Research on CNC Machining Technology of the Upper Shell of Electro-hydraulic Servo Valve

Jingjie Guo¹,²,a, Shaojie Ma¹,* ,Xiangjin Zhang¹,**,Xianghui Han¹

¹ School of Mechanical Engineering, Nanjing University of Science and Technology, Nanjing, PR China
² School of Mechanical and Electrical Engineering, Henan Institute of Science and Technology, Xinxiang, PR China
*a guojingjie@vip.163.com
* Corresponding author: 438729185@qq.com
** Corresponding author: z_x_j888@163.com

Abstract—The CNC machining technology of the upper shell of electro-hydraulic servo valve is complex, and the machining accuracy is required to be high. According to the existing cutting tools and machine tools, the CNC machining process with CNC lathe and 4-axis machining center is designed. First of all, the aluminum alloy blank is roughened and finished on the CNC lathe. After the processing is completed, the two ends of the blank are processed on the CNC lathe, and rough milling, fine milling, drilling and boring processing are carried out with the 4-axis machining center. After the 3D CAD model of the upper shell is constructed, the tool path of rough machining and finish machining is generated by MasterCAM software, and then the G code is generated by the post processor and input to the machining center for machining. The NC machining technology of the upper shell can effectively improve the machining efficiency and accuracy.

1. Introduction

The electro-hydraulic servo system has the advantages of fast response, strong bearing capacity and high control accuracy. It has been widely used in industry and agriculture, national defense and military industry, aerospace and other fields [1-3]. Servo valve is the core component in the electro-hydraulic servo control system. It has the advantages of high control power, high control precision and good reliability. Its reliability directly determines the reliability of the servo mechanism. Servo valve is generally a highly integrated multi porosity integrated body. Due to its complex shell structure and high assembly accuracy requirements, it is difficult to process. Therefore, the machining of the shell is an important link affecting the quality of the whole servo valve [4-5]. The upper shell of a certain type of electro-hydraulic servo valve has many apertures and profiles which are not in one plane, so the machining is limited due to its complicated structure. In order to ensure the machining accuracy and assembly accuracy, the machining technology and tool path design of the upper shell of the electro-hydraulic servo valve were studied.
2. Process analysis of mechanical structure drawing of the upper shell of Electro-hydraulic Servo Valve

2.1. Mechanical Structure of the Upper Shell
The mechanical structure drawing of the upper shell of electro-hydraulic servo valve is shown in Figure 1. It can be seen from Figure 1 that the part has several profiles such as horizontal planes, inclined planes. In addition, there are holes and inner cavity holes. This part is a kind of precision fitting part, and the precision of the fitting surface is very high. It is difficult to clamp the part when machining the part, and the inclined plane needs to be processed by rotating angle or clamping several times at different positions.

2.2. Analysis of processing technology requirements
The technical requirements analysis of parts is mainly to analyze whether the parts can be processed by existing machine tools on the premise of meeting the technical requirements (such as roughness, manufacturing tolerance, etc.). First of all, it analyzes whether the technical requirements are reasonable. If the technical requirements are too high, the machining accuracy can be guaranteed, but the performance requirements of machine tools and cutting tools are high, which easily leads to high manufacturing costs. Secondly, on the basis of reasonable technical requirements, it analyzes how to select machine tools and cutting tools to meet the machining accuracy and technical requirements, and formulates the processing technology.

2.3. Preliminary division of processing steps
The mechanical structure of the parts is mainly composed of a series of complex structures such as mounting holes, through holes, planes and inclined planes with various diameters. The surface roughness requirements of the parts are relatively high (Ra 3.2). Compared with other processing
methods, milling has the advantages of high production efficiency and wide processing range. It is especially suitable for the processing of complex shape combination parts, especially in the processing of various complex curved surfaces, it has incomparable advantages compared with other processing methods. Moreover, in the milling process of parts, good surface integrity of machined surface is extremely important, because surface defects often accelerate the damage of parts, so surface integrity is an important factor to determine the performance of parts [6-8]. According to the configuration of existing tools and machine tools, the preliminary division of processing steps is shown in the Table I.

| Processing Step | Details of Processing Technology |
|-----------------|----------------------------------|
| Rough machining | Saw processing                    |
|                 | Rough turning                     |
|                 | Rough milling                     |
| Finish machining| Fine turning                      |
|                 | Fine milling                      |
|                 | Fine boring                       |

3. Details of machining process

As mentioned above, the mechanical structure of parts is very complex, and it is difficult to process all parts by using single function CNC machine tool. In addition, if the part is machined on a 3-axis milling machine, it is difficult to ensure the machining accuracy due to too many clamping times. Therefore, the parts need to be processed on CNC lathe and 4-axis machining center. Firstly, the saw machine is used to process the blank, and then the CNC lathe is used for rough turning and fine turning for both ends of the blank, and the other parts of the blank are respectively rough milling, fine milling and fine boring by the 4-axis machining center.

3.1. Processing of rough parts

The blank of the part is made of profile aluminum bar, and the requirement of tool strength is not high when aluminum alloy workpiece is processed, so the manufacturing cost can be reduced. Circular aluminum alloy bars with a diameter of 125 mm and a length of 105 mm are selected and cut with a saw machine.

3.2. Rough machining

As shown in Figure.2, the end face of the blank is roughened on the NC lathe to make the length of the blank 97.5 mm. Then rough turning the outer circle of Φ 83mm and rough turning of circular groove of Φ 51 × Φ 24 × 25.5. Rough mill two 96 × 52 planes on the 4-axis machining center. Secondly, rough milling 60 degree inclined plane, rough milling end face and end face groove Φ 18 × Φ 23 × 1.4. Then drill holes with milling tools on the 4-axis machining center, milling and boring Φ 14mm and Φ 12mm inclined holes, and rough milling R6 mm oil groove.
3.3. Finish machining
Finish milling the 195-degree U-groove with a radius of 6 mm is carried out on a 4-axis machining center. Besides, the length of the workpiece is 96mm, then the outer circle is Φ 60 * 19mm and the outer circle is Φ 24mm, the inverted angle is 30 degrees and the fillet is R2 mm. the remaining plane and slope of the workpiece are finish milled On the 4-axis machining center, and then the Φ 53mm and Φ 15mm are finish bored.

3.4. Design and selection of fixture
Three jaw chuck can be used for positioning and clamping on CNC lathe. Milling U-shaped groove on the 4-axis machining center can be positioned and clamped with a flat vise. For other surfaces of the workpiece machined on the 4-axis machining center, the special fixture should be designed for clamping and positioning, as shown in Figure.3.
3.5. Determination of cutting parameters
Cutting parameters is a very important parameter, and the selection of cutting parameters has a very important impact on processing efficiency, processing quality, production costs and so on. Reasonable cutting parameters refer to the cutting parameters which make full use of the dynamic performance of machine tool and cutting performance of cutting tools to obtain higher production efficiency and lower processing cost on the premise of ensuring quality.

In the cutting process, the metal removal rate is closely related to the cutting depth \( a_p \), feed rate \( f \), cutting speed \( v \), and maintains a linear growth trend. Therefore, in order to ensure a reasonable cutting rate, it is necessary to coordinate the relationship between the three, which can neither make the tool damage too much nor affect the processing efficiency. The three factors of cutting parameters, namely cutting depth \( a_p \), feed rate \( f \) and cutting speed \( v \), have influence on the tool life. The cutting speed \( V \) is the most important factor affecting the tool life, followed by the feed rate \( f \), and finally the cutting depth \( a_p \). Therefore, in order to ensure the service life of the tool, we should first adopt a larger back feed and select a large cutting depth; then select a larger feed rate. Finally, according to the relationship between the three, the cutting speed can be calculated [9].

The selection of cutting depth is mainly based on the material of the part and the performance of the machine tool. For contour processing, because the material of the part is aluminum alloy, the requirement for tool strength is not high. The cutting depth can be 2 mm and the finishing depth can be 0.5 mm.

The selection of feed rate depends on the machining accuracy and surface roughness requirements of parts, as well as the different materials of cutting tools and workpieces. The determination of cutting speed can be obtained by consulting the cutting manual.

Checking the power of the machine tool is to comprehensively consider whether the machine can be used according to the value given by the machine itself. The value can be checked according to the name plate on the back of the machine tool.

4. CNC programming of part
The CAM software MasterCAM is used for CNC programming of the part. Because the CNC machining of the part is more complex, according to the characteristics of the special fixture and 4-axis machining center, the center point of the left end face of the workpiece is set as the programming origin. The rough milling tool is the \( \Phi 50 \) flat top milling cutter in the tool magazine. The spindle speed is 5000r / min, and the feed speed is 3200 mm / min. The finishing milling tool is the \( \Phi 10 \) round nose milling cutter in the tool magazine. The spindle speed is 6500r / min, and the feed speed is 3500 mm / min. Other parameters such as feed rate per tooth, linear speed and cutting speed are automatically calculated by MasterCAM.

4.1. Rough milling on the upper surface of the part
As shown in Figure. 4a, the upper surface of the part is roughly milled with a flat end cutter with a diameter of \( \Phi 50 \) to save processing time.

Figure.4a Tool path of rough milling on the upper surface of the part
4.2. **Rough milling on the side of the part**
As shown in Figure 4b, the flat bottom cutter with diameter of Φ 50 is used to rough mill the side of the part to achieve the purpose of fast cutting.

![Figure 4b Tool path of rough milling on the side of the part](image)

4.3. **Rough milling on the lower surface of the part**
As shown in Figure 4c, the lower surface of the part is roughly milled with a flat end cutter with a diameter of Φ 50, so as to achieve the purpose of fast cutting the surplus part.

![Figure 4c Tool path of rough milling on lower surface of parts](image)

4.4. **Finish milling on the side of the part**
As shown in Figure 5a, a round nose milling cutter with a diameter of Φ 10 is used to finish mill the side of the part to improve the machining accuracy.
4.5. Finish milling on the lower surface of the part
As shown in Figure 5b, a round nose milling cutter with a diameter of Φ 10 is used to finish mill the lower surface of the part, so as to improve the machining accuracy of the lower surface.

5. Conclusions
The design of the CNC machining process of the upper shell follows the principle of milling surface before milling hole and rough machining before finish machining. It can not only set the precise positioning benchmark, but also effectively improve the processing efficiency. The roughness of the workpiece after machining is required to be Ra 3.2. According to the design needs and technical requirements, the use of CNC lathe and 4-axis machining center for CNC machining of parts, compared with only using 3-axis CNC milling machine for multiple clamping for NC machining, can reduce the processing time by more than 30%, reduce the manufacturing cost, and ensure the machining accuracy of the part.
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