Design and engineering practice of robot end effector oriented to intelligent manufacturing

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Keywords: engineering practice; robot end effector; intelligent manufacturing

Abstract: The development of intelligent manufacturing puts forward higher requirements for robot end effector, including high precision, high stability and high adaptability. Firstly, this paper analyzes the design requirements of robot end effector, and points out its special requirements in different intelligent manufacturing scenarios, such as anti-static ability in electronic manufacturing and hygienic standards in food processing. Then, the article puts forward the design principles and concepts, emphasizing modularization, standardization and reliability first, and integrating the design concepts of intelligence, flexibility and cooperation. Specific design methods include demand analysis, structural design, control system design and prototype testing. Through the application case in the automobile manufacturing production line, the performance of the robot end effector in practical application is demonstrated, and its excellent performance in grasping stability, operating accuracy and load capacity is verified through performance test and evaluation. The research shows that the robot end effector can meet the requirements of high precision and high reliability of intelligent manufacturing, which provides a strong support for the development of intelligent manufacturing.

1. Introduction

Through the deep integration of information technology and manufacturing technology, intelligent manufacturing realizes the intelligence, automation and high efficiency of the production process, which greatly improves the production efficiency and product quality of the manufacturing industry. In this transformation, robot technology, as one of the core supports of intelligent manufacturing, plays an important role [1]. As an important part of the interaction between the robot and the external environment, the performance of the robot end effector directly affects the working ability and application scope of the robot. In the intelligent manufacturing environment, robots need to complete all kinds of complex and delicate operation tasks, such as precision assembly, material handling, surface treatment, etc., which requires the robot end effector to have the characteristics of high precision, high stability and high adaptability [2].

Therefore, it is particularly important to study the design and engineering practice of robot end effector for intelligent manufacturing. The purpose of this study is to deeply discuss the design principle, method and technology of robot end-effector, and combine with the actual demand of intelligent manufacturing, develop a robot end-effector with excellent performance and diverse functions, which provides strong support for the development of intelligent manufacturing. Based on the basic concept, classification and application of robot end-effector, this paper expounds in detail the design requirements, design principles and concepts of robot end-effector for intelligent manufacturing, as well as the specific design methods. At the same time, through engineering practice cases, the application effect of robot end effector in intelligent manufacturing is demonstrated, and its performance is tested and evaluated.

2. Design of robot end effector for intelligent manufacturing

2.1. Design requirement analysis

The robot end effector needs to meet higher performance requirements, including high precision to complete precise operations such as tiny parts assembly and surface treatment [3]; High strength and high wear resistance ensure the stability and durability when working continuously for a long time; As well as high flexibility and adaptability, so as to quickly adjust to the changes of different tasks and product specifications, thus ensuring the efficient operation of the production line.

In different intelligent manufacturing application scenarios, the robot end effector also needs to meet some special requirements. For example, in the electronic manufacturing industry, due to the tiny and fragile electronic components, the robot end effector needs to have the ability of anti-static and micro-force control to avoid damage to electronic components. In the food processing industry, the robot end effector needs to meet the food hygiene standards and be easy to clean and disinfect to prevent food pollution [4]. In the automobile manufacturing industry, the robot end effector needs to have the ability to bear heavy load and high-speed movement to meet the requirements of handling and assembly of automobile parts.

2.2. Design principles and concepts

The design of robot end-effector for intelligent manufacturing should follow the principles of modularization, standardization and reliability priority to enhance flexibility, compatibility and long-term stable operation [5-6]. In addition, the innovative ideas of intelligence, flexibility and cooperation should be integrated into the design, automatic decision-making can be realized by integrating intelligent components, flexible materials should be adopted to adapt to different objects, and safe and friendly human-computer interaction or cooperation between machines should be ensured, so as to meet the diversified needs in the intelligent manufacturing environment.

2.3. Specific design method

When designing a robot end effector, it is necessary to communicate with users in depth to clarify the specific requirements, covering the operating object, environment and task requirements, and define the main functions and performance indicators of the end effector, such as grasping, handling, assembly, testing and other capabilities, as well as its accuracy, load capacity and speed [7]. Based on these requirements analysis results, the designer will conceive the preliminary structure and driving mode, consider different types of driving elements and transmission mechanisms, and ensure that the end effector can accurately complete the scheduled actions.

On the basis of preliminary design, detailed design is carried out, 3D model is established by using CAD software, and virtual assembly and finite element analysis are carried out to ensure the correct cooperation between components and the strength of key components. At the same time, select appropriate sensors and design the control system to achieve accurate control and feedback and improve the reliability and stability of the system [8-9]. The effectiveness of the design is verified by prototype manufacturing and testing, and the design is optimized according to the test results. Finally, after the successful prototype test, we enter the stage of engineering design and mass production to ensure the consistency and reliability of products, and at the same time, we continue to collect user feedback, pay attention to the development trend of technology, and constantly optimize and upgrade the end effector to meet the development needs of intelligent manufacturing.

3. Engineering practice of robot end effector

3.1. Application of robot end effector in automobile manufacturing production line

In a modern automobile manufacturing production line, robots play a vital role. From body welding, parts assembly to painting inspection, robots participate in almost every production link. Among them, the robot end effector, as a component of direct interaction between robot and automobile parts, its performance directly affects the efficiency and quality of the production line.

The case selects the assembly link of parts in the automobile manufacturing production line, specifically the assembly of parts in the engine compartment. Because there are many kinds of components in the engine compartment, their shapes are complex, and the assembly accuracy is extremely high, a robot end effector specially designed for automobile manufacturing is selected. The end effector has the functions of multiple degrees of freedom, high-precision positioning and flexible grasping, and can meet the assembly requirements of parts with different shapes and sizes.

Aiming at the high-precision requirements of engine compartment assembly in automobile manufacturing, the solution is to adopt high-precision sensors and advanced control systems, and optimize the structural design to reduce error accumulation and ensure the accurate positioning and assembly accuracy of the end effector. In order to ensure the reliability of the robot end effector in long-term continuous work, high-quality materials and advanced technology are selected, and strict quality control and testing are carried out. In order to realize safe and efficient man-machine cooperation, a safe interactive interface with force feedback sensor and anti-collision device is designed to ensure the safety of robot and human cooperation.

3.2. Performance testing and evaluation

The test methods and standards include grasping stability test, which evaluates the stability and reliability of the end effector by using parts with different shapes and materials, and requires that there is no slip or damage during grasping and the force is moderate; The operation accuracy test is to place the object in the specified position, and the end effector will position and grab it and measure its error to ensure that the error is within the acceptable range to meet the production accuracy; The load capacity test is to gradually increase the load, observe the movement state, and ensure that the end effector can run stably without abnormality under the rated load.

The experimental data show that the robot end effector is excellent in grasping stability, operating accuracy and load capacity. Table 1 reflects the test results of the robot end effector on three key performance indexes. Grasping stability, operating accuracy and load capacity. The grasping stability test shows that the end effector can successfully grasp parts with various shapes and materials without any slippage or damage, which shows that it has high reliability and adaptability. The test result of operation accuracy shows that the average positioning error is 0.083mm, which is far better than the precision requirement of the production line, and reflects the high precision performance of the end effector. The load capacity test proves that the end effector can run stably under the rated load, even if it exceeds the rated load, there is no abnormal performance, showing good bearing capacity and stability. These test results show that the robot end effector performs well in practical application and can meet the requirements of high precision and high reliability of automobile manufacturing production line.

Table 1 Comparison of performance test results of robot end effector

test item	test condition	test result	remarks
Grasping stability	Parts with different shapes and materials (such as plastic, metal, rubber, etc.)	No slip or damage, and the success rate is 100%	Ensure the stability and reliability in the grabbing process
Operating accuracy	Place the object in the specified position for positioning and grabbing	The average positioning error is 0.083 mm	The error range is between ±0.05mm and 0.1 mm
loading capacity	Gradually increase the load to the rated load range	Stable operation under rated load, no abnormal phenomenon	The maximum test load is 120% of rated load

In this Figure 1, the abscissa represents the load and the ordinate represents the operating state index. During the process from the load value of 0 to the rated load of 50, the running state index has been kept at 100, which indicates that the end effector can run stably and in good running state within the rated load range. When the load value reaches the rated load of 50 and the load increases to 60, the running state index drops to 90, which reflects that the running state of the end effector begins to deteriorate after exceeding the rated load, and there may be some situations that affect the running efficiency or stability, showing that the load capacity of the end effector tends to decline when exceeding the rated load.

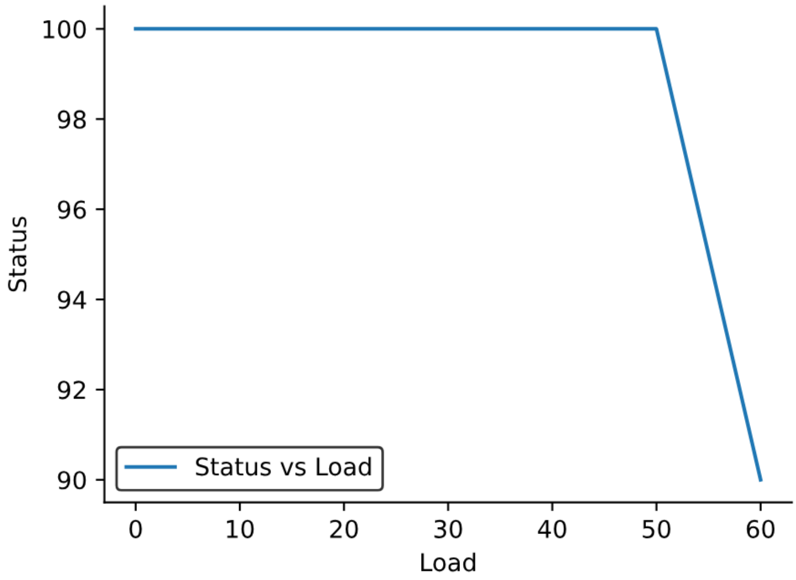

Figure 1 Variation of load capacity with load increase

The application case of the robot end effector in automobile manufacturing production line shows that its design effect is good and it can meet the requirements of precision, reliability and man-machine cooperation of production line. Through the performance test and evaluation, the practical application performance of the end effector is further verified, which provides strong support for its wide application in the field of intelligent manufacturing.

4. Conclusion

Under the background of intelligent manufacturing, the robot end effector is the key component of the interaction between the robot and the external environment, and its design is very important for improving the working ability and application scope of the robot. In this study, the design principle, method and technology of robot end effector are deeply discussed, and a series of design requirements, principles and concepts are put forward in combination with the actual needs of intelligent manufacturing. Through the design principles of modularization, standardization and reliability priority, as well as the innovative ideas of intelligence, flexibility and cooperation, the robot end effector with excellent performance and various functions has been successfully developed in this study. In engineering practice cases, this study shows the application effect of robot end effector in automobile manufacturing production line. Especially in the assembly process of engine compartment components, the designed end-effector shows the functions of multiple degrees of freedom, high-precision positioning and flexible grasping, which meets the requirements of precision, reliability and man-machine cooperation of production line. The performance test and evaluation results show that the robot end effector has excellent grasping stability, operating accuracy and load capacity, and can meet the requirements of high precision and high reliability of automobile manufacturing production line.

Acknowledgments

The Research Project on Teaching Reform in Higher Education in Shaanxi Province: "Civilization Classics, Masterful Craftsmanship - Research on the Construction of a Course System for Creative Design and Practice of Mechanical and Electrical Products Based on Traditional Chinese Craftsmanship Heritage"(23BY008)

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