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Research on Precision Machining Technology of Thin-walled Parts

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Abstract: Precision machining of thin-walled parts has always been a problem worth exploring in machining industry. Thin-wall parts are parts with relatively thin wall thickness, which are usually used in high-precision mechanical devices, aerospace equipment, automotive parts and other fields. Thin-wall parts are difficult to process and require high manufacturing technology. There are many difficulties and challenges in processing and manufacturing. Moreover, the deformation prediction technology is very important in the processing or clamping process of thin-wall parts, which can help manufacturers predict and optimize the design and processing technology of parts, so as to improve the accuracy and quality of parts and reduce the production cost.

Keywords: Thin-wall parts, Precision machining, High precision, Manufacturing process, Deformation prediction.

1. Introduction

Today, with the rapid development of precision machining technology, the design and processing of parts are becoming more and more difficult, and thin-walled parts are one of them. Lightweight, thin-walled, high strength, corrosion resistance are the main advantages of thin-walled parts, but this also leads to its lack of poor rigidity, weak strength, etc., under the action of cutting force and cutting heat, it is easy to produce deformation, affecting the dimensional accuracy, position accuracy and surface roughness of parts, it is difficult to meet the design requirements of parts. We will focus on the main process characteristics of thin-walled parts; Processing status and main problems; The deformation prediction technology during machining or clamping is discussed.

2. The Main Process Characteristics of Thin-walled Parts

Thin-walled parts are widely used in aerospace industry because of their light weight and high specific strength. (Figure 1).However, due to the low stiffness of thin-walled parts, elastic deformation and flutter are easy to occur, which seriously affects the machining accuracy and workpiece surface quality. It is necessary to use advanced processing technology and precision processing equipment, such as CNC machining, laser cutting, electric pulse processing, etc.

Figure 1. Aircraft skin

Thin-walled parts need to be made of high-quality materials. Due to its wall thickness, it needs to have good strength, hardness, toughness and corrosion resistance, and some special materials with high strength, high hardness, high toughness and high corrosion resistance are widely used in the manufacture of thin-walled parts.

Thin-walled parts require sophisticated tooling and tooling fixtures. The manufacturing accuracy of molds and fixtures is required to be high, and it must be ensured that the geometric shape and size of the parts are completely consistent with that of the parts to ensure the accuracy and quality of thin-walled parts.

The surface treatment requirements of thin-walled parts are high. Thin-walled parts usually require surface treatment, such as polishing, spraying, coating, etc., to enhance their surface finish, corrosion resistance and aesthetics.

The manufacturing process of thin-walled parts requires strict control. In the manufacturing process, the processing parameters, materials, equipment and processes need to be carefully controlled to ensure that the size, shape, performance and quality of the parts meet the requirements.

Thin-walled parts need special attention to thermal deformation. Because the wall thickness of thin-walled parts is thin and easy to be affected by heat, a series of measures need to be taken to prevent thermal deformation during processing, such as controlling the processing temperature and using cooling devices.

The assembly and use of thin-walled parts need to be careful. Due to its wall thickness, it is easy to be affected by external forces, so special care is needed in assembly and use to avoid problems such as deformation and rupture of parts.

The processing cost of thin-walled parts is higher. Due to its high manufacturing process requirements, manufacturing difficulties, high material requirements, and the need for special equipment and technical support, the processing cost of thin-walled parts is usually higher.

In short, the manufacture of thin-walled parts is a very complex and difficult work, which requires a certain amount of professional knowledge and skills, as well as advanced equipment and technical support to ensure the quality and accuracy of parts.

3. Precision Machining Technology of Thin-walled Parts

Numerical control machining: Numerical control machining is the use of computer-controlled numerical control machine tools for processing, to achieve high precision and high efficiency processing process. For thin-walled parts, CNC machining can realize high-precision machining of thin-walled parts by precisely controlling machining parameters, reducing cutting force, reducing vibration, etc. To accommodate the fast production cycle and improve the machining efficiency of thin-wall parts, Zexuan Zhu has proposed a digital dual-drive thin-wall parts manufacturing framework that enables machine operators to manage product changes, making the start-up phase faster and more accurate. The framework consists of three parts: preparation, processing and measurement, and is specifically driven by digital twin technology. By creating and updating workpiece digital twins in different states, various manufacturing information and data can be integrated and made available to machine tool operators and other digital twins.

Laser cutting: Laser cutting is a processing method of cutting materials through a high energy laser beam, with very high precision and speed. For thin-walled parts, laser cutting can achieve high-precision cutting without contact and deformation, which is suitable for various materials, such as metals, plastics, ceramics and so on.

Electric pulse machining: Electric pulse machining is a technology that uses the electrochemical principle of electric pulse to process materials, which can realize high-precision machining of thin-walled parts. By controlling the parameters of the electrical pulse, such as pulse amplitude, pulse width, frequency, etc., tiny discharge holes can be formed on the thin-walled material, so as to realize the machining of thin-walled parts.

Precision mold: Precision mold is an essential tool for the manufacture of thin-walled parts, and high-precision molding and processing of thin-walled parts can be achieved through precision mold. Precision molds usually use advanced manufacturing processes, such as electric discharge machining, wire cutting, micro-machining, etc., to ensure the high precision and long life of the mold.

Temperature control and humidity control technology: thin-walled parts are easily affected by heat during processing, so temperature control and humidity control technology is very important in the precision processing of thin-walled parts. By controlling the temperature and humidity of the processing environment and taking appropriate cooling measures, the thermal deformation and thermal stress of thin-walled parts can be reduced to ensure the processing accuracy and quality.

Detection and measurement technology: thin-walled parts usually require high-precision dimensional measurement and morphology detection. Therefore, the use of advanced measuring instruments and technology, such as coordinate measuring instrument.

With the development of precision machining technology, there will certainly be a variety of advanced processing technologies, such as fluid pressure forming, additive manufacturing and so on.Shijian Yuan believes that he has developed a new generation of fluid pressure forming technology has been developed for the three typical structures of tubes, sheets, and shells, and hard-to-deform material components that are urgently needed for aerospace, aircraft, automobile, and high-speed train industries.

4. The Processing Status of Thin-walled Parts and The Main Problems Faced

High difficulty: The manufacture of thin-walled parts is a very complex and difficult work, which requires a certain amount of professional knowledge and skills, as well as advanced equipment and technical support to ensure the quality and accuracy of parts.

High cost: thin-walled parts have high manufacturing process requirements, difficult manufacturing, high material requirements, and the need for special equipment and technical support, so the processing cost of thin-walled parts is usually higher.

High precision requirements: thin-walled parts usually have high precision and high surface quality requirements, so it is necessary to use high-precision processing equipment and precision processing technology, such as CNC machining, laser cutting, electric pulse processing, etc.

Thermal deformation problem: Because the wall thickness of thin-walled parts is thin, it is easy to be affected by heat, so a series of measures need to be taken to prevent thermal deformation in the processing process, such as controlling the processing temperature and using cooling devices.

Low efficiency: thin-walled parts usually have complex shapes and structures, so their processing efficiency is usually low, and efficient processing programs and precise process control are needed to ensure processing efficiency and quality.

The automatic processing of thin-wall parts needs the support of automated production equipment such as robots, but there are still some problems in robot processing technology, such as operating accuracy and operating speed, which need to be improved.

Environmental protection issues: The processing of thin-walled parts involves the consumption of many materials and energy, so environmental protection measures need to be taken to reduce the impact of processing on the environment. For example, the use of green processing materials and technologies, optimization of processing technology, reduce waste generation and so on.

In short, the processing of thin-walled parts is faced with complex problems, and it is necessary to constantly explore new technologies and methods to improve processing efficiency and quality, and reduce costs and environmental impact

At present, with the continuous development of industrial manufacturing technology, the processing accuracy and quality of thin-walled parts have been greatly improved, but there are still some problems:

Material selection: The material selection of thin-walled parts is very important. At present, the materials used in most thin-walled parts are mainly metals, plastics, ceramics and so on. Because the wall thickness of the thin-walled parts is thin, the performance requirements of the materials are higher, and they need to have high strength, hardness, wear resistance and corrosion resistance. At the same time, the process ability and weld ability of the material also need to meet the requirements.

The manufacturing process is difficult: due to the wall thickness of thin-walled parts, the processing is difficult, and a series of advanced manufacturing processes and equipment need to be used, such as laser cutting, electric pulse processing, numerical control processing, etc. At the same

time, special attention needs to be paid to prevent the occurrence of hot deformation, hot cracking and other problems during the processing.

Detection difficulty: Due to the wall thickness of thin-walled parts and high dimensional accuracy requirements, the detection is also very difficult. At present, the commonly used detection methods include coordinate measurement, microscope detection, X-ray detection and so on. However, these methods also have some limitations, such as the accuracy is not high enough, can not be fully detected and so on.

High environmental protection requirements: The processing of thin-walled parts involves a large number of waste water, waste gas, waste slag and other problems, so the environmental protection requirements are also high. It is necessary to use advanced environmental protection technologies and equipment, such as exhaust gas purifiers, wastewater treatment equipment, etc., to reduce the impact on the environment.

High processing cost: Due to the high manufacturing process requirements of thin-walled parts, difficult manufacturing, high material requirements, and the need for special equipment and technical support, the processing cost of thin-walled parts is usually higher.

5. Deformation Prediction Technology for Thin-walled Parts During Machining or Clamping

The deformation prediction technology in the process of machining or clamping of thin-walled parts is to predict the deformation that may occur in the process of machining or clamping by establishing a mathematical model, analyzing the material properties, geometric shapes, process parameters and other factors, so as to take timely measures to correct or optimize. The following are commonly used thin-walled parts deformation prediction techniques:

Finite Element Analysis (FEA) : Finite element analysis is a numerical analysis method that uses computers to simulate real situations. By dividing the parts into small finite element regions, the stress and deformation in each region are analyzed, and finally the stress and deformation distribution of the whole part is obtained. This method can predict the deformation of parts in the process of machining or clamping, and can optimize the design of parts by adjusting the strength, stiffness, thickness and other parameters.

Mathematical model method: Mathematical model method is to predict the deformation of parts by establishing mathematical equations or models. This method usually uses physical principles or empirical formulas to build mathematical models, such as sheet metal bending deformation model, thin shell deformation model, etc. By adjusting the model parameters, the deformation of the parts can be predicted, and the design and machining process of the parts can be optimized.

Experimental method: The experimental method is to measure the deformation of parts in the process of processing or clamping through experimental testing. This method usually uses equipment such as grating measurement and displacement sensor to measure the deformation of parts, and can optimize the design and processing of parts by changing the processing parameters.

6. The Deformation Prediction Technology in The Process of Machining or Clamping Thin-walled Parts Still Faces Some Challenges and Problems

The complexity of material properties: thin-walled parts are usually composed of complex materials, and their mechanical properties will change with the deformation of the material. Therefore, the complexity of material properties needs to be taken into account when predicting deformation.

The influence of multiple factors: the deformation of thin-walled parts during processing or clamping is not only affected by the material, but also affected by a variety of factors, such as cutting parameters, tool shape, temperature and pressure during processing. Therefore, it is necessary to consider the comprehensive influence of various factors on deformation.

Improvement of model accuracy: Establishing an accurate mathematical model is the key to predicting the deformation of thin-walled parts. However, due to the complexity of materials and processes, both the establishment and verification of the model require a lot of experiments and calculations. Therefore, how to improve the accuracy of the model is a difficult problem.

The difficulty of real-time prediction: In actual production, due to the many variables in the processing process and difficult to predict, it is very difficult to predict the deformation of thin-walled parts in real time. Therefore, it is necessary to develop an efficient prediction method in order to adjust the process parameters in time during the machining process to minimize the deformation of the parts.

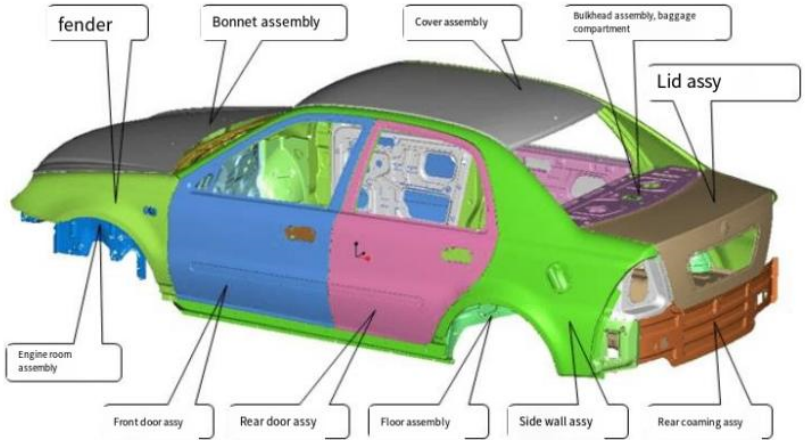

Figure 2. Automobile body construction

7. Thin-walled Parts Manufacturing

Taking body parts in automobile manufacturing as an example, body parts usually adopt thin-walled structures, such as body panels, doors, hoods, etc. Deformation prediction technology during processing or clamping is crucial to ensure the quality of parts and reduce production costs.(Figure 2. Automobile body construction)

In the processing of body parts, the deformation of thin-walled parts is mainly affected by the following factors:

Material characteristics: Body parts usually use high-strength steel or aluminum alloy materials, its mechanical properties are complex, prone to plastic deformation and elastic recovery, so it is necessary to consider the complexity of material characteristics when predicting deformation.

Cutting parameters: Cutting parameters such as tool speed, feed rate and cutting depth, etc., will directly affect the deformation of thin-walled parts. For example, the tool speed is too high or the feed is too large, easy to cause heating, deformation and slit problems, so it is necessary to accurately control the cutting parameters.

Clamping force: In the clamping process, the size and distribution of the clamping force also has a great impact on the deformation of thin-walled parts. Therefore, it is necessary to design and optimize the clamping force reasonably before clamping.

In order to predict the deformation of thin-walled parts, the finite element method can be used to establish a mathematical model, which takes material characteristics, cutting parameters and clamping force into account, and simulates various factors in the machining process. Through the simulation calculation, the key parameters such as the deformation amount, deformation position and deformation shape of the part can be predicted, so as to adjust the process parameters and clamping force and other factors to reduce the deformation of the part.

For example, for the machining process of the body plate, the finite element method can be used to establish a mathematical model, set different cutting parameters and clamping force in the model, and predict the deformation of the body plate and deformation position and other parameters through simulation calculation. In actual production, according to the results of simulation calculation, the cutting parameters and clamping force are adjusted to reduce the deformation of the body plate.

In addition, in order to predict the deformation of thin-walled parts more accurately, the morphology measurement technology and digital forming technology can also be used for real-time monitoring and feedback.

Shape measurement technology can judge the deformation of parts by measuring their shape changes. For example, the optical measuring instrument can be used to measure the morphology of thin-walled parts in real time, and the measurement results can be compared with the simulation results, so that the process parameters and clamping force can be adjusted in time.

Digital forming technology can quickly obtain the deformation information of parts by digitizing the 3D geometric information of parts. For example, using a laser scanner to digitize thin-walled parts and compare with the results of analog calculations, the deformation of parts can be found in time and adjusted.

In summary, the deformation prediction technology in the processing or clamping process of thin-walled parts is very critical, which can help manufacturers reduce production costs, improve production efficiency and ensure the quality of parts. At the same time, with the continuous development of topography measurement technology and digital forming technology, the deformation prediction of thin-walled parts will be more accurate and reliable.

References

[1] Yan B A O, Bin W, Zengxu H E, et al. Recent progress in flexible supporting technology for aerospace thin-walled parts: A review[J]. Chinese Journal of Aeronautics, 2022, 35(3): 10-26.

[2] Zhu Z, Xi X, Xu X, et al. Digital Twin-driven machining process for thin-walled part manufacturing[J]. Journal of Manufacturing Systems, 2021, 59: 453-466.

[3] Yuan S. Fundamentals and processes of fluid pressure forming technology for complex thin-walled components [J]. Engineering, 2021, 7(3): 358-366.

[4] Zhang D L, Gao K, Zhou T R. Discussion on NC machining process of thin walled parts technical measures[J]. Applied Mechanics and Materials, 2015, 701: 864-868.

[5] Hao W. NC Milling Process Planning for Thin-Walled Parts with Low Rigidity[J].

[6] Ma J, He G, Liu Z, et al. Instantaneous cutting-amount planning for machining deformation homogenization based on position-dependent rigidity of thin-walled surface parts[J]. Journal of Manufacturing Processes, 2018, 34: 401-411.

[7] Liu H, Luo L L, Zhang Y. Technology Strategies of Controlling Machining Deformation for NC Milling of Thin-Walled Frame Component Parts[J]. Advanced Materials Research, 2014, 912: 1423-1427.