
Original Research Article

Research and application of precision machining technology in mechanical design and manufacturing and its automation

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Abstract: This paper deeply discusses the current situation, key technology, practical application and future development trend of precision machining technology in the field of mechanical design and manufacturing and automation. Precision machining technology, as the core means to improve product quality and production efficiency, has shown irreplaceable value in high-end equipment manufacturing, aerospace, electronic information and other key fields. This paper not only analyzes the basic principle and unique process characteristics of precision machining technology, but also reveals its far-reaching influence and significance on the mechanical design and manufacturing industry through detailed application cases of automatic production line. On this basis, this paper further looks into the future development direction of precision machining technology, aiming to provide useful reference and inspiration for researchers and engineers in related fields, and jointly promote the continuous progress and innovative development in the field of mechanical design, manufacturing and automation.

Keywords: Mechanical design and manufacturing and automation; Precision machining technology; Process characteristics; Application examples; Future trend

1. Research background and research significance

With the rapid development of the global manufacturing industry, the accuracy, performance and quality requirements of products are increasingly improved, and the importance of precision machining technology, as the key means to achieve these requirements, is becoming more and more prominent. In the field of mechanical design and manufacturing, precision machining technology is not only related to the final quality of products, but also the core factor of improving production efficiency, reducing costs and enhancing market competitiveness. Therefore, in-depth research on precision machining technology is of great significance to promote the development of manufacturing industry to the high-end, intelligent and green direction. The growth of the demand for precision machining technology in the manufacturing industry is mainly due to the improvement of product complexity and the intensification of market competition. In the modern mechanical design, more and more products need to reach the processing accuracy of micron or even nanometer level, which poses a higher challenge to the precision machining technology. At the same time, with the continuous improvement of consumers' product quality and personalized demand, the manufacturing industry must rely on precision machining technology to meet these needs, so as to stand out in the fierce market competition. The importance of precision machining technology in mechanical design and manufacturing is also reflected in its double improvement of product quality and production efficiency. By adopting advanced precision machining techniques, precise control of part size, shape and surface quality can improve the precision and stability of the product. In addition, the precision machining technology can also effectively shorten the processing cycle, reduce the production costs, and provide strong support for the sustainable development of the manufacturing industry.

However, despite the significant progress made in precision machining technology research at home and abroad, there are still many problems and challenges. For example, the processing accuracy and efficiency of the existing technologies still need to be improved, the energy consumption and pollution problems in the processing process need to be solved urgently, and the popularization and application degree of the precision machining technology still need to be strengthened. Therefore, it is of great significance to deeply study the precision processing technology and explore new processing methods and processes to promote the development of the manufacturing industry to the high-end, intelligent and green direction. To sum up, this paper aims to explore the development status, key technologies, application examples and future trends of precision machining technology in the field of mechanical design and manufacturing and automation, in order to provide useful reference and inspiration for researchers and engineers in related fields, and jointly promote the continuous progress and innovative development of the manufacturing industry.

2. Overview of the precision machining techniques

2.1. Definition and classification

Precision machining technology, as a core technology in modern manufacturing industry, its definition covers all the technical means from micro scale to macro scale, high precision and high surface quality processing of materials. This technology not only requires extremely high machining precision, but also emphasizes the full use of material properties and minimizes material loss. In terms of classification, precision machining technology can be mainly divided into ultra-precision machining, fine machining and special machining.

Ultra-precision machining, usually refers to the processing accuracy of sub-micron level or even nanometer level processing technology, it has a wide range of applications in optics, electronics, medical and other fields. Micromachining, mainly focus on the processing of small scale parts, such as micro structure manufacturing^[1] in microelectromechanical system (MEMS). And special processing, covering laser processing, electric spark processing, ultrasonic processing and a series of non-traditional processing methods, they can handle difficult to process materials or achieve special shape processing.

2.2. Principles of technology

The basic principle of precision machining technology is based on the high-precision mechanical system, the advanced control technology and the efficient material removal mechanism. Various parameters in the processing process, such as cutting force, cutting speed, feed amount, are accurately controlled to achieve the high precision removal of materials. The key technical elements include precision control, material removal rate and surface quality, which jointly determine the final quality of the processed parts.

2.3. Process characteristics

The process characteristics of precision machining technology are mainly reflected in two aspects: one is high precision, it can ensure that the size and shape accuracy of high level, meet the needs of various precision equipment; the second is high surface quality, through fine machining process, can obtain smooth surface, no defect surface, which is crucial to improve the performance and life of products^[2]. In addition, precision machining technology also has the characteristics of a wide range of application, processing complex shape and structure, which makes it widely used in aerospace, automotive, medical and other fields.

3. Analysis of the key technologies of precision machining

3.1. Ultra-precision machining technology

Ultra-precision machining technology, as a high-end branch of the field of precision machining technology, its technical principle is mainly based on high-precision mechanical system, advanced detection and control system, and optimized processing strategy. In terms of technological process, ultra-precision machining usually includes precision measurement, data processing, path planning, high-precision processing and follow-up testing and other links. This technology is widely used in areas requiring extremely high accuracy, such as the manufacturing of optical lenses and semiconductor wafers. In optical lens manufacturing, ultra-precision machining technology can ensure that the surface roughness, shape accuracy and optical performance of the lens meet the design requirements, so as to improve the light transmittance and imaging quality of the lens. In semiconductor wafer processing, ultra-precision machining technology is used to realize the key steps such as leveling and patterning of the wafer surface to provide a high-quality substrate for subsequent chip manufacturing.

3.2. Microfine machining technology

Micromachining technology, mainly focuses on the manufacture of small scale parts and structures. Among them, LIGA technology (lithography, electric casting and injection molding) and fine EDM are two representative technologies^[3]. LIGA technology forms fine patterns on the substrate through the photolithography process, then transforms the patterns into metal structure through the electric casting process, and finally realizes batch reproduction through injection molding. This technology is widely used in MEMS devices, microfluidic chips and other fields. Fine electric spark processing, then use the instantaneous high temperature and high pressure generated by the electric spark discharge to remove the material, to realize the processing of the fine structure. This technology has the advantages of high machining precision and wide range of machining materials, and is widely used in biochips, micromolds and other fields.

3.3. Special processing technology

Special processing technology, covering laser processing, ultrasonic processing, water jet cutting and a series of non-traditional processing methods. These technologies are usually not limited by physical properties such as hardness and toughness of materials, and can handle difficult to process materials or achieve processing of special shapes. Laser processing, using high-energy laser beam to ablate, melt or vaporize materials, so as to achieve the removal of material and shape change. This technology is widely used in the field of aerospace in the aircraft skin cutting, punching and other processing. Ultrasonic processing, then using the cavitation effect produced by ultrasonic waves in the liquid to remove the material, especially suitable for the processing of brittle materials, such as ceramics, glass and other^[4]. Water jet cutting, using the abrasive carried by high speed water flow to wash the material cutting, has the advantages of high processing accuracy, small environmental pollution, has been widely used in medical equipment and other fields.

4. Application of precision machining technology in mechanical design and automation

4.1. Application in the automated production line

In the field of mechanical design and manufacturing and its automation, the integration of precision

machining technology has greatly promoted the development of automatic production line. The integration of precision machining equipment and automatic control system is the key to realize the efficient and high-precision production. This integration not only improves the automation level of the production line, but also ensures the high precision and high surface quality of the machining parts by accurately controlling the various parameters in the machining process, such as cutting speed, feed amount, cutting force and so on^[5]. Taking the automobile manufacturing industry as an example, the combination of precision machining technology and automatic production line has significantly improved the processing accuracy and consistency of auto parts. By adopting high-precision CNC machine tools and automatic control system, the accurate machining of auto parts can be realized, so as to improve the assembly accuracy and driving performance of automobiles. In addition, this integration also enables the production line to achieve 24 hours of uninterrupted production, greatly improving the production efficiency.

4.2. Case analysis to improve production efficiency and processing accuracy

In an aviation parts manufacturing enterprise, through the introduction of precision machining technology and automatic control system, the high-precision machining of the aero-engine blades has been successfully realized. The enterprise adopts the five-axis linkage CNC machine tool, combined with the advanced cutting tool and cutting parameter optimization technology, so that the machining accuracy of the blade has reached the micron level. At the same time, through the precise control of the automatic control system, realize the automation and intelligence of the processing process, greatly improve the production efficiency^[6]. This case fully demonstrates the significant advantages of precision machining technology in improving production efficiency and machining accuracy.

4.3. Application in high-end equipment manufacturing

The application of precision machining technology in the field of high-end equipment manufacturing is also extensive and important. In aero-engine manufacturing, precision machining technology is used to process key components such as turbine blades and combustion chambers, and the machining accuracy and surface quality of these parts directly affect the performance and life of the engine. By adopting precision machining technology, we can ensure that the dimensional precision and shape precision of these components meet the design requirements, thus improving the overall performance of the engine. In the precision machine tool manufacturing, the precision machining technology also plays an important role. The accuracy and stability of the machine tool directly affect the quality and production efficiency of the processed parts. By using the precision machining technology to manufacture the key components of the machine tool.

4.4. Contribution to product quality and performance improvement

The application of precision machining technology has made a significant contribution to the improvement of product quality and performance. First, through the accurate control of the various parameters in the processing process, we can ensure the high precision and high surface quality of the machining parts, so as to improve the quality and performance of the product. Secondly, precision machining technology can also realize the processing of complex shapes and structures, to meet the diversified needs of product shape and function. In addition, by optimizing the processing strategy and tool path, it can also reduce the waste of materials and the consumption of processing time, and reduce the production cost.

4.5. Intelligent development trend

With the rapid development of artificial intelligence, big data and other technologies, precision machining technology also presents a development trend of intelligence. By combining the precision machining technology with artificial intelligence, big data and other technologies, the adaptive control and optimization of the processing process can be realized. For example, by real-time monitoring of various parameters and data in the processing process, and using artificial intelligence algorithm to analyze and process, the deviations and errors in the machining process can be found and corrected in time, so as to ensure the high precision and high surface quality of the machining parts. At the same time, this intelligent control can also automatically adjust the processing strategy and tool path according to the changes and requirements of the processing tasks, so as to realize the flexibility and efficiency of the processing process. To sum up, the application prospect of precision machining technology in the field of mechanical design and manufacturing and automation is broad and of great significance. By continuously promoting the integration and innovation of precision machining technology, automation and intelligent technology, the production efficiency, product quality and competitiveness of the mechanical design and manufacturing industry can be further improved.

5. Challenges and future trends of precision machining technology

5.1. Challenges

As one of the core technologies of modern manufacturing industry, precision machining technology has made remarkable progress and widely application, but it still faces many challenges.

5.1.1. Technical difficulty and cost issues

First of all, the technical difficulty is a major challenge facing the precision machining technology. With the continuous improvement of machining accuracy and surface quality requirements, precision machining technology needs to constantly break through the existing technical bottleneck, and research and develop new processing methods and processes. This requires a large amount of scientific research investment and technology accumulation, which puts forward high requirements for the research and development ability and financial strength of enterprises. At the same time, the manufacturing cost of high-precision processing equipment is relatively high, which makes the popularization of precision and application of precision processing technology limited. In addition, the cost problem is also one of the challenges facing the precision machining technology. Although precision machining technology can improve the quality and performance of products, the corresponding processing costs will also increase. How to reduce processing cost and improve production efficiency on the premise of ensuring processing accuracy and surface quality is an important problem to be solved by precision machining technology.

5.1.2. The challenge of cross-domain technology integration

With the continuous development of science and technology, the intersection of precision machining technology and other fields is more and more close. However, this cross-domain technology convergence also poses challenges. There are differences in the technical background, knowledge system and application scenarios in different fields. How to realize the effective integration of precision machining technology and other technologies and give full play to their respective advantages is a problem that needs in-depth study. At the same time, cross-domain technology integration also needs to solve technology standards, data sharing, collaborative

innovation and other problems^[7], to promote cooperation and exchanges between different fields.

5.2. Future trend

In the face of challenges, precision machining technology also shows a broad development prospect and future trend.

5.2.1. The development trend of higher precision and higher efficiency

With the continuous upgrading of manufacturing industry and the intensification of market competition, the accuracy and efficiency of products are demanding higher and higher. Precision machining technology will continue to develop towards higher precision and more efficient direction. In the future, the precision processing technology will adopt more advanced processing equipment, more optimized processing strategy and more efficient tool path planning, in order to achieve higher precision processing and more efficient production. At the same time, the research on the error control and compensation technology in the processing process will also be strengthened to improve the accuracy and consistency of the processed parts.

5.2.2. Green manufacturing and sustainable development direction

Green manufacturing and sustainable development are the important trends in the current manufacturing industry. Precision machining technology will also be in the direction of green manufacturing and sustainable development. In the future, precision machining technology will focus on reducing energy consumption, material consumption and emissions in the processing process, and use environmentally friendly materials and clean energy, to reduce the impact on the environment. At the same time, it will also strengthen the research on the recycling technology of waste equipment and materials to realize the recycling and conservation of resources.

5.2.3. Intelligent, networked and service-oriented transformation

With the rapid development of artificial intelligence, big data, the Internet of Things and other technologies, the precision machining technology will also transform to be intelligent, networked and service-oriented. In the future, the precision machining equipment will be equipped with more advanced sensors, controllers and actuators to realize the automation and intelligent control of the processing process. At the same time, a network platform of precision machining technology will also be established, to realize the interconnection and data sharing between equipment, and to improve production efficiency and collaborative innovation capacity. In addition, the precision machining technology will also develop to the direction of service, providing customized processing solutions and technical services, to meet the personalized needs of customers. To sum up, although the precision machining technology is facing many challenges, but it also shows a broad development prospect and the future trend. By constantly breaking through technical bottlenecks, reducing processing costs, strengthening cross-field technology integration and innovation, as well as developing to the direction of higher precision, higher efficiency, green manufacturing, intelligent, network and service-oriented, precision processing technology will provide strong support and guarantee for the transformation and upgrading and sustainable development of modern manufacturing industry.

6. Conclusion and outlook

Precision machining technology plays an pivotal role in the field of mechanical design, manufacturing and automation. It is the key to improve product accuracy, optimize performance and reduce cost. Through the in-depth analysis of key technologies such as ultra-precision machining, micromachining and special machining,

combined with the application of optical lens, semiconductor wafer, MEMS devices and other examples, we have fully witnessed the infinite potential of precision machining technology. Looking forward to the future, we look forward to the precision machining technology can continue to move forward on the road of higher precision and higher efficiency, while integrating the concept of green manufacturing to promote the transformation and upgrading of the manufacturing industry. We firmly believe that precision machining technology will become an important driving force for the development of manufacturing innovation and contribute more to the prosperity of the global economy.

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