions and evaluate the effectiveness. The effectiveness of this method is verified based on the results of measuring the experimental position error as well as checking the product surface quality. Finally, the authors draw conclusions to evaluate the effectiveness of this study.

MATHERIAL AND METHODS

The CNC milling machine controller.

The CNC control cabinet.

Designing control cabinets for self-made CNC milling machines is a necessary and highly complex job. Rapidly advancing automation technology coupled with a wide range of products makes design and installation more challenging. A good control cabinet can ensure the safe operation of the self-made CNC machine without any unexpected problems. Based on the configuration of the CNC milling

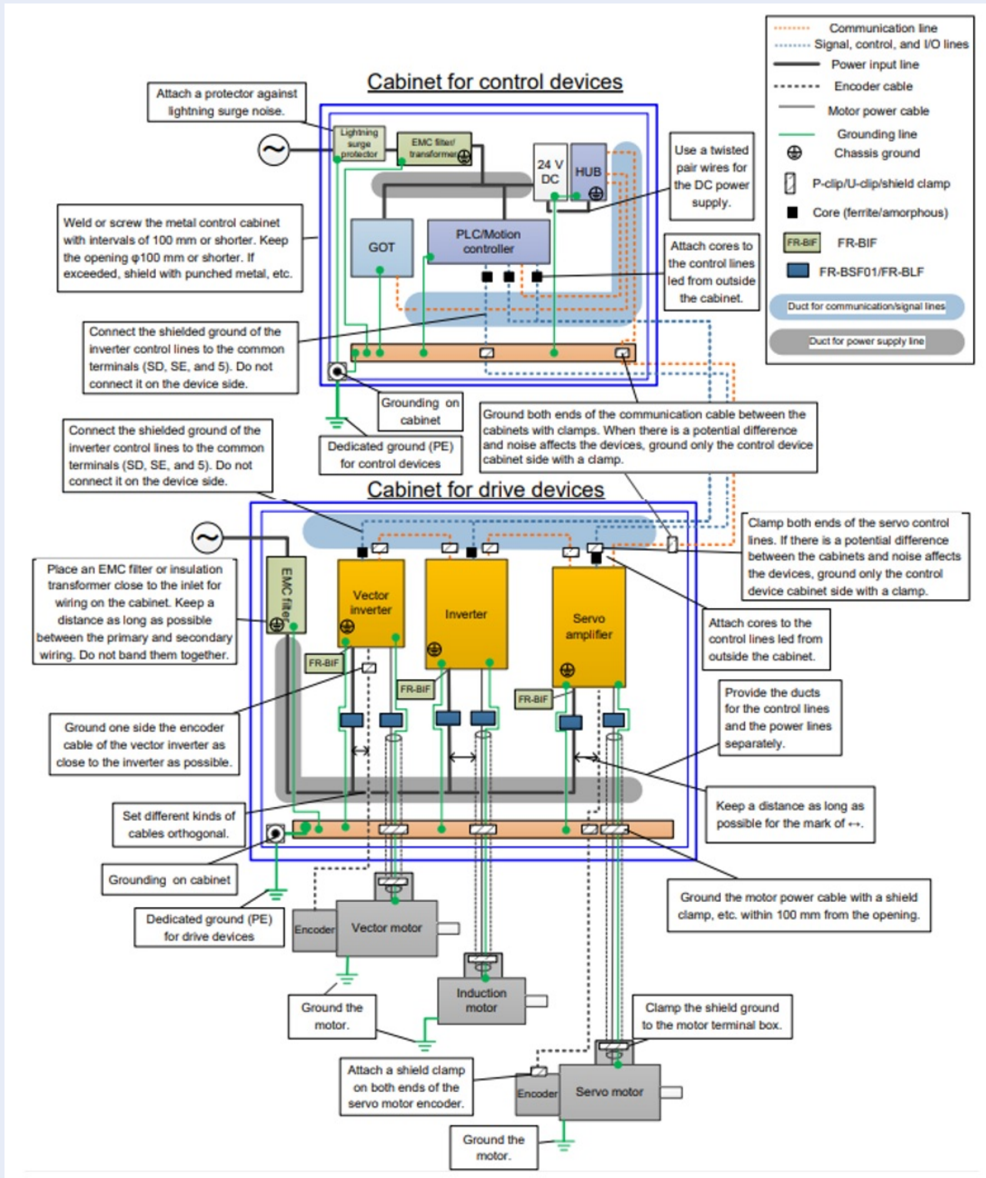

Figure 1: Recommended wiring diagram inside the cabinet (separation by dedicated cabinet).[3]

machine, the diagram of the controller includes the PC, and the hardware components in the control cabinet can be determined as shown in Figure 3.

Figure 3 shows that inside the PC, there is a PCI-e interface card that performs the control signal generation function, and the motion control unit in the control cabinet has the function of receiving control signals. The Breakout Board (BoB) in the Motion control unit are used to connect to the Servo pack which controls the motor's motion. In addition, the BoB is also connected to output relays to receive signals from peripheral devices such as limit switches, power buttons, emergency stop buttons, etc. 110VAC and 24VDC voltage supplies are used for electrical power equipment.

After determining the component devices for the controller, the authors arranged them on the control panel to determine the required workspace and size for the control cabinet. The control cabinet has been arranged as shown in Figure 4. Problems with control signal interference are a particular concern for safety and performance. Therefore, keeping the source of interference away from the control signal transmission/receiving system or low voltage wiring should

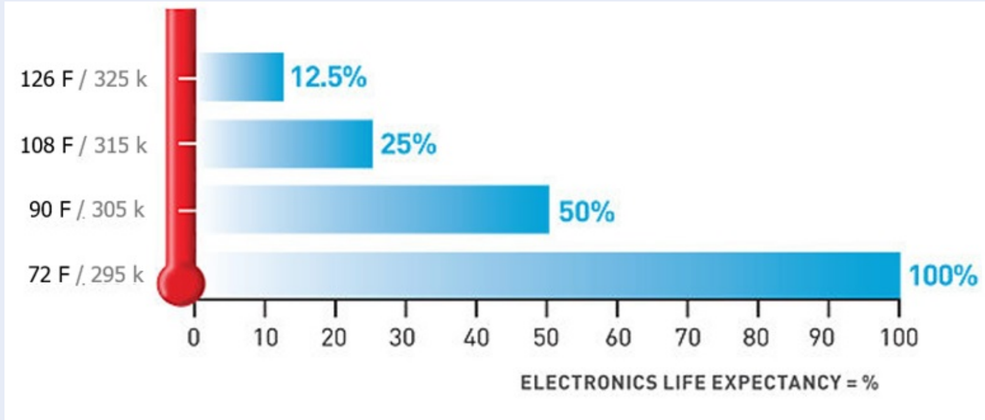

Figure 2: The life expectancy of electronics.[4]

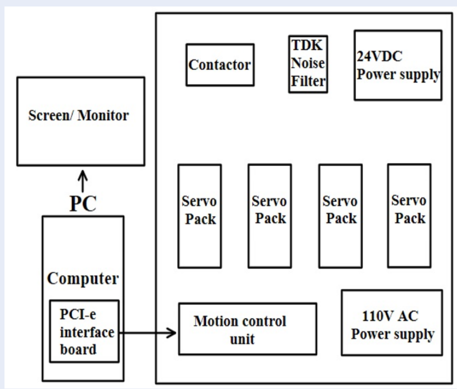

Figure 3: The diagram of the controller.

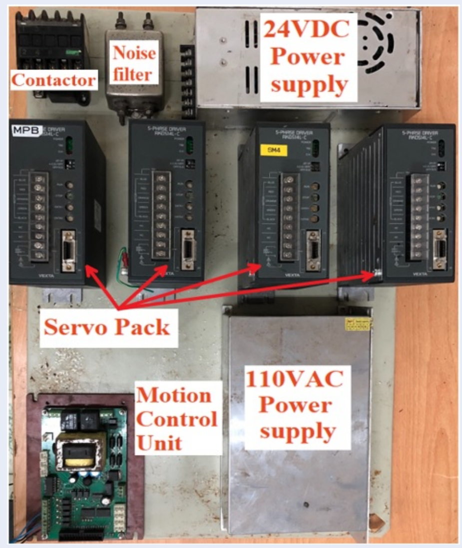

Figure 4: The construction of self-made control cabinet

be kept separate from the control circuitry and signal wiring.

Inside the control cabinet designed as shown in Figure 4, the inverter is considered a source of interference, so it has been isolated.

Solution for reducing heat.

When the working environment is clean air with a standard laboratory temperature of 300 °K, we can use a cooling fan solution to convection air. However, the fan should be accompanied by dust extraction slots fitted with dust filters to minimize the amount of dust entering the cabinet. This solution is commonly used and is called forced convection cooling, as shown in Figure 5.

In addition, the hot air in the control cabinet can be cooled by a dedicated air conditioner. The special structure of the air conditioner is to separate the air inside the electrical cabinet from the outside, helping to prevent dust, garbage, and chemicals from entering from the outside. This method is considered a closed-loop cooling solution. The feature of the air conditioner is that it can be heat pumped, so it can be used to cool cabinets located in high-temperature environments from 308 °K to 328 °K. Meanwhile, the method of cooling by compressed air (vortex cooling) through the filter system is ejected from the expansion device, pushing the hot air out. Widely used in places with lots of dust, the air contains corrosive substances. However, two above methods are very expensive and are often applied to control cabinets with special operating conditions. Therefore, fan has been selected for

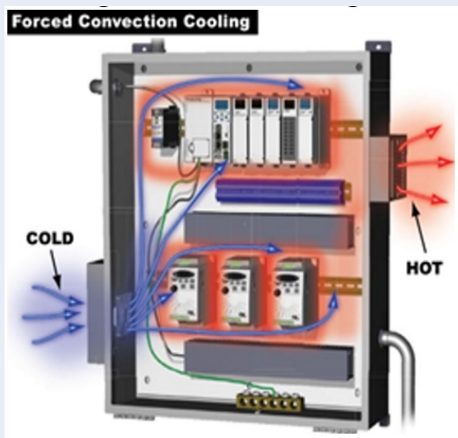

Figure 5: The forced convection cooling.[7]

the forced convection cooling method to match the actual conditions and reduce costs in this study.

Theory of CNC machine tools dynamic error.

Definition of dynamic error.

Today, CNC milling machines are commonly used in many areas of manufacturing processing. For the purpose of increasing production capacity, the speed of the milling machine is usually pushed up as fast as possible. Therefore, ensuring the accuracy of the milling machine operating at high speed is a concerning problem. Machine tool errors are the deviation of the tool position relative to the workpiece, mainly caused by quasi-static and dynamic errors. The quasi-static error is when the machine tool does not move (spindle does not rotate or worktable does not move) or the speed of motion is low, including geometric and errors by thermal generated dynamic errors have not been clearly defined so far and are generally considered to be related to feed-drive motion. The goal of dynamic error control is to achieve high trajectory accuracy. When the feed rate was increased from 150 mm/min to 8000 mm/min, the trajectory error of the circle-diamond-square tool path was increased from 6μm to 11 μm[8]. Not only the feed rates but also the acceleration/jerk and the tool path curvature affect the dynamic errors, and the trajectory errors[9]. In this section, a simple model for the feed-drive system[10] (Figure 6) is presented to investigate the cause of dynamic errors,

The mechanical structure and control of one stage in a CNC machine tool are shown in Figure 6. This stage moves by controlling the rotation of the motor through a system of ball screws and linear rails. Motor control is divided into two types: closed-loop control and semi closed-loop control. To have an overall control scheme for CNC milling machines, Zhao et al.[11] systematized and classified the errors related to each stage. Then their definitions like control, dynamic, kinetic/thermal, and process errors, as shown in Figure 7.

In modern control systems for CNC machines, closed-loop control is often used because of its high accuracy and reliability. For closed-loop control, along with the encoder built into the motor, encoders or linear scales are installed directly on the machine's stages to achieve high accuracy. Some studies[12] indicate that the higher the feed rate, the greater the dynamic error. At the feed rate of 10m/min, the dynamic error accounts for 80% of the total position errors. Other causes of CNC milling machine position tracking errors can also be considered from control system failures, including system response[13] and state feedback control[14]. When the electrical equipment inside the control cabinet operates at high temperatures, control system errors will arise under the influence of high ambient temperature. The term steady-state error is used for the error that occurs between the deviation of the input value set to the control system and the output value after it has stabilized. Steady-state errors can arise from the non-linear behavior of electrical devices in the control system. The steady-state error is influenced by confounding factors or phase delay[15] which causes the following error for digital control.

The heat effect problem in CNC machining, especially position accuracy, is often considered as cutting heat on the technological system (cutting tools, fixtures, workpiece, drive systems of axes) because these objects directly affect position errors. Therefore, the approach of this paper can be considered quite unique. The ambient heat in the electrical cabinet can affect the life, voltage value, amperage, performance and energy consumption of the equipment in the electrical cabinet. Heat affects the hardware of the devices, not the control algorithm. Therefore, this article has clearly stated the influence between the ambient temperature in the CNC machine control cabinet to the control devices. Since then, the errors arising from the hardware of the control devices causing the dynamic errors on the CNC machine and related research works have been presented. When the hardware has a thermal error, especially a status error (delay), it is difficult for the CNC machine to operate normally, the machining error is obvious, easy to recognize and must be corrected immediately because this is a basic error for CNC machines.

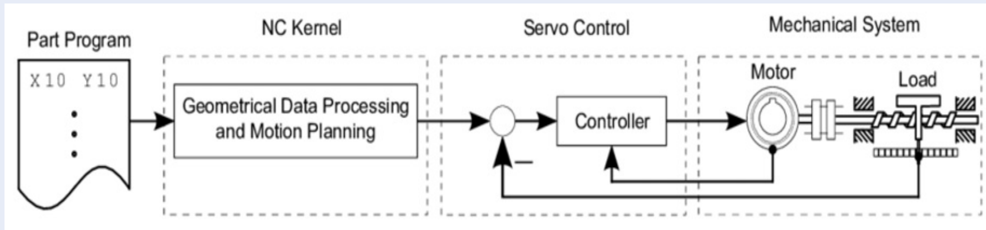

Figure 6: The control structure of one axis in a CNC machine tool. [10]

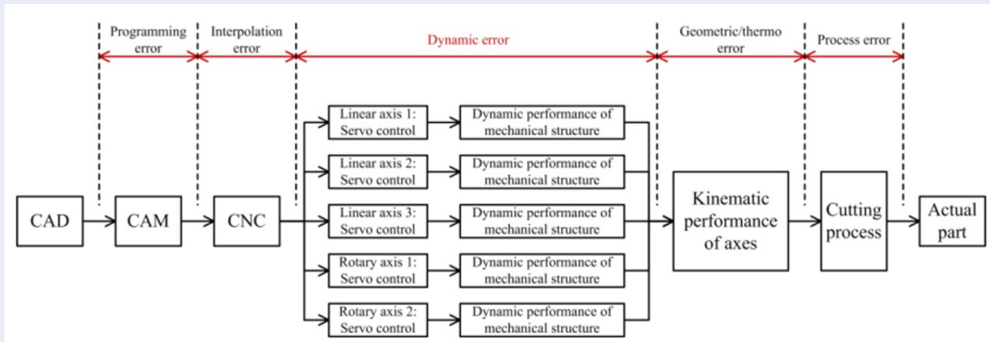

Figure 7: Classification of errors in CNC machine tools. [11]

Theory of determining position error.

Absolute vector survey in which the position error of the extrapolated coordinates is expressed as:

$$\triangle \vec{r} = \sum_{i=1}^{n} \frac{\partial \vec{r}_i}{\partial q_i} \triangle q_i \quad (1)$$

In there: Δq_i is the error of the point q_i at O_n (is the origin), O_n at the n link.

The absolute value of the distance error of the n link is expressed as:

$$|\triangle \vec{r}| = \sqrt{(\triangle x_n)^2 + (\triangle y_n)^2 + (\triangle z_n)^2} \quad (2)$$

Inside: $\triangle x_n$, $\triangle y_n$, $\triangle z_n$ is the corresponding error of the coordinates at O_n when surveyed in the reference system, so the position error is a function of the Descartes coordinates of the point and is defined by:

$$\triangle r_n = \int_x \int_y \int_z \triangle r_n (x,y,z) \, . \frac{dxdydz}{V} \quad (3)$$

If we are only interested in the mean error of a finite number of points, we can use the concept of position arithmetic mean error in terms of:

$$\triangle r_{cp} = \sum_{i=1}^{n} \left(\frac{\triangle r_i}{n} \right) = \sum_{i=1}^{n} \left(\frac{\sqrt{(\triangle x_n)^2 + (\triangle y_n)^2 + (\triangle z_n)^2}}{n} \right) \quad (4)$$

Ansys CFX simulation.

Ansys CFX is a computational fluid dynamics (CFD) software tool that delivers reliable and accurate solutions quickly and robustly across a wide range of CFD and Multiphysics applications. CFX is recognized for its outstanding accuracy, robustness, and speed in simulating turbo-machinery, such as pumps, fans, compressors, and gas and hydraulic turbines. FEA can be used to model conductive heat transfer in solid components such as electronic components and electrical circuits [16]. The components in the control cabinet are modeled in 3D and then using Ansys software for meshing. The 3D modeled construction of the control cabinet is shown in Figure 8.

Mesh quality is achieved by three levels, including coarse meshing, medium meshing and fine meshing. Meshed models will be evaluated for quality according to 2 criteria ”Element Quality” and ”Orthogonal Quality”. These are two standard criteria in evaluating the heat transfer process and the effect of temperature on materials. The research chooses to mesh with fine mesh level through the evaluation criteria to create accuracy for the obtained results. The problem of simulating heat reduction for the control cabinet for two options of fan placement (behind and on the side of the cabinet) is set up.

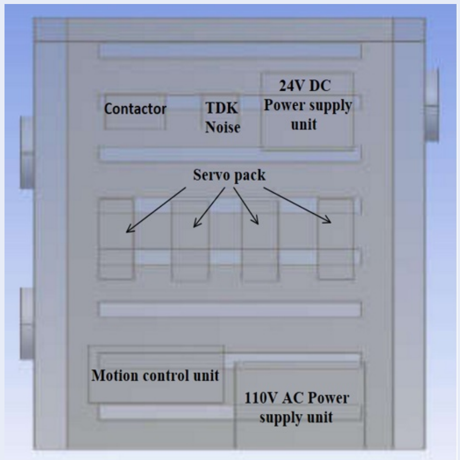

Figure 8: The 3D modeled construction of the control cabinet

- Option 1: the fan placed behind the cabinet, there has a number of fans are two, with one fan blowing air from outside into the control cabinet and one fan drawing hot air from inside the control cabinet to the outside. The model of option one is shown in Figure 9a.
- Option 2: the number of fans is 3, with two fans blowing cold air from outside into the electrical cabinet (lower left side of the cabinet) and one fan drawing hot air from inside the cabinet (upper right side of the cabinet), shown as Figure 9b.

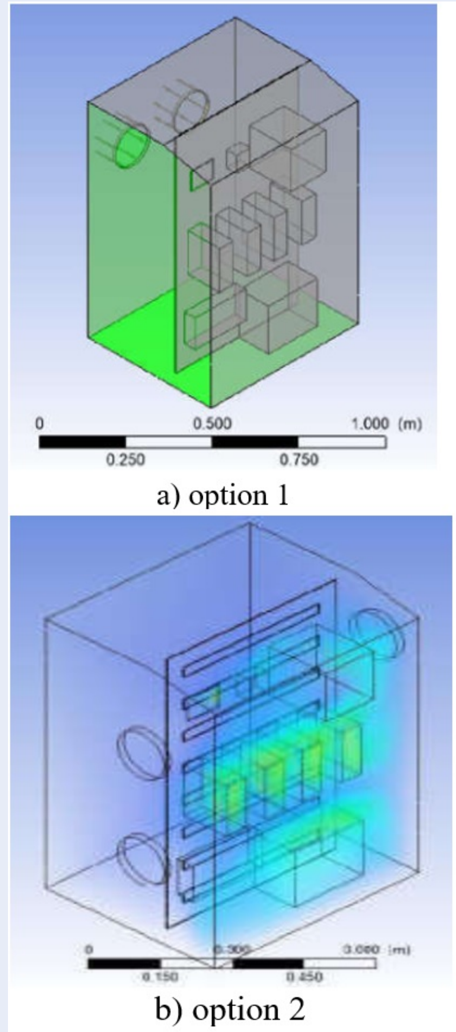

Figure 9: Control cabinet model

RESULTS AND DISCUSSION

CNC milling machine preparation.

The structure of the CNC milling machine is designed and manufactured in the double column type, which can withstand good vibration and high rigidity. The CNC milling machine tool is divided into two systems. One is a translation system, which includes translation X-axis and Z-axis. The other is a workpiece system that provides for translation Y-axis and rotation axis A. In which, the translating X, Y, Z axes of the CNC machine used a ball-screw feed drive system, the rotating axis through the gearbox reducer. The maximum travel ranges of the X, Y, and Z translating stages are 800 mm, 500 mm, and 250 mm, respectively. The CNC milling machine has a large travel range, and under the high-speed operation condition, a ball-screw feed drive system was chosen. Ball-screw feed drive systems have been widely used in high-precision machine tools. The specifications of the CNC milling machine tool for this investigation have been represented in Table. 1.

Thermal analysis results.

Through the evaluation criteria, the research chooses meshing on a high mesh level (smooth) with 139660 nodes and 534023 elements to create accuracy for the obtained results. The Figure 10 shows the results of model meshing with high mesh level.

In which, initial conditions include: Problem type (Analysis Type) suitable for the problem of stability (Steady State), Fluid and Particle Definitions at Air (307°K, 1 atm), INLET and OUTLET setup, set temperature, thermal conductivity for each element in the control cabinet as shown in Table 2.

Firstly, the authors simulated the temperature of the control cabinet in the natural state without using any

Table 1: The specifications of the CNC milling machine tool.

Stages	Travel (mm)/degree	Accuracy (μm)	Maximum travel speed (mm/min)
X-Axis	800mm	25	2000
Y-Axis	500mm	25	2000
Z-Axis	250mm	25	2000
A-Axis		25	2000

Table 2: Temperature and heat flux before installing the cooling fan system.

Components	Radiation coefficient	Initial temperature (°K)	Radiation intensity (W/m^2)
Breakout Board	0.87	325,4	566.78
Noise filter	0.59	323	428.11
Contactor	0.93	312.8	504.82
Servo pack 1	0.91	316.2	515.79
Servo pack 2	0.91	316.2	515.79
Servo pack 3	0.91	316.2	515.79
Servo pack 4	0.91	316.2	515.79
24VDC power supply	0.85	313.2	463.76
110VAC power supply	0.85	314.4	470.90

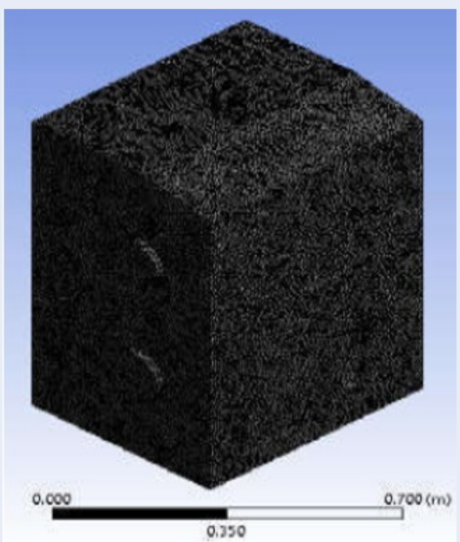

Figure 10: The results of model meshing with high mesh level (smooth).

cooling method to investigate the initial heat. The results show that with the two ventilation holes of the original control cabinet at the back, the heat generated from electrical equipment is concentrated in the front. The average temperature of the devices is above 317.067 °K, and the highest is BoB with 325.4 °K. This heat was partially trapped by the flat panel so that the hot air only recirculated in front and was not allowed to escape. During the operation of the control cabinet, the hot air will move turbulently inside the cabinet and increasingly. This will be very dangerous for the control cabinet to operate for a long time. After investigating the initial heat inside the control cabinet, heat reduction options are set up, and simulation is carried out. The analysis results of the options are shown in Figure 11a and Figure 11b.

The simulation results show that after applying the cooling fan, the initial average temperature of over 317.06 °K has been significantly reduced to over 311.07 °K with option 1 and 309.55 °K with option 2. The temperature simulation results are listed in Table 3.

From the results in Table 3, it shows that option 2 with the solution of setting a fan on the side of the cabinet helps to reduce heat better than option 1. The better heat reduction solution will help the equipment work better, ensuring durability and device stability. At the same time, the authors propose to create more holes in the flat plate, helping air to circulate and exchange

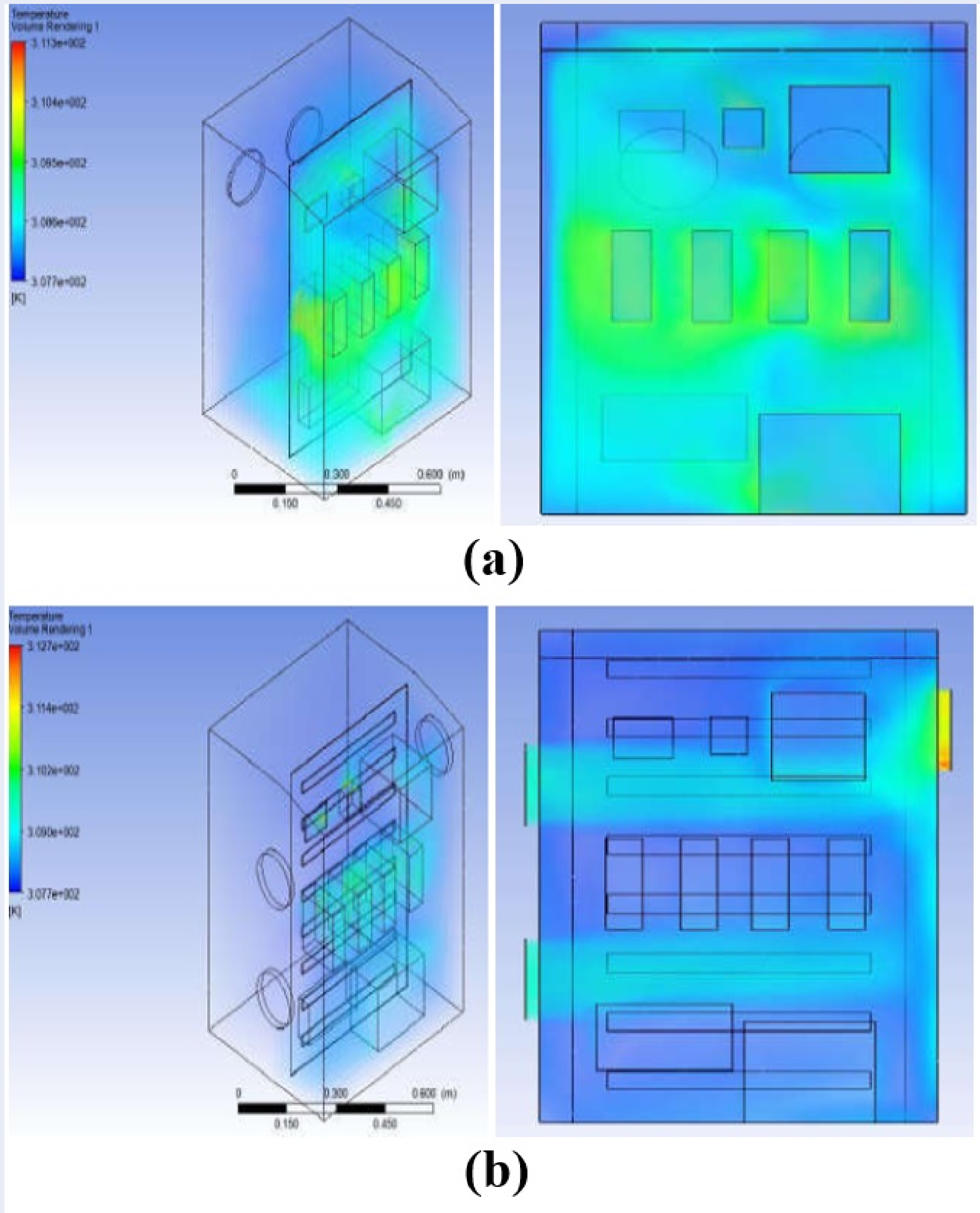

Figure 11: a. The temperature of the control cabinet with option 1, b. The temperature of the control cabinet with option 2.

heat better. According to the heat transfer characteristics of electrical equipment, the process of reducing heat by using cold air mainly occurs in the form of convection. Comparing the air flow speed simulation results are listed in Table 4 and as shown in Figure 12 of the two options will help us easily evaluate and choose the appropriate option.

The use of blower and suction fans to enhance heat exchange this process becomes forced convection. The places near the fan will have a larger flow rate, and the heat dissipation coefficient will also be large. The temperature will drop faster and better. Based on that, rearranging electrical equipment as well as arranging exhaust and blowing fans will help us be proactive in designing control cabinets. Besides, it can be seen that the result of the decrease in temperature and wind speed inside the control cabinet with option 2 is better than option 1. The air flow in the cabinet is evenly cir-

Table 3: The temperature simulation results

Components	Initial temperature (°K)	Temperature Option 1 (°K)	Temperature Option 2 (°K)
Breakout Board	325.4	311.76	309.60
Noise filter	323	312.67	310.10
Contactor	312.8	309.9	308.88
Servo pack 1	316.2	310.81	309.56
Servo pack 2	316.2	311.13	309.95
Servo pack 3	316.2	311.20	309.9
Servo pack 4	316.2	311.18	309.77
24VDC power supply	313.2	309.53	308.81
110VAC power supply	314.4	311.45	309.38
Average	317.06	311.07	309.55

Table 4: The air flow speed simulation results.

Components	Option 1		Option 2	
	Temper-ature (°K)	Speeds (m/s)	Temper-ature (°K)	Speeds (m/s)
Breakout Board	311.76	0.952	309.60	1.737
Noise filter	312.67	1.327	310.10	1.59
Contactor	309.9	1.413	308.88	2.101
Servo pack 1	310.81	0.896	309.56	0.962
Servo pack 2	311.13	0.887	309.95	0.938
Servo pack 3	311.20	0.707	309.9	0.877
Servo pack 4	311.18	0.914	309.77	0.92
24VDC power supply	309.53	1.406	308.81	1.776
110VAC power supply	311.45	0.690	309.38	1.006

culated and the cooling air from the outside is brought to exactly where it needs to dissipate heat, reducing the heat inside the cabinet.

The experimental measurement result.

There are many additional tools to serve the needs of precision measurement and alignment for multi-axis CNC milling machines. The authors using Ditron D60-3V digital linear scale systems to measure the accuracy of CNC milling machines. Ditron D60-3V digital Scales (Figure 13a) are used as a stand-alone measuring system (Figure 13b) with a digital display for three output axes, which can be convenient for installation. Along with high operability and accuracy, the resolution of systems can be customized from 0.001 - 0.005 mm. The measurement systems can be set up as shown in Figure 13c.

In this article, the position tracking error measurement of CNC milling machines is mentioned. Position error has many causes such as toolpath error, mechanical part error, assembly error, load during cutting and cutting force, dynamics during acceleration and deceleration…etc. Therefore, it is difficult for research to give precise quantitative results instead of general qualitative results. To limit the above causes, the authors have taken measures to control the accuracy of the machine. Besides, it is necessary to ensure the stability of the technology system (cutting depth, feed-rate, spindle speed), vibration, cutting force, tool wear, tool trajectory...etc. From there, it is proved that the position error is caused by heat generated in the electrical cabinet of the CNC machine

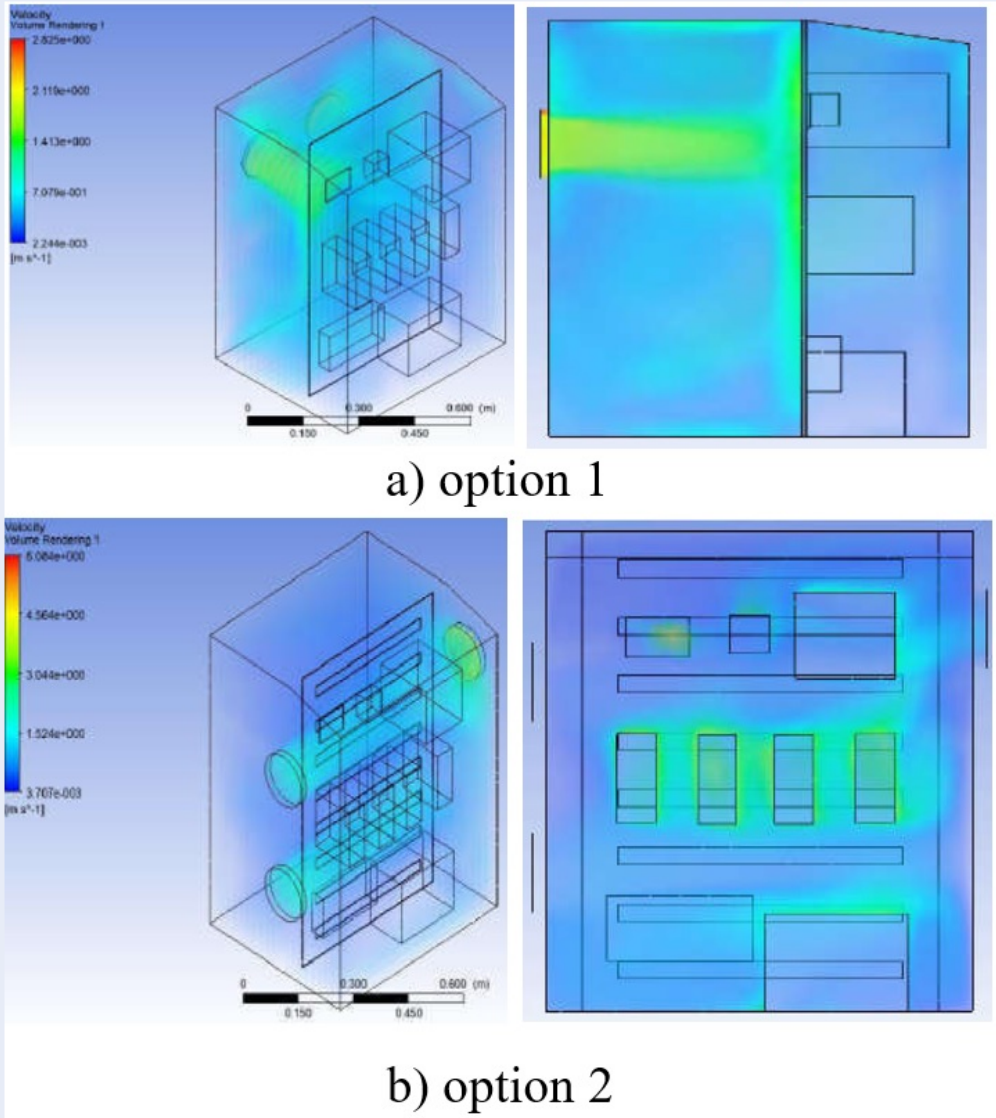

Figure 12: The air flow speed of the control cabinet with 2 option

The investigation is carried out in two case studies. Case study 1 is the control cabinet operates under a high-temperature environment (over 325.4°K) and case study 2 is the control cabinet operates under temperature environment after reduced (at 309.6°K). The experimental measurement methods are performed by moving the axes in a circular orbit with a radius r of 50 mm in turn on the X-Y, X-Z, Y-Z planes. The experimental process was performed without the impact of external forces (cutting forces), the feedrate, motion trajectory and test position on the CNC milling machine were the same in both cases. The position coordinates of some special points are recorded in Table 5 and Table 6.

From the error results in Table 5, the average error of the 3 translation axes X, Y, Z is respectively: $\overline{\triangle X_1}$ = 0.027mm, $\overline{\triangle Y_1}$ = 0.024mm, $\overline{\triangle Z_1}$ = 0.023mm. Based on the theoretical of position error, following equations (1)-(4), the experiment maximum position error is $\overline{\triangle r_{cp1}}$ = 0.0428mm≈42.8μm.

From the error results in Table 6, the average error of the 3 translation axes X, Y, Z is respectively: $\overline{\triangle X_2}$ = 0.024 mm, $\overline{\triangle Y_2}$ = 0.023mm, $\overline{\triangle Z_2}$ = 0.022 mm. Based on the theoretical of position error, following equation (2)-(5), the experiment maximum position error is $\overline{\triangle r_{cp2}}$ = 0.0398 mm≈39.8 μm.

Comparing the position errors from the experimental measurement results in Table 5 and Table 6, it can

Table 5: Measuring results in case study 1.

Plane	X-Y (mm)		X-Z (mm)		Y-Z (mm)	
Angle (0)	X_1	Y_1	X_2	Y_2	X_3	Y_3
0	50	0	50	0	50	0
10	49.265	8.660	49.266	8.704	49.264	8.704
20	47.009	17.077	47.010	17.081	47.011	17.081
170	-49.212	8.709	-49.213	8.706	-49.215	8.706
180	-49.974	0.023	-49.974	0.022	-49.976	0.022
-10	-49.267	-8.707	-49.212	-8.661	-49.216	-8.660
-160	46.957	-17.125	46.960	-17.124	46.961	-17.125
-170	49.213	-8.708	49.266	-8.705	49.264	-8.706
-180	49.975	-0.024	49.975	-0.021	49.975	-0.021

Table 6: Measuring results in case study 2.

Plane	X-Y (mm)		X-Z (mm)		Y-Z (mm)	
Angle (0)	X_1	Y_1	X_2	Y_2	X_3	Y_3
0	50	0	50	0	50	0
10	49.265	8.660	49.264	8.704	49.264	8.704
20	47.009	17.079	47.010	17.081	47.010	17.081
170	-49.216	8.707	-49.214	8.705	-49.215	8.706
180	-49.975	0.023	-49.974	0.022	-49.977	0.022
-10	-49.214	-8.705	-49.215	-8.661	-49.216	-8.660
-160	46.958	-17.125	46.962	-17.123	49.961	-17.123
-170	49.216	-8.706	49.215	-8.705	49.214	-8.706
-180	49.976	-0.024	49.975	-0.021	49.976	-0.021

be seen that these errors tend to decrease gradually. This is represented by the position error value in the three directions X, Y, Z, and the total position error. From the accuracy value in Table 1, it can be determined that the total allowable position error value of the CNC milling machine is 43.3μm. The total position error in case study 1 (42.8 μm) is larger than in case study 2 (39.8 μm). Both case studies are smaller than the total allowable position error of the CNC milling machine (43.3 μm). This shows that during operation, the temperature generated inside the control cabinet can also affect the operation ability as well as the accuracy of the CNC milling machine. However, the position error of the X-direction in case study 1 ($\overline{\triangle X_1}$ = 27μm) has exceeded the allowable accuracy of the CNC milling machine (25μm) and vice versa in case study 2 has achieved the required accuracy ($\overline{\triangle X_2}$ = 24μm). Therefore, limiting the ambient temperature inside the control cabinet is necessary to help the CNC milling machine operate stably and achieved the desired accuracy. However, the authors need to implement more evaluation activities based on the products after experimental processing. Experimental processed products are also divided into 2 case studies similar to the position error measurement method, as shown in Figure 14.

The sample model selected for the experiment processing product is small size 50x50x8 mm with many complex motifs. The above products are processed with the same cutting mode and feed-rate and processed on the same material. The intermediate factors that can cause falsification of the test product processing results have also been eliminated or minimized by the authors. The above efforts are aimed at demonstrating the influence of heat generated inside the control cabinet on control devices, thereby affecting the

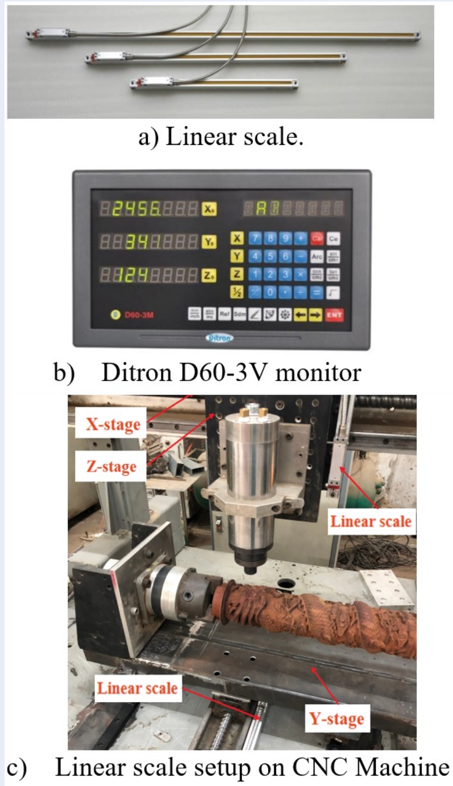

Figure 13: Setup Ditron D60-3V digital linear scale system on CNC machine.

Figure 14: Experimental processed products

quality tof the processed product.

Comparing the surface quality of the processed product from 2 case studies as shown in Figure 14. It is easy to recognize that the product quality from case study 2 is better than case study 1. During the simultaneous movement of the axes, the rapid and continuous change of the acceleration is determined by the operating stability of the control cabinet. From there, decide on the ability to operate synchronously and limit the deviation of the tracking trajectory of the CNC milling machine. Therefore, the authors can confirm that for the CNC milling machine to operate stably for a long time, it is necessary to limit the ambient temperature inside the control cabinet.

CONCLUSIONS

In this paper, an experimental investigation is presented based on the influence of the temperature inside the control cabinet on the correct operation of the CNC milling machine. Based on the results of simulation analysis, recommendations can be made on the selection of a suitable and effective heat reduction method. To evaluate the influence of the temperature inside the control cabinet on the position tracking error of the CNC milling machine, the authors conducted experimental measurements with precise measuring instruments as well as based on the products. machined. With the results obtained from this study, the following conclusions can be drawn:

- Using Ansys CFX simulation software, the authors surveyed and proposed solutions to reduce the ambient temperature inside the control cabinet. The simulation results only have relative meaning because the authors have simplified the included control cabinet model. To achieve accurate simulation results, we need to consider other components inside the electrical cabinet such as wires, signal wires, trays, etc. However, in this paper, based on the simulation results, the authors have selected a solution for the placement of the cooling fan according to option 2 and achieved certain efficiency.

- The effectiveness of the cooling solution for the control cabinet is evaluated through the experimental position error measurement results shown in Table 5 and Table 6. The average errors in the three directions XYZ tend to decrease. The total position error tends to decrease. It can be reduced by approximately 3μm from 42.8μm to 39.8μm. However, the position error of the X-direction in case study 1 ($\overline{\triangle X_1}$ =27μm) has exceeded the allowable accuracy of the CNC milling machine (25μm) and vice versa in case study 2 has achieved the required accuracy ($\overline{\triangle X_2}$) =24μm). This further confirms that the temperature inside the electrical cabinet can affect the position accuracy of the CNC milling machine as well as the surface quality of the product.
- There are certain limitations in this paper. However, from the obtained results, the authors can convince that it is very important to design the control cabinet as well as choose the appropriate heat reduction plan in the electrical cabinet. The survey method proposed in the article can be applied to design before manufacturing control cabinets for other CNC milling machines in the future.

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LIST OF ACRONYMS

CNC: Computer Numerical Control
BoB: Breakout board.
PLC: Programmable Logic Controller.
MCU: Motion Control Unit.

CONFLICT OF INTEREST

Nhi NGO-KIEU, Hung NGUYEN-QUOC, Toan PHAM-BAO, Luan VUONG-CONG, declare that they have no conflict of interest.

CONTRIBUTIONS

Nhi NGO-KIEU designed the research. Hung NGUYEN-QUOC, Toan PHAM-BAO, and Luan VU ONG-CONG processed the corresponding data. Hung NGUYEN-QUOC wrote the first draft of the manuscript. Nhi NGO-KIEU helped to organize the manuscript. Toan PHAM-BAO revised and edited the final version.

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Bài nghiên cứu

Đề xuất giải pháp giảm nhiệt cho tủ điều khiển máy phay CNC tự chế tạo

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TÓM TẮT

Ngày nay, máy phay CNC xuất hiện trong hầu hết các lĩnh vực sản xuất và được ứng dụng rộng rãi trong các ngành công nghiệp. Bên cạnh đó, bộ điều khiển CNC sử dụng phần mềm LinuxCNC (LinuxCNC controller) được đánh giá là có giá thành khá rẻ và kích thước nhỏ gọn. Do đó, nó có thể được sử dụng rộng rãi để phục vụ nhu cầu tự chế tạo máy CNC và đáp ứng thị hiếu của thị trường Việt Nam. Trong quá trình hoạt động, có nhiều yếu tố ảnh hưởng đến hoạt động của bộ điều khiển như nhiệt độ và độ ẩm bên trong tủ, khả năng tương thích điện từ (EMC), độ rung ... vv. Hoạt động liên tục trong thời gian dài, việc tỏa ra một lượng nhiệt lớn do các thiết bị điện bên trong tủ điều khiển là điều khó tránh khỏi. Nhiệt độ môi trường cao bên trong tủ điều khiển có thể ảnh hưởng đến sự ổn định và khả năng đáp ứng của thiết bị điện, do đó làm giảm độ chính xác của máy CNC. Việc khảo sát dựa trên các phép đo thực nghiệm sẽ đưa ra các ước tính tốt nhất cho phương án làm mát của tổng đài. Nhưng những việc như vậy sẽ tốn rất nhiều thời gian, công sức và tiền bạc. Nhân tiện, phần mềm mô phỏng Ansys CFX được coi là một giải pháp đáng tin cậy để hỗ trợ các phương pháp khảo sát thực nghiệm. Trong bài báo này, trước hết nhóm tác giả đã thiết kế và mô hình hóa vỏ tủ điện và các thiết bị bên trong tủ điều khiển thành mô hình 3D. Sau đó, nhóm tác giả áp dụng phần mềm Ansys CFX để mô phỏng sự thay đổi nhiệt độ bên trong tủ điều khiển sau khi áp dụng các phương pháp làm lạnh. Nhóm tác giả đề xuất giải pháp hạn chế nhiệt độ môi trường cao bên trong tủ điều khiển và dựa trên kết quả mô phỏng để đánh giá hiệu quả từ đó lựa chọn phương pháp phù hợp. Đối với các phân xưởng quy mô nhỏ không có hệ thống làm mát, phương pháp khảo sát này có thể là giải pháp phù hợp. Để đánh giá hiệu quả của phương pháp đề xuất để giảm nhiệt, các tác giả đã đo và đánh giá sai số theo dõi vị trí của máy phay CNC. Bên cạnh đó, một số sản phẩm đã được xử lý để so sánh và đánh giá chất lượng. Cuối cùng, dựa trên kết quả thu được trong bài báo, một số kết luận được rút ra để kiểm chứng tính hiệu quả của phương pháp nghiên cứu này.

Từ khoá: Máy phay CNC, Bộ điều khiển LinuxCNC, Nhiệt độ tủ điều khiển, Ansys CFX

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