Design and Control of Automatic Tool Changer for Machine Center

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Abstract. Automatic tool changer (ATC) device is an essential part in CNC Machining centers, which can make the machining centers smoothly running using the tool magazine and automatic tool changer control system. In order to reduce the non-cutting during work, improve productivity and reduce production costs, machinery part and control system of ATC are designed based on the disk tool magazine and tool change process of machinery arm. In this system, PLC is used as brain to magazine the tool moving, automatic tool selection, cutter spindle sleeve rollover and exchanging control. Results show that the designed automatic tool changer device and control system have the characteristic of stable performance, precise control, simple operation, and convenient monitoring. From the view of industrial applications, this system has well practical value.

Introduction

With the development of processing technology, high efficiency and automation of high-speed machining become the future trend in the manufacture. In the CNC machine centers with the quality of comprehensive, multi-function and high precision, the automatic tool changer (ATC) device is most key part. Advanced CNC machining centers can improve efficient and lower cost by fast changing tools, which is contributed by reduce the non-cutting and errors caused by multiple work piece clamping[1, 2]. In CNC machining centers, machining process is very complex, such as multi-action, tool changing and need more coordinated between the actions. Therefore, whether the performance of ATC system is good or not directly affects the efficiency and stable operation of machining centers [3, 4]. In order to meet the requirement of high-speed machining in the future, a set of automatic tool changer was designed and equipped with Mitsubishi PLC as controller, which are in charge of the control of choosing tool from tool magazine and exchanging tool by machine hand, including automatic tool selection, cutter spindle sleeve rollover and exchange controlling. In fact, based on nearest principle, this device can make motor drive automatically select required tool during work-piece process. The required tool is rotated to given position from the magazine, and then exchanged with the tool in spindle [5]. By collaboration of automatic tool changer hardware and PLC software, the work reliability are promoted, tool changing time reduced, and the work efficiency improved.
Mechanical structure Design of Automatic Tool Changer

The machine with automatic tool changer consists tool magazine and tool changer. The tool magazine is so complex that the shape, placement, the number of tools, transportation tool path and other factors had to be taken into account by its designer[6]. Generally, the tool changer can be designed with no intermediate switching mechanism such as mechanical gripper, or designed with mechanical hand tools to exchange. In this paper parameters of automatic Tool Changer are following, number of tools 24, maximum tool diameter 60mm, tool form BT40, minimum speed of cutter 60 r/min, and cutter disk diameter 600 mm. Cutting tool selecting and exchanger are realized by disk rotation and mechanical gripper, respectively. Tool magazine is placed on the side of CNC machine, which have advantage of relatively flexible tool layout, expansion capacity and running smoothly. Due to the small inertia, time of tool preselecting and tool change reduce sharply, while the speed of tool change increase.

Magazine Design

Number of tools and tool select time should be taken into account while design magazine[6, 7]. Generally tool holder located on disc is asked to keep equal spacing except for different sizes of tool diameter. The tool holder usually is arranged smaller spacing for small diameter tool, otherwise arranged wide spacing for maximum size diameter tool. Fig.1 provides the structure of tool magazine, rotating cutter disk, which diameter is calculated according to the tool number in the tool magazine and the maximum tool diameter. The space should be left between adjacent two tools. Tool Magazine includes four parts, cutter disk and tool holder, reversing and positioning mechanism, reversing mechanism and motor.

Cutter disk mechanism design. Cutter speed and tool storage capacity are affected by the magazine structure. Compare with square cutter, the disk cutter can not only maximize storage more tools, but also make the movement distance of cutter tool short. This structure is relatively simple and can low process requirements.

Table 1. Parameters of FANUC-αC12/2000i.

<table>
<thead>
<tr>
<th>Motor type</th>
<th>Rated output power (kW)</th>
<th>Static torque (Nm)</th>
<th>Rated torque (Nm)</th>
<th>Maximum rotational speed (r/min)</th>
<th>Moment of inertia GD2/4(kgm^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FANUC</td>
<td>1.8</td>
<td>12</td>
<td>12</td>
<td>2000</td>
<td>0.0062</td>
</tr>
</tbody>
</table>

As shown in Fig.2, disc cutter is connected and fixed with ring gear by a bolt. The motor drives disc cutter through a transmission mechanism connected with the ring gear, and can stop at the given position after finishing the automatic tool selection process according to the machine instructions. Compared with single-pole plate, the structure of disc cutter connected with ring gear can meet the requirements of tool selection, strength and effectively extend the working life. According to tool storage capacity the cutter disk is divided to 24 divisions. The each division have a set of tool holder positioning block, on which tool holder and the tool are located. Tool holder is fixed in the tool storage disc by bolt. To avoid interference between tools, the space between each tool should be asked during cutter tool change process. The
structure can avoid to replace the cutter axis of rotation and replace different tools according to various process. In this system, to change a tool can finish at least one process, thus shorting the processing time and reducing the processing cost. The motor parameters are listed in Table 1.

![Figure 1. structure of the tool magazine.](image1)
![Figure 2. structure of cutter disk design.](image2)

**Rotating and positioning mechanism design.** (1) Gear transmission mechanism. Due to the compact structure, in short distance transmission, drive efficiency is high and working is relatively stable and reliable. In this paper the follow parameter are used, as shown in Fig.3, the transmission ratio 2, small gear 20, pitch circle diameter 64mm, big gear is 40, all gear tooth thickness 40mm, pressure angle 20 degree, and so on.

(2) Worm drive mechanism. This structure have many advantages, such as larger meshing area, more stable and reliable, lower vibration noise and good self-locking feature. In this paper the follow parameter are used, as shown in Fig.3, center distance 180mm, pitch circle diameter of worm wheel 120mm, gear 30, pitch circle diameter of worm 60mm, modulus 2, pressure angle 20 degree.

**Reversing mechanism design.** To overcome the large area caused by vertical tool magazine and more tools in fixed cutter disk, reversing mechanism of tool holder is needed to be designed executing tool holder flip and changing the direction of the tool. As shown in Fig.4, reversing mechanism of tool holder is composed of two position sensors, the hydraulic cylinder, the piston rod and the lifting body. Tool holder moves upward driven by the turret drive mechanism connected to the hydraulic cylinder piston, and turns following counter-clockwise traction mechanism.

![Figure 3. structure of positioning mechanism.](image3)
![Figure 4. reversing mechanism of tool holder.](image4)
Manipulator Design

There are two types for tool changer, one is non-intermediate switching mechanism such as mechanical gripper, and the other adopts mechanical hand tools to achieve exchange[8]. Tools magazine with non-intermediate switching mechanism has the advantages of flexibility in the arrangement and more number tools. As shown in Fig.5, in this paper, it is adopted manipulator changer, in which the robot gripper with hook form is fixed at each end. In this device rotary cutting tool can realize exchanging movement when seizing the exchange position of the holder at the same time and drive the shank-taper axis with cutting tool to rotate. Driver device adopts hydraulic cylinder, which can convert the circulating liquid to kinetic energy, potential energy, with advantages of eliminate speed-changing mechanism in driven process, non-complicated connections, stable energy supply for a long time and so on.

Fig.5 is the structure of ATC Manipulator, which illustrates the tool-changing as follows,

1. Cutter holder flip 90º counter-clockwise
2. Gripping with Manipulator rotating 90º Clockwise

Before changing tools, the angle between center line of two hook-shaped gripper and line of the vertical center for tool holder is 90 degree. After the oil into the hydraulic cylinder, it drives tool holder flip 90º counter-clockwise. When the trigger stroke position switch, PLC gives a gripping order, and the oil entering pressure cylinder 3 to promote the drive mechanism.

3. Removing. When receiving the machine instruction, the pressure oil enters into cylinder 1, drives the main shaft 13 declining, at the same time manipulator 14 declining and the tools removing.

4. Exchanging. When the main shaft 13 touches the trip switch, the machine give an exchanging instruction. The pressure oil enters into cylinder 11, manipulator rotate 180º counter-clockwise and the tool exchanging finish.

5. Inserting. After exchanging, baffle ring on the rack 12 triggers position switches, the machine give an exchanging instruction, the hydraulic oil into the cylinder 1.

6. Resetting. The main shaft trigger position switches 19, the hydraulic oil into the left oil chamber of cylinder 11, the mechanism restore the original position.

![Figure 5. the structure of the ATC Manipulator.](image)
Mechanical structure Design of Automatic Tool Changer

Automatic tool changer control system primarily consists of the magazine tool selection and tool exchange.

**PLC selection and wiring diagram.** In this paper Mitsubishi PLC FX3U-80MR/ES-A is adopted, which input and output points are all 40. It has the advantages of run faster, enabling PID control adjustment, signal interchange modulus, high counting and other functions. The I/O wiring diagram is shown in Fig.6.

**Tool selection.** The system can select the required tool random based on PLC software memory. Establish the data sheet according to cutting tool number, import PLC memory before processing. While machine tool changer gives an instruction to the PLC, the closest routes are calculated by PLC based on the principle of proximity.

**Tool holder reversal controlling.** Cutting tool can stop at the exchange position, when PLC giving an instruction of moving oil. At same time, tool holder reversal system drives cutter tool rotate 90° counter-clockwise.

**Timing diagram design of tool change.** During the tool exchange processing, the tool, hydraulic cylinders and mechanical hand will work together accurately and avoid mutual interference behavior. According to the various agencies before and after the operation, timing diagram of Automatic Tool Changer is shown in Fig.7.

Figure 6. I/O wiring diagram of PLC.

Figure 7. The timing diagram of automatic tool changer.

**Conclusion**

The automatic tool changer device is constructed in detail, including machinery part, control system design, and PLC program. The main advantage is adopting mechanical hand tools to achieve exchange and using PLC to carry out tool magazine, like moving, automatic tool
selection, cutter spindle sleeve rollover and exchanging control. Results show that this device can reduce the defect rate during processing, increase productive efficiency, and productive competitiveness.

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References


