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Exploration of CNC System for Polyurethane Sponge Cutting Device

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Abstract: Polyurethane sponge has been widely used in various industries such as automotive, medical, and furniture due to its excellent properties. With the continuous development of society, consumers' demand for the quantity and quality of polyurethane sponge continues to grow. At the same time, the demand for diversified and personalized sponge products is becoming increasingly prominent, which puts higher demands on the production technology of polyurethane sponge. Cutting, as a crucial process in sponge production, has a decisive impact on the quality and production efficiency of sponge products. However, the current level of automation in the CNC system of polyurethane sponge cutting machines in China is relatively low, mainly relying on a combination of manual and mechanical methods to complete cutting work, which cannot meet the growing demand for sponge products in the current market. This article is based on the architecture of "industrial computer+motion controller", combined with the characteristics of polyurethane sponge cutting process and the requirements of automation control, and conducts in-depth research on the CNC system of sponge cutting machine. Based on the mechanical structure characteristics of sponge cutting machine tools, a CNC system hardware platform with industrial computer and MC1004 motion controller as the core was constructed. In terms of software development, a hierarchical modular design concept is adopted to propose the upper computer software for the CNC system of sponge cutting machine, which can achieve communication function with MC1004, support the parsing, display and editing of graphic files, generate machining programs, perform machining simulation and tracking, etc. In response to the problem of excessive empty stroke in sponge processing paths, ant colony algorithm was introduced to optimize the processing path, significantly improving processing efficiency. The ultimate goal is to achieve stable operation and high-precision machining of the CNC system for sponge cutting machines, which is beneficial for improving the efficiency of the machine and enhancing the competitive advantage of polyurethane sponge cutting machines in the market. This provides a theoretical basis for the innovative research and development of polyurethane sponge cutting machines in the future.

Keywords: Sponge Cutting Machine; Layered Modularization; CNC System; Path Optimization.

1. Introduction

Polyurethane sea has the characteristics of low density, good resilience, strong sound absorption, and wear resistance. Its excellent sound absorption performance can effectively reduce noise pollution and improve the comfort of the living environment; Meanwhile, its excellent resilience makes polyurethane sponge perform well in shock absorption, which is of great significance for improving product quality and service life [1]. In the automotive industry, polyurethane sponge is widely used in components such as seats and interior parts to improve ride comfort and reduce vehicle noise. In the field of construction, polyurethane sponge, as an insulation material, can effectively improve the insulation performance of buildings and reduce energy consumption. In addition, polyurethane sponge also plays an irreplaceable role in furniture manufacturing, sports equipment and other fields. With the increasing demand for quality of life, the demand for polyurethane sponge is also constantly increasing, especially in terms of environmental protection, energy saving, comfort, etc., and the advantages of polyurethane sponge are more prominent. It is expected that the market demand for polyurethane sponge will continue to grow in the future.

Since the reform and opening up, with the progress of the times and the development of automation control technology, the traditional and inefficient sponge production method mainly based on manual cutting has been eliminated by China's sponge manufacturing industry. However, compared with traditional developed industrial countries in Europe and America, the CNC system technology content of sponge cutting machines developed domestically is insufficient, and the level of intelligence and automation is not high, which has a significant gap with traditional developed industrial countries in Europe and America. In addition, the CNC system of polyurethane sponge cutting machines abroad is expensive, and the installation and maintenance costs are high in China. Most small and medium-sized sponge production enterprises in China cannot afford the purchase and maintenance costs of CNC systems for foreign sponge cutting machines. Therefore, most of the cutting machine CNC systems currently used by sponge production enterprises in China are developed domestically, and their automation level is not high, which cannot complete fully automated processing, resulting in low efficiency and raw material utilization of sponge product production. Moreover, due to the need for manpower for cutting, labor and production costs increase, making it difficult for China's sponge products to achieve industrial upgrading and improve competitiveness in the international market.

Therefore, in order to further promote the development of the domestic polyurethane sponge manufacturing industry and accelerate the upgrading of the domestic sponge manufacturing industry, it is necessary to develop a set of CNC systems for sponge cutting machines with independent intellectual property to address the prominent problems of low automation level, low cutting accuracy, and low production efficiency in the current development of China's sponge manufacturing industry. By developing the CNC

system for sponge cutting machines, the automation and intelligence level of the sponge manufacturing industry has been improved. This not only fully responds to the national policy of "Made in China 2025", promotes the development and transformation of China's sponge manufacturing industry towards intelligent manufacturing, comprehensively improves the production efficiency of sponge manufacturing enterprises and the production quality of sponge products, but also helps to adjust and optimize the production structure of China's sponge manufacturing industry, effectively reducing the cost of sponge production.

2. Research Status of CNC System for Polyurethane Sponge Cutting Machine

In the 1960s, in industrialized countries such as Europe and America, due to the increase in labor scale and costs, in order to effectively reduce labor costs and improve the quality and profit of sponge products, developed industrial countries such as the United States, Japan, and France introduced automation technology into the sponge manufacturing industry and highly automated sponge cutting devices. Firstly, advanced cutting methods such as laser cutting, mechanical punching cutting, ultrasonic cutting, and water jet cutting have been developed for cutting. In terms of cutting technology, computer technology has been introduced, utilizing the excellent processing performance of computers, combined with graphic knowledge and intelligent algorithms, to complete functions such as sponge sample design, sample information processing, intelligent layout of samples, automatic optimization of cutting paths, etc., improving the comprehensive utilization rate of sponge raw materials and the production efficiency of sponge products.

At present, against the backdrop of rapid development in the global manufacturing industry, the research and application of CNC systems for cutting machines have reached a high level in developed countries. From a technical perspective, foreign cutting machine CNC systems have achieved high integration and intelligence. Developed countries represented by Germany, Japan, and the United States commonly use advanced control algorithms and high-speed processors in their cutting machine CNC systems, resulting in significant improvements in cutting accuracy and speed. For example, the CNC system launched by Siemens in Germany has won widespread praise worldwide for its efficient and stable performance and precise control algorithms. At the same time, the CNC system of FANUC Corporation in Japan has also occupied a place in the field of cutting machines with its high precision and reliability. In terms of product types, there are a wide variety of CNC systems for cutting machines abroad, with specially customized models tailored to the cutting needs of different industries and materials. For example, in the field of sponge cutting, the CNC system of DMG Mori's cutting machine in Germany has been widely used in aerospace, automotive manufacturing and other fields due to its efficient and precise cutting performance. From the perspective of market application, foreign cutting machine CNC systems have penetrated into various industrial fields. According to statistics, in recent years, with the rise of intelligent manufacturing, the market size of cutting machine CNC systems has been growing year by year, especially in high-end manufacturing fields such as automobiles, electronics, aerospace, etc., where the demand for cutting machine CNC systems is more urgent. These industries have extremely high requirements for cutting accuracy, efficiency, and stability, thus placing higher demands on the performance and technical level of CNC systems.

China started relatively late in the CNC system of cutting machines, and overall lags behind the level of developed industrial countries in Europe and America. There is a significant gap in the automation level, efficiency, and stability of sponge cutting CNC systems compared to developed industrial countries in Europe and America. In recent decades, Chinese universities and enterprises have conducted research on the relevant technologies of CNC systems for sponge cutting machines, and have also achieved corresponding results. Zhejiang University of Technology has developed a sponge cutting CNC system based on PCI-1240U motion control card, designed the cutting control software for sponge materials, and realized the automation of the machining process from sponge data reading to controlling the machine tool. Zhejiang University has conducted research on key technologies in the high-speed cutting process of sponges, and has studied contour reconstruction algorithms, interpolation algorithms, and acceleration/deceleration planning algorithms for sponge contours expressed using parameter curves, improving the smoothness of machine tools in high-speed cutting processes. Hangzhou University of Electronic Science and Technology has conducted research on the layout algorithm of sponge materials to address the issue of raw material utilization, and proposed a heuristic sponge material layout algorithm based on NFP algorithm. Although domestic universities and enterprises have achieved some corresponding results in the field of cutting machine CNC systems, the stability and functionality of domestically developed sponge cutting machine CNC systems still cannot compare with developed countries in Europe and America, and there is a significant gap.

3. Proposal of Hardware Structure for CNC System of Polyurethane Sponge Cutting Machine

The hardware structure of the CNC system for sponge cutting machine mainly consists of industrial computer, MC1004 motion controller, sensors, servo drivers, AC servo motors, and vacuum adsorption devices. The numerical control system proposed in this article adopts an open mode of "industrial computer+motion controller", using high-performance industrial computer as the upper computer software development and operation platform of the numerical control system, to complete tasks with low real-time performance such as graphic data processing, mathematical operations, and human-computer interaction. The motion controller adopts MC1004 motion controller as the motion control core of the numerical control system, to complete tasks with high real-time performance such as interpolation, motor control, and signal processing. The industrial computer is connected to the MC1004 motion controller through Ethernet to exchange operational information between the industrial computer and feedback information from the motion controller. The motion controller is connected to the driver through its own servo drive interface, and outputs pulse signals to control the servo driver to drive each servo motor to rotate, driving each axis of the machine tool to complete the corresponding motion. The

digital output port mainly controls the electrical system of the machine tool through relays, mainly to complete the switching of high-speed tool vibration and vacuum suction system.

Due to the high-frequency vibration of the cutting tools and the use of fast processing speeds during normal cutting and processing, sponge cutting machines inevitably cause significant impact and vibration interference to the equipment on site. At the same time, the working site of sponge cutting machines is subject to high temperatures, dust, and electromagnetic interference between different devices. Compared to ordinary personal computers, industrial computers have better abilities in high temperature resistance, dust prevention, anti-interference, and impact resistance. Therefore, this CNC system adopts IPC-510 industrial control computer, which is made of steel material and has good anti electromagnetic interference, anti dust and anti vibration capabilities. It can operate stably in the environment of sponge cutting.

4. Discussion on Software Design of Numerical Control System for Polyurethane Sponge Cutting Machine

In the numerical control system of the sponge cutting machine, the upper computer software is an application software designed to implement various functions of the sponge cutting machine, and also undertakes the task of communicating with the MC1004 motion controller. This article analyzes and integrates the functions required for the entire sponge processing process based on the requirements of sponge processing technology. Using a layered modular design approach, the upper computer software is divided into a communication layer and an application layer. The first layer is the communication layer, which mainly completes real-time communication between the upper computer software and the MC1004 motion controller through the Hlink communication function library provided by Hollysys. The second layer is the application layer, mainly composed of graphic file parsing module, graphic display module, graphic editing module, machining program generation module, machining simulation module, and machining tracking module.

Some functional modules of the upper computer of the sponge cutting machine CNC system need to communicate in real time with the MC1004 motion controller to complete information exchange. Only by establishing a connection between the upper computer and the MC1004 motion controller can the upper computer software send functional instructions to the MC1004 motion controller through the industrial computer, thereby controlling the sponge cutting machine tool. It is also a preparatory step for implementing various functional modules in the application layer.

The parsing module of graphic files mainly uses DXF format files for parsing. There are two formats for DXF files. One is binary format, which consumes less resources and has fast reading speed but weak readability. The other is ASCII format, which consumes more resources but has stronger readability than binary format. Therefore, in order to facilitate the processing of DXF files, the CNC system adopts ASCII format DXF files as the source of sponge data [4].

5. Exploration of Optimization Algorithm for Sponge Processing Path

Due to the randomness of drawing sponge processing graphics in drawing software and the need to modify the graphics during drawing, the graphic information stored in DXF files is stored in the order of drawing, which generally results in the processed graphics read back being unordered. In the process of sponge processing, the total stroke is composed of the fixed stroke of the cutting tool cutting the shape and the idle stroke of the tool moving between different shapes. When cutting sponge, if the processing is directly carried out according to the order of the read processing graphics, it will result in excessive idle stroke, which will seriously affect the processing efficiency of the sponge. Therefore, in order to improve the efficiency of sponge processing, it is necessary to find the shortest path for processing and reduce idle travel.

Ant colony algorithm is a heuristic algorithm proposed by Italian scholars Dorigo et al. to simulate the foraging process of ants. In the process of searching for food, any ant in the ant colony will leave pheromones on every path it travels. Other foraging ants in the ant colony can determine their foraging direction by sensing the concentration of pheromones on the foraging path. If the foraging path is shorter, the ants will travel back and forth more times, leaving more pheromones. The concentration of pheromones on the path will be higher, and the probability of subsequent ants choosing this path will also be greater. This is a positive feedback mechanism, and the pheromones on the path will evaporate over time. After a long period of foraging in the ant colony, the pheromones on the shortest foraging path will be significantly higher than those on other paths, which will guide all ants to gather on this path. On the shortest foraging path.

Although ant colony algorithm is an efficient algorithm for solving TSP problems, with strong robustness and good search ability, there are also many shortcomings as the number of solutions increases [5]. Therefore, in the CNC system for sponge cutting, it is necessary to improve the ant colony algorithm. The greedy algorithm always makes the best choice in the current situation when solving problems, while when applied to the TSP problem, it always selects the graph closest to the current graph from the remaining available graphs. It is an efficient algorithm with fast solving speed. The greedy algorithm can quickly and effectively obtain a machining path.

6. Conclusion

This article takes the numerical control system of the sponge cutting machine as the research object, and based on the "industrial computer+motion controller" mode, conducts relevant research on the design of the hardware structure of the sponge cutting machine, the development of the upper computer software of the numerical control system, and the optimization algorithm of the sponge processing path, verifying the feasibility of the numerical control system of the sponge cutting machine. The article discusses the design of the hardware structure of the CNC system for sponge cutting machines. Based on the analysis of the mechanical structure and processing characteristics of sponge cutting, an industrial computer is used as the development and operation platform of the numerical control system, and the MC1004 motion

controller is used as the motion control core of the numerical control system to complete the design of the hardware structure of the numerical control system. Explored the design of the upper computer software for the numerical control system of the sponge cutting machine. In the Windows operating environment, based on the QT5.9 development platform, the development of functional modules such as communication between the upper computer and MC1004 motion controller, graphic file parsing, graphic display, graphic editing, machining program generation, machining simulation, and machining tracking was completed by calling the relevant communication functions of the Hlink communication dynamic library. Proposed an optimization method for sponge processing path. Through the analysis and classification of the optimization problem of sponge processing path, based on the ant colony algorithm, the greedy algorithm was introduced to improve the ant colony algorithm in response to its shortcomings. Compared with the original ant colony algorithm, the improved ant colony algorithm can shorten the iteration times of the algorithm, reduce the running time of the algorithm, and have better optimization effects on the sponge processing path. This ultimately provides a theoretical basis for the stable operation and high-precision machining of the CNC system of the sponge cutting machine.

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