International Journal of Multiphysics
Volume 18, No. 3, 2024
ISSN: 1750-9548

The Ergonomic Design Appearance of Vertical Machining Center

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Abstract

To improve the accuracy of machining and quality of the equipment used, it is important to consider the human–machine environment when designing a vertical machining center. The designer should make full use of ergonomic principles to design the appearance of the product. This paper considers the variety of unit components that feature in the design of the CY-VMC850 vertical machining center based on its function and aesthetics. The authors propose an ergonomic design for the vertical machining center. In light of applications of the equipment, the vertical machining center and its functional components were designed using data based on human–machine theory and achieved good results. Fully consider the ergonomic equipment structure configuration, machine interface layout, operator's comfort level and psychological state and other factors, effectively improve the operating environment of operators, to reduce operator fatigue, improve the efficiency of complex parts processing.

Keywords: Ergonomics, vertical machining center, appearance, design, human-computer interaction, efficiency

1. Introduction

The vertical machining center is automated machining equipment that uses digital information to control the motion of the machine tool and its machining process. It is equipped with a tool magazine and an automatic tool changer. Once the workpiece is clamped on the workbench, the equipment can continuously carry out milling, boring, and drilling. This process is highly concentrated, which significantly reduces the time available to adjust the workpiece for clamping and measurement, When using this equipment to obtain good quality parts with high processing accuracy, the structural configuration of the vertical machining center, the modes of input and output of the machine, the structural layout of its operation panel, difficulty of operation of the equipment, accuracy of its operation, and the operational psychology directly affect the accuracy of machining of the parts. When designing the exterior of the vertical machining center, it is important to consider the human–machine environment and apply the principles of ergonomic design to ensure the convenience, practicability, and comfort of use of the equipment during its operation. This paper proposes such an ergonomic design based on the appearance of each unit component used in the CY-VMC850 vertical machining center. The entire set of design can create useful human–computer interaction, effectively improve the operator's working environment, reduce fatigue, and improve production efficiency. The research and design described here can also serve as reference for designers.

In the context of external protection and exterior design in vertical machining centers in recent years, the curved glass surface and acrylic board have been used, and exhibit a strong sense of modernity. At the Beijing International Machine Tool Show in 2019, different designs of the machining center were shown. The appearance design based on a curved shape evinces a soft, intimate, and rounded psychological feeling. The shape is shown in Figure 1. The appearance design based on the straight line gives a feeling of regularity, stability, and generosity, and this shape is shown in Figure 2. In addition, the machining center is designed with a bevel on the front, and the aim is to make the overall appearance more vivid. The relevant shape is shown in Figure 3.

In research in ergonomics on machining centers, CNC lathes, and CNC milling machines, Li[1] used transparent material for the machine tool casing to form a machine observation window for its processing work area. Liu and Chen[2] analyzed the humanized method of design for CNC lathes and proposed the ergonomic design of these unit components in the appearance of CNC lathes through examples. Peng et al. [3] design allows the operator to better understand the status of the machining center. He proposed a humanized design for the observation window of the machining center. Zhang[4] discussed the shape of CNC machine tools from the perspectives of safety, heat dissipation, and color. Cai[5] designed and analyzed the control mechanism of CNC machine tools using ergonomics, and Liu and Liu[6] combined ergonomics, computer science, and cognitive psychology to study their functional and operational characteristics. They obtained a set of design principles for the human–machine interface of these tools. Liu et al.[7] obtained the ergonomic principles of the design of a CNC machine tool by analyzing the height of its lathe console, control panel, and the handle of the joystick. Based on ergonomics and user experience, Yan and Zhuang[8] designed a human–machine interface in the context of the appearance of CNC lathes. The interaction of the human–machine interface of the design object was optimized and a scheme for the design of the CNC lathe was obtained. Liu et al.[9] used the turning and milling machine tools as an example to discuss the application of ergonomics to the design of the appearance of equipment. Ko[10] proposed the application of fuzzy theory to assembly design and operationally complex evaluation models with the aim of enhancing the balance between assembly design and complexity of user operation for efficient decision making. If the mechanical structure, appearance, and design of the vertical machining center are inappropriate, the efficiency of the operator decreases, and he/she can easily be fatigued or discomforted. This increases the chances of accidents. Therefore, the appearance of the vertical machining center and its human–machine interface must be based on the mechanical structure of the vertical machining center, and should consider the human–machine environment. The appearance, mechanical structure, performance and functions of the products to be implemented must be designed with the physical and mental attitudes of the machine operators in mind. The relevant research is lacking in China. The humanized design of the vertical machining center must be studied using such elements as the appearance of the machine, choice of color, the comfort of use of the operation panel, and choice of exterior materials to meet the needs of customers.

Figure 1 Curved shape-based appearance

Figure 2 Straight line design

2. Materials and Methods

2.1 Analysis of research method

The protective cover design of the vertical machining center has the following requirements, as shown in Table 1.

International Journal of Multiphysics
Volume 18, No. 3, 2024
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Figure 3 Beveled appearance

(1) Coordination. As the exterior image of the machining center, the structural design of the outer protective cover must be coordinated with the overall shape.

(2) Ergonomic design. The designers should integrate knowledge and principles of ergonomics from the perspective of the operator. To provide operators with the safest and most comfortable working space, the design allows for emotional integration between the operator and the machine.

(3) Harmony of function and shape. The design of the protective cover of the vertical machining center must consider the conditions of production. An aesthetically pleasing appearance of protection for the machine tool protection should also be considered.

(4) Color. The vertical machining center is operated by humans, and its colors should be adjusted according to the worker’s activities and aesthetic requirements.

(5) The design must consider the impact and requirements of humans regarding the machine tool, the space occupied by the human body, the force required on the tool, the worker’s operating habits, and time. The overall height of the machining center was controlled within the range of height and arm length to enables the worker to operate and routinely maintain the equipment[11].

Table 1 The main structure dimensions of adults in China

Gender / Measurement item	Man	Woman
Height (mm)	1678	1570
Weight (kg)	59	52
Upper arm length (mm)	313	284
Forearm length (mm)	237	213
Thigh length (mm)	465	438
Calf length (mm)	369	344

When operating the equipment, workers sometimes need to consider not only its main structural dimensions, but also the design in combination with the horizontal dimensions of their own bodies. Research has revealed the standard horizontal dimensions for adults in China shown in Table 2.

Table 2 Standard size of adults in China

Gender / Measurement item	Man	Woman
Chest width (mm)	280	260
Chest thickness (mm)	212	199
Shoulder width (mm)	375	351
Maximum shoulder width (mm)	431	397
Hip width (mm)	306	317
Bust (mm)	867	825
Waistline (mm)	735	772

2.2 Research in ergonomics on the appearance design of vertical machining center

The main contents of the research here are as follows:

(1) Ergonomic theory provides data on the size of the human body and range of human activity. Its results can be adapted to the physiological and psychological needs of the operator when designing the device. This can help reduce fatigue in operators working on the equipment for long periods[12].

(2) In designing the appearance of the operation panel of the vertical machining center, the human－machine interface is crucial. This ensures the reliable transmission of processing information during the operation of the equipment.

(3) The designer should use the graphic design-related features of standard operating buttons in the human－machine interface design of the vertical machining center. The operator's habits are studied to ensure that the machining operation can be carried out accurately[13].

(4) In the appearance design of the vertical machining center, designers should combine ergonomic methods, and the design should consider the shape, color, material, and observation window in each direction as well as the working space.

2.3 Ergonomic design of appearance of vertical machining center

In the appearance design of the vertical machining center, it is necessary to make full use of experiential knowledge of vision, hearing, and touch to improve the efficiency and quality of the machined parts[14]. The appearance design of the vertical machining center includes a protective cover, double door, door handle, an observation window on the door, a side observation window, electric control cabinet, and control system of the CNC system. The mechanical structure affects the external components as well as the overall appearance of the device. Because the vertical machining center has a large volume, its protective cover is the largest component. Its structural composition is shown in Figure 4 and 5. The vertical machining center's appearance thus determines the style of design[15]. The visual effect of its appearance directly determines the user's first impression of the CNC machine. The protective door is located in the middle of the front of the main structure, and is important in its appearance. The observation window designed on the protective door is the visual center of the front of the vertical machining center, and provides a finishing touch to the appearance of the equipment. Observation windows have various shapes, and different windows are composed of different materials. Figure 4 and 5 provides a schematic illustration of the machine.

3. Discussion of Results

3.1 Ergonomic design of protection units of vertical machining center

The appearance and design of the protective parts of the vertical machining center affect people's evaluation of the overall performance of the machine tool. The design features an ergonomic analysis of components of the protection unit. These include fixed covers on the left and right, protective doors, handles, and observation windows.

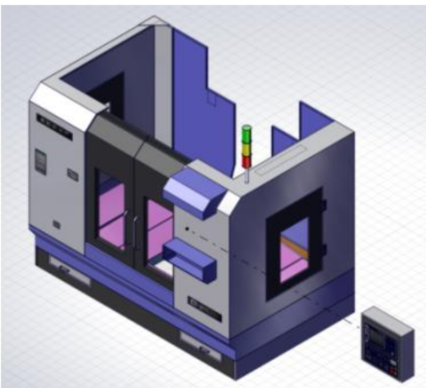

Figure 4 Appearance of the vertical machining center

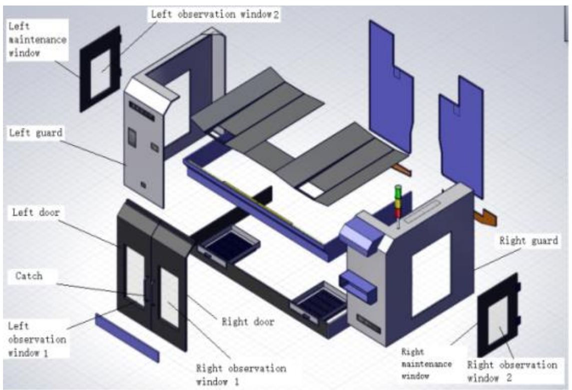

Figure 5 Diagram of vertical machining center

The corresponding minimum functional and optimal functional sizes are: The minimum functional size is equal to the percentile of body size plus the corrected functional value.

(1) The best function size is equal to the percentile of body size plus correction function value plus psychological correction.

(2) Therefore, the minimum functional size of the height of the service door on the left and right guards is 1570 mm (1545 + 25 = 1570). The best functional size is 1685 mm (1545 + 25 + 115 = 1685), as shown in Figure 6. The front of the right side of the shield is equipped with a CNC control box.

3.1.1 Ergonomically designed protective cover of vertical machining center

Figure 4 and 5 show an assembly drawing and a diagram of each unit of the protective cover of the vertical machining center. The left and right shields do not directly affect the work of the operator, but their structural shape affects the appearance of the vertical machining center.

A maintenance door is usually designed on the left and right shields of the vertical machining center, and an observation window is installed on the door to maintain and repair the equipment, and to observe the machining process. According to the GB/T12985-91 national standard, the 50th percentile of the height of Chinese adult males was chosen as the design standard.

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(2) The minimum functional size of the height of the service door on the left and right guards is 1570 mm (1545 + 25 = 1570). The best functional size is 1685 mm (1545 + 25 + 115 = 1685), as shown in Figure 6.

The front of the right side of the shield is equipped with a CNC control box. The mounting position and dimensions of the control box must also be ergonomic, as shown in Figure 7. According to the 50th percentile of the height of adult men in China set as design standard, the height of the display center of the CNC control box from the ground should be 1590 mm (according to Formula 1, 1568 + 25 = 1593 mm. Simplified to 1590 mm). The maintenance door should be designed to ensure that the upper body of a maintenance operator can easily enter the machine tool[16]. The size of the maintenance door is based on the 50th percentile of the width of the shoulders of Chinese adult men as design standard. The minimum functional width of the maintenance door is 700 mm, and its dimensions are shown in Figure 6.

3.1.2 Ergonomic analysis of front protective door of vertical machining center

The front protective doors of the vertical machining center are key to the appearance design of the machine tool, and act as functional components. Their shapes and sizes have an important influence on the convenience of operation of the vertical machining center. There are two sliding doors, on the left and right. It is necessary to consider that they need to be compatible with the protective covers[17].

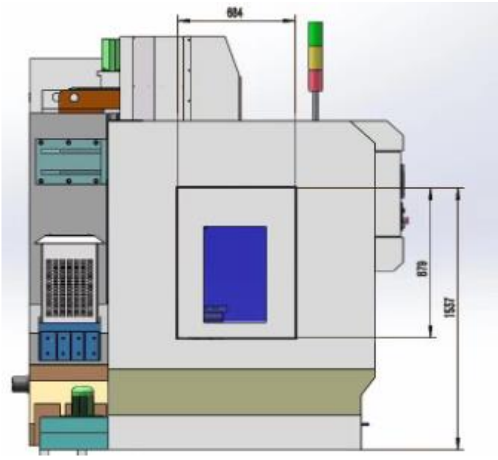

Figure 6 Dimensional drawing of the service door box on the right shield

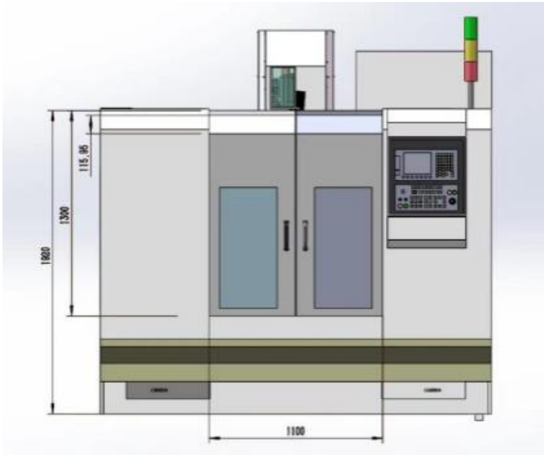

Figure 7 Dimensional drawing of the CNC control on the left guard of the machine tool

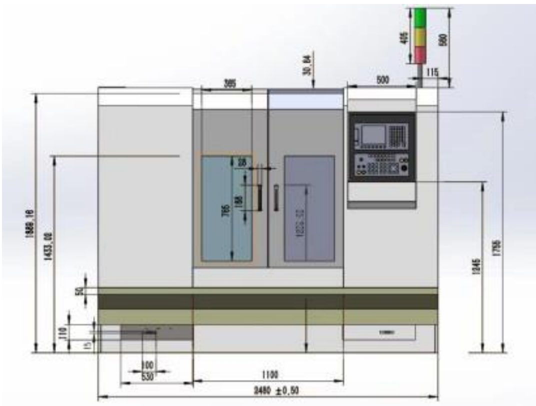

Figure 8 Dimensional drawing of the left and right protective doors in the front of the machine

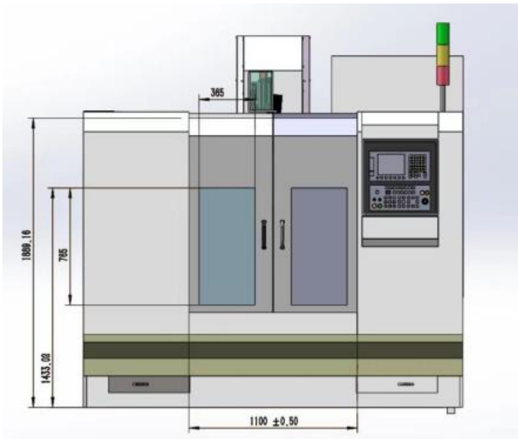

Figure 9 Dimensions of the viewing window on the front sliding door

The sizes of the sliding doors should be such that the maximum size when they are open is greater than the maximum size of the workpiece, and a certain margin should be left to facilitate the entry and exit of the workpiece. If the operator handles the workpiece himself/herself, the left and right sliding doors are opened 100 mm wider than the workpiece being processed. If the workpiece is loaded and unloaded by a crane, the width of the doors after opening is 200 mm greater than the workpiece. Figure 7 and 8 are dimensional drawing of the front protective door of the vertical machining center. The width of the left and right guard doors is 1100 mm, which satisfies the size requirements of the workpiece.

3.1.3 Ergonomic analysis of observation window of vertical machining center

When the CNC machine tool starts the machining process, the operator usually stands in front of the protective door. Through the observation window on the door, the operator observes the condition of the workpiece. The operator's range of observation is thus the main factor in the design of the window on the protective door. The height of the observation window is based on the 50th percentile of the height of adult men in China as well as the best horizontal field-of-view of the operator (15 degrees left and right). The best vertical field of view is 25 degrees and lower 30 degrees to ensure that the operator has an appropriate field of view. Figure 9 shows a 765×385 mm observation window. Its height is 1433 mm, which satisfies the design requirements[18].

To ensure that the operator can clearly observe the machining process through the observation window, it is typically composed of one of the following: acrylic sheet, plexiglass, tempered glass, explosion-proof glass, and laminated glass. Different types of equipment feature different materials with varying thickness according to their requirements. Because the workpiece is machined by a high-speed rotating tool on the vertical machining center, the risk in machining is higher, The viewing window should be strong enough to withstand the impact of a machined part or the rotating tool. Laminated glass with a thickness of 8mm was thus used as material for the observation window.

3.1.4 Ergonomic analysis of vertical door handle of vertical machining center

The handle on the protective door of the vertical machining center is the component that the machine operator touches the most. Its design thus has a significant influence on the safety, comfort, and efficiency of the operator[19].

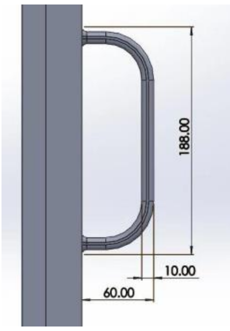

Figure 10 Front sliding door: upper handle, size 1

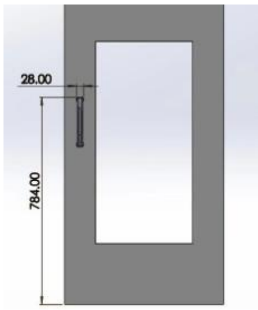

Figure 11 Front sliding door: upper handle, size 2

The height of the position of the handle on the left and right guard doors should be set according to 1024 mm, the 50th percentile of the height of the elbows of adult Chinese men. Formulae 1 and 2 can be used to determine that the height of the center of the handle should be 1024 mm + 25 mm = 1050 mm, as shown in Figures. 9, 10, and 11. Figure 9 shows the shape of the front of the vertical machining center, including the positions of the left and right protective door handles. Figures.10 and 11 show their design dimensions. The width of the handle should be based on the hand length of the human. The width of the vertical handles is set to 15~28 mm, and its length depends on the width of a person's palm, generally between 71 and 97 mm. A suitable length of the handle is thus 125~195 mm, and its cross-sectional shape should ensure some area of contact between the handle and the palm. The larger the area of contact of the handle, the smaller the compressive stress when using it. Most handles on the guard doors are round, cross-sectional, rectangular, or elliptical. In order to prevent relative the palm from slipping on the handle, the handle with an elliptical cross-section is selected, with dimensions of 188×28 mm.

3.2 Ergonomic analysis of CNC control box in vertical machining center

As a highly automated processing equipment, the function of the vertical machining center needs to satisfy the processing requirements of the parts and demands on the performance of the operator. A suitable human-machine interface helps ensure this.

3.2.1 Ergonomic analysis of the installation of CNC control box in vertical machining center

When he/she operates the vertical machining center, the operator along with the machine tool and the operating environment form an integral operating platform. Using design data, a reasonable working height of the CNC control box of the vertical machining center is determined, and the requisite range of the arms of the operator for appropriate activities is satisfied to set a reasonable distance between the CNC control box and the vertical machining center[20]. In Figure 12, the maximum radius that the arms can reach is 720 mm, the radius of the most powerful grip is 600 mm, and the optimal operating height is 1018~1670 mm. According to ergonomic principles, the operating device and display device for the control area should be placed at a range of height of 900~1600 mm.

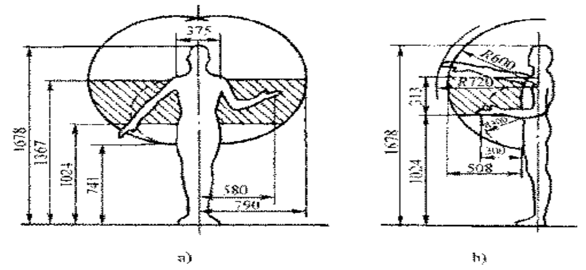

Figure 12 Operating height and working range of operation standing position

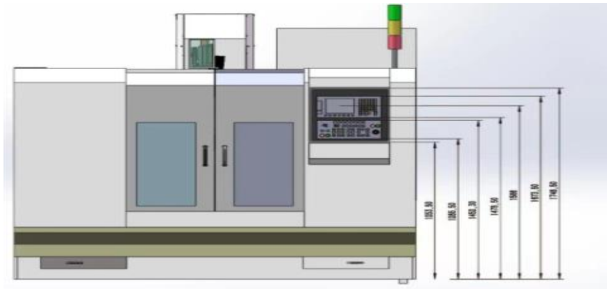

Figure 13 Position of CNC control box according to operator comfort

For the vertical machining center, the operation panel is mounted on the control box of the CNC system. As shown in Figure 13 the lower part of the machine’s operation panel is 1254 mm high, and the width of the panel is 184 mm. The height of the human–machine interface center is 1430 mm and the upper part of the CNC system’s operation panel is 1673 mm high. This design satisfies the requirements of the field-of-view of the human eye for observation and the range of optimal operating areas for the operator.

3.2.2 Ergonomic analysis of human–machine operation panel on CNC control box of vertical machining center

The human﹣machine interface of the CNC control box consists of two parts: the operation panel of the numerical control system, and the machine’s operation panel. The standard settings of the human﹣machine interface shown in Table 3 were used. Figure 14 shows the design of the human﹣machine interface of the operation panel on the CNC control box of the vertical machining center, including the operation panels of the numerical control system and machine. The design follows the principle of the golden section, which makes it easy to arrange keys on the operation panel. Keys on the panel are classified according to function. The human﹣machine interface is divided according to visual flow, distribution of sight, and convenience of operation.

The chosen size of the square buttons is 18×18 mm, the radius of the

button is 10 mm, radius of the emergency button was 25 mm. Figure 15 shows a 3D assembly drawing of the CNC control box, featuring the CNC operation panel and the machine’s operation panel.

Table 3 Melting points and elemental analyses

Manipulator and manipulation	Basic Size/mm		Operate Force/N	Working Ditance/mm
	Diameter (Round)	Side Length (Square)		
Button: Press with your index finger	3–5 10 12 15	10×10 12×12 18×18 20×20	1–8	<2 2–3 3–5 4–6
Button: Press with your finger	18–30		8–35	3–8
Button: Press with your palm	50		10–50	5–10

Finally, the layout of the human–machine interface is coordinated with the overall color of the machine tool, as shown in Figure16 and17 shows an exploded view of the structural components of the vertical machining center. Equally importantly, this design was applied to machinery production.

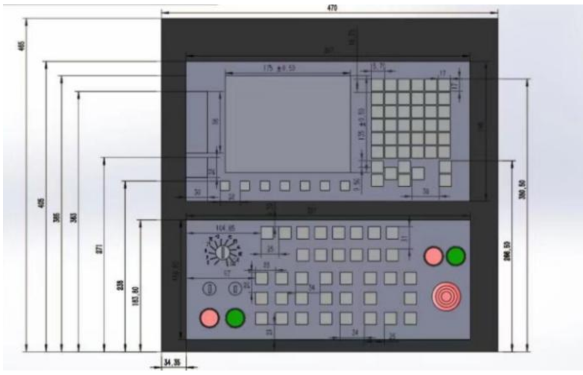

Figure 14 Dimensional drawing of the human–machine interface design

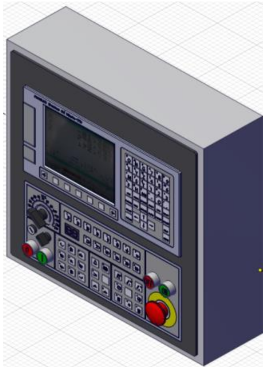

Figure 15 3D assembly drawing of the CNC box

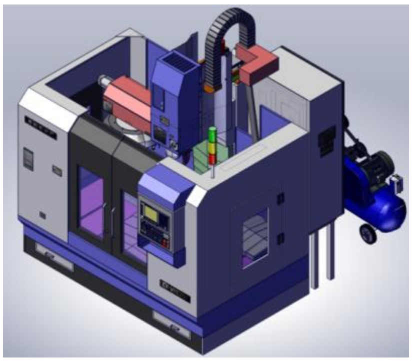

Figure 16 Rendering of machine design

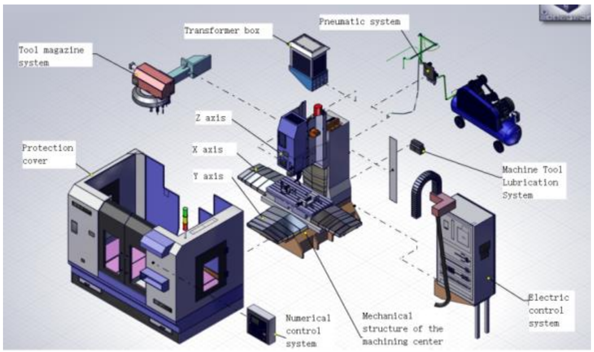

Figure 17 Structure of the vertical machining center: exploded view

4. Conclusions

The design and analysis of the appearance of the vertical machining center and related units in this paper make it clear that the appearance design of the CNC machine tool should be based on principles and methods of ergonomics. The design should follow principles of convenience, safety, and comfort, thus highlighting the "people-oriented" concept of design. The designer should analyze and study the overall appearance of the vertical machining center, human–machine panel, position of installation of the CNC control box, color and related appearance of the local unit, and the design program. It can optimize the human–machine environment, improve the function of the vertical machining center, and improve human–computer interaction for the operator. This method of design has important use value and practical significance for promoting a humanized design of high-end CNC machine tools in China.

Acknowledgments

This project was funded by the Major Special Research and Development Project in Yunnan Province (202402AE090027), the Science Research Fund Project of the Yunnan Provincial Department of Education (2019J0189) and the Southwest Forestry University Teaching reform project (YB202310), Liberal Arts Program of Southwest Forestry University (11050218).

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