Application and Key Research Technology of Angle Head

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Abstract—Angle head is a kind of machine tool accessory. After the angle head is installed on the machine tool, the rotation center line of the tool can be angled with the spindle rotation center line to process the workpiece. It has been widely used in various fields of machining such as aerospace, automobile, engineering machinery, etc. The use of an angle head can increase the processing range and adaptability of the machine tool, enable some processing that is difficult to complete with traditional methods, and reduce the repeated clamping of the workpiece, and improve the processing accuracy and efficiency. This paper briefly introduces the application occasions of angle heads and several classification methods, focusing on the characteristics of 90° angle heads, universal angle heads, specific angle output angle heads and non-standard customized angle heads. It also summarizes the current situation and key research technologies of the angle head, and finally looks forward to the application and development trend of the angle head.

1. INTRODUCTION

Angle head is a kind of machine tool accessory head applied to CNC gantry boring-milling machine and CNC floor-type milling-boring machine, or machining center. The spindle of the machine tool drives the gear set, the gear set transmit power to change the direction of rotation of the tool. After the angle head is installed on the spindle of the machine tool, the rotation center of the angle head spindle can process the workpiece at any angle or a certain angle with the rotation center of the machine tool spindle. Without changing the structure of the machine tool, the processing range of the machine tool and the adaptability of the processing of complex parts can be expanded. Some processing that is difficult to complete with traditional methods can be realized, without requiring the workpiece to be repositioned for a secondary operation. The angle head can improve processing accuracy and efficiency, especially the processing of the inner and outer sides of some box parts, and when drilling, milling grooves, and milling boss in the cavity [1]. Because the angle head expands the use performance of the machine tool, it is equivalent to adding an axis to the machine tool. It is even more practical than the fourth axis when some large workpieces are not easy to flip or require high precision.

2. TYPES AND APPLICATION OF ANGLE HEAD

Angle heads are also called side milling head. According to the weight and processing condition, it is divided into light angle head, medium angle head, and heavy angle head. The characteristic of the light angle head is light weight (usually 5-15kg), high accuracy, and low torque. This type of angle head can be installed in the tool magazine and can be freely converted between the tool magazine and the spindle of the machine tool. This type of angle head use positioning block to locate, the output is generally collet
or BT30 taper shank. The characteristic of the Medium angle head is medium quality (usually 15-20kg), high precision and larger torque, etc. and their processing range is wider than light angle head, so it is widely used in the market. The characteristic of the heavy angle head is heavy weight (generally above 50kg), lower accuracy than medium and light angle head, larger torque than medium and light angle head, and good rigidity. It is usually used on gantry boring-milling machine tool. This type of angle head is fixed and locked with a connecting plate, which can support multiple types of output forms for processing. According to the output form, it can be divided into single output angle head, dual output angle head, vertical and horizontal dual angle head, single output angle head are more common, with better rigidity, and can be widely used in various applications. The dual angle head adopts two-way output, and high concentricity accuracy. It can solve the symmetrical holes with high concentricity, which requirements processed from both ends, avoid the trouble of manual rotation and meter correction, and significantly improve production and processing efficiency. The vertical and horizontal angle head can be used for vertical and horizontal processing at the same time, or they can be processed separately. The angle head adopts the principle of two-way thrust bearing and bevel gear separation, which makes the correction more convenient and faster. Its internal adopts high-speed thrust bearing, fixed in two directions, which can bears heavy cutting. According to different use environments and processing requirements, the types of angle head can be divided into 90° angle head, universal angle head, specific angle output angle head and non-standard customized angle head [2].

2.1. 90° angle heads

The spindle of the angle head forms 90° angle with the spindle of the machine tool. It is also called a right-angle head. The input of this type of angle head can be BT30, BT40, BT50, and the output can be ER chuck or a tool holder for side machining of the workpiece; Angle heads include single output type (Fig. 1), dual output types such as (Fig. 2) and offset type for processing the inner surface of deep cavities (Fig. 3). Such angle heads are widely used in the processing field. It is the inner and outer sides of the processed product.
2.2. Universal angle heads

The angle between the spindle center of the universal angle head and the spindle of the machine tool is continuously adjustable within 0-90°. It is used for the processing of a specific angle surface of the workpiece. Because its angle can be adjusted at will, it is called a universal angle head, as shown in Fig. 4. There are certain requirements for the angle setting. Some angle adjustments are set at 15°, and some angle adjustments are set at 5°. The adjustable accuracy of universal angle heads produced by some European machine tool accessory manufacturers can reach 1° or even 0.1°. The output of this type of angle head is ER chuck.
2.3. **Specific angle output angle heads**

The angle formed by the output spindle of the specific angle output type angle head and the spindle of the machine tool can be arbitrarily specified, such as 45 degrees, as shown in Fig. 5, which is mainly used to process the specific angle surface of the workpiece, which is convenient and practical. The output of this type of angle head can be an ER chuck or a tool holder.
2.4. Non-standard customized angle heads

Non-standard customized angle heads are non-standard customized products, and their external dimensions are determined according to the parts processed by the user, so they are generally not sold directly in the market. The angle heads are generally based on the actual processing needs of the customer and entrust a certain strength to produce Design and make to order by business. Many large gantry boring and milling machines, large turning-milling and machining centers will use non-standard customized angle heads, which are mainly used for the processing of large workpieces in the fields of aerospace, military, energy equipment and construction machinery. As shown in Figure 6, the extended 90° angle head customized by the user is mainly used for the processing of the inner hole of the narrow box.

![Fig. 6 Non-standard customized angle head](image)

3. THE DEVELOPMENT TREND AND KEY RESEARCH TECHNOLOGY OF ANGLE HEAD

3.1. The development trend of angle head

The development of CNC machine tool industry in my country is relatively late, and the corresponding machine tool accessory-angle head has developed relatively late. The structure of the angle head is sophisticated and complex, and the level of technology is high. It involves parts materials, processing technology, quality of assembly workers, and processing equipment. Item factors, so the development is slow. In recent years, the mainland has only gradually emerged manufacturers focusing on the research and manufacture of angle heads, but the processing and manufacturing of angle heads generally have the characteristics of low precision and low speed, and there is still a certain gap in quality and performance compared with Taiwan and foreign products. At present, the performance requirements of domestic parts processing, which cannot be satisfied. Especially for large and complex structural parts and box parts in the aerospace industry[4]. At present, high-precision and high-speed angle heads mainly rely on imports. In Taiwan manufacturers, the brand with the most complete specifications is HOLD WELL, and Gongyang only produces heavy-duty; there are many foreign manufacturers, such as the United States PALEC, DORIAN in the United States, MIMATIC in Germany, MADAULA in Spain, OMG in Italy, etc. Foreign products generally have high prices and high maintenance costs and long periods. Therefore, it is an urgent task to focus on the research and development of angle heads with sufficient rigidity, high precision and high speed, and it is particularly critical to strive to break the foreign technology monopoly.
Therefore, it is of great significance to carry out detailed research on the angle head. Through the analysis of the application requirements of the angle head, the weak part of the angle head is obtained, and then the development and optimization of the angle heads are provided as a basis based on the analysis results. Analyze the angle head's structure, force analysis and operating conditions, study the characteristics of the key components of the angle head, establish the finite element model of the angle head, and use the finite element analysis software ANSYS Workbench or UG NX to perform static analysis on the angle head. Simulation analysis of mechanics, modal and dynamic characteristics [3], optimization and analysis of the transmission structure and external size structure of the angle head, provide theoretical basis and technical support for the long-term stable operation of the angle head, and make it develop towards the direction of high speed, high precision and high reliability.

3.2. The key research technology of angle head
First of all, the most critical part of the angle head is the spindle. The spindle is an executive component that realizes parts processing through tools. The comprehensive performance of the spindle's machining accuracy, processing technology, and material properties has a greater impact on the part processing. The parts are processed continuously on the spindle. It is completed in ground rotation, and the verticality of the spindle rotation center line and the box body has strict requirements. If the quality of the spindle is not good enough, the processed parts cannot meet the design requirements. Therefore, when developing the angle head, pay attention to the overall performance of the angle head spindle.

Secondly, the quality of the bearing is a key part that affects the quality of the angle head. The force generated during the processing of the angle head is mainly borne by the bearing. The spindle and the inner ring of the bearing rotate continuously, and the bearing will wear after a period of time. To ensure the angle head for sufficient rigidity and rotation speed, the bearing must have a certain amount of pre-tightening. The size of the pre-tightening is related to the bearing model, accuracy grade, material of the machined parts, processing parameters and other factors. It is studied through analysis software and experiments. Because of the high speed of the Angle head, the high precision P4 bearings are usually used.

Third, the gear accuracy grade of the angle head is directly related to the speed. The higher the accuracy grade, the higher the linear speed of the gear can ensure the high speed requirements of the angle head. The gear also needs to be grinded and pressurized to reduce the surface pores. The operation is smoother. Under continuous high-speed operation, the temperature rise of the angle head is kept within a reasonable range, and the machining accuracy of the parts is stable to achieve the best performance requirements [5].

Finally, the material of the part is one of the important factors affecting the stability of the angle head. The selection of the part material is to first consider the use environment and processing parameters of the angle head. Due to the small size and shape of the angle head, the high speed, and the smaller torque relative to the accessory milling head, the vibration is not large during the cutting process, and the high-strength aluminum alloy shell is generally selected. The material of the spindle should be low-carbon alloy steel, and the bearing mounting surface and taper hole should be carburized and quenched to improve the surface wear resistance. Gears are mainly used to transmit power and have a high speed. Generally, low-carbon alloy steel is used for carburizing and quenching to meet wear resistance requirements.

4. Conclusions
With the rapid development of the aerospace and manufacturing industry in China, some large and complex structural parts and box parts have replaced a large number of assembly parts, which significantly increase the processing requirements of machine tools. Compared with traditional tool processing methods, the angle head can effectively solve the processing of large structural parts with complex features such as the narrow regions, high-precision side holes, and difficult-to-machine deep groove structures[6]. And the angle heads can effectively solve the problems of poor processing quality stability, high manufacturing costs, and long manufacturing cycles caused by traditional process
solutions, and avoid design complex tool and transform station. The research and development of angle heads has received extensive attention from many experts and scholars. Therefore, the development and application of advanced angle heads is one of the important ways to promote the healthy development of my country’s manufacturing industry. The inevitable trend of development in high speed and other directions.

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