Research on Bamboo Hat ATC Control Design and Adjustment

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Abstract: Based on the FANUC 0iMateMD machine center, this paper introduces the structure of the bamboo hat ATC, the working principle, the process and the flow of automatic tool- change. By designing electrical diagram and PMC program and using correct adjustment methods, it realized the automatic tool- change control.

1. THE STRUCTURE OF THE BAMBOO HAT ATC

The bamboo hat ATC is a common tool- changer in small machining center. As shown in Fig. (**1**), it is generally made up of connecting plate, magazine bracket, dividing mechanism, and horizontal moving device. The horizontal moving device realizes the extended and retracted ATC. The dividing mechanism realizes accurate positioning; it carries the tool required in the next procedure to the designated location [1]. The ATC rotary motion is achieved by which three-phase motor drive the dial of the sheave dividing mechanism uniform rotary motion, thus to drive the sheave intermittent rotary motion. When the round pin on dial does not enter the slot of the sheave, the concave arc S_2 in the sheave and the convex arc S_1 in dial are sealed, and lock the sheave. In order to avoid rigid impact when the sheave starts or stops, the round pin enters and leaves the slot, the slot center line is tangent to the circle taking the center A of round pin as the center, namely the pin to the position of Fig. (**1**), $O_1A \perp O_2A$, the termination edge of locking arc S_1 in the dial is reaching at the location of the center line O_1A, losing lock function, the sheave is then released and starts to rotate. When the pin rotates to the A1, $O_1A_1 \perp O_2A_1$, the start edge of locking arc S_1 in the dial is reaching at the location of the center line O_1A_1, the sheave is locked [2]. By locking and releasing the sheave, the uniform rotary motion of ATC motor is converted into the intermittent rotary motion of the sheave, thus the process of tool selection is completed.

2. THE PRINCIPLE AND THE CONTROL DESIGN OF AUTOMATIC TOOL-CHANGE

The fixed tool changing mode is adopted in the bamboo hat ATC, that is, the number of tool sheath is the tool number, the tool taken from which tool sheath must put back to the original tool sheath, so there is no need to search the tool.

The motion tool-change can be divided into three steps; taking tool, returning tool and changing tool. The tool exchange is actually two movements of taking tool and returning tool, as shown in Fig. (**2**). The instruction of tool-change is issued, followed by execution of the motion of returning tool in the first place. The process of returning tool implies that Z axis arrives at the tool-change position, the spindle accurately stops, the ATC is extended out to be ready to catch tool, then the spindle loses the tool, and the ATC is back to the original position. The process of taking tool implies that the Z axis arrives at the ready position, the ATC motor forward or reversely rotates to find the target tool in the nearest route, then the target tool is revolved to tool-change position, the ATC is extended out, the spindle accurately stops and looses the tool, the Z axis arrives at the tool-change position, the spindle clamps the tool, the ATC retracts, and the Z axis returns to the tool-change ready position again, the electrical connection diagram is shown in Fig. (**3**). The tool-change movement using M06 instructions is complex, which can in general be divided into a number of M commands, and combined with the axis movement commands to complete, these instructions are in turn combined, and stored in a special macro program file. By using the #1000-#1002 macro variables corresponding to the corresponding bit of G54 signal in PMC program [4], it realized these discriminations that whether the tool number in T instruction is 0, and is consistent with the tool number on the spindle or the spindle has tool in the flow diagram (Fig. **4**). When the M6 instruction is read, the system will automatically and sequentially execute the G code and M code in this macro program. The process of automatic tool-change is as follows:

① The mode selection switch is allocated to "MDI" mode.

② Enter the MDI screen, input " M06 T** EOB "(**=0 ～16), press the [INSERT] button, the instruction is put into the CNC system.

③ Press the "start" button, the system calls the macro program tool- change according to the flow chart (Fig. **4**), looks for the target tool number and automatically changes tool.

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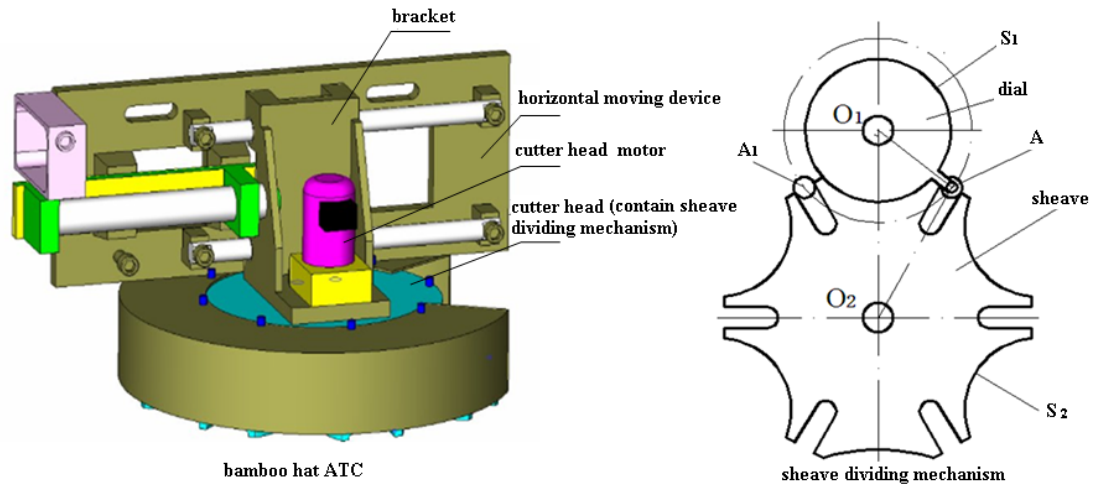
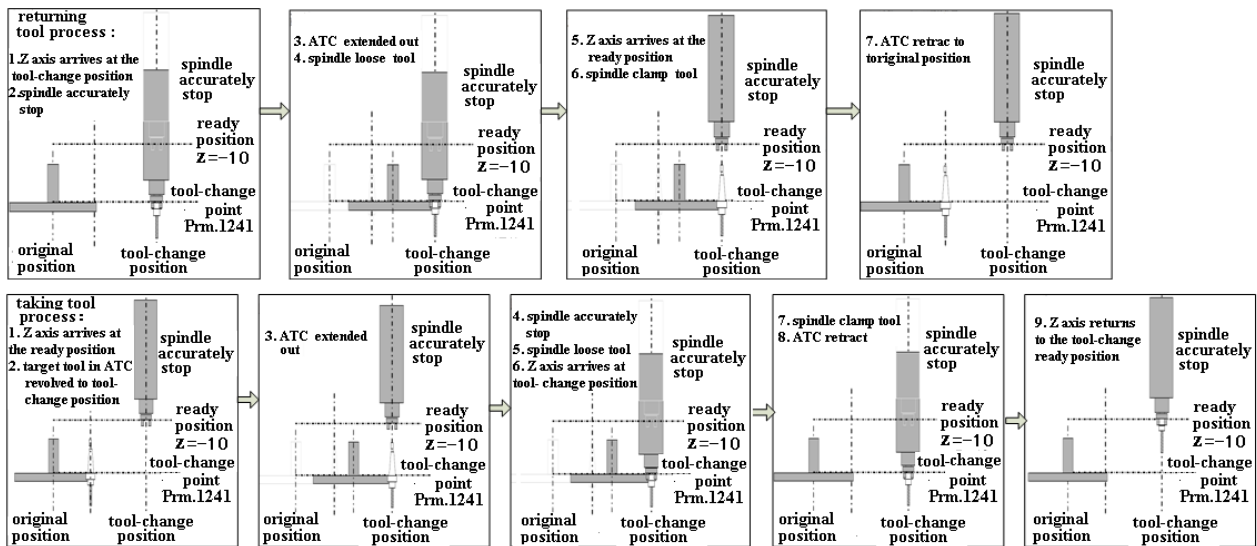**Fig. (1).** Bamboo hat ATC structure diagram.

Fig. (2). The process tool change diagram.

In order to execute the macro program content and the actual mechanical action together, according to the process tool-change (Fig. **4**), the electrical principle diagram of ATC (Fig. **3**) and the input and output allocation (Table **1**), with the meaning of M code in the tool-change macro program in Table **2**, the M code and the corresponding relay linked [3], the ladder program (Fig. **5**) was developed to achieve PMC control design of the bamboo hat ATC.

3. THE BAMBOO HAT ATC DEBUGGING

1. Spindle Orientation and Debugging Tool-change Point

(1) When spindle orientation and debugging tool-change point (second reference point), first of all, the machine tool should return to the reference point, and then manually move cutter head under the spindle, and instal the handle on the claw of cutter head.

(2) Then in the hand wheel manner the Z axis will slowly move downward, during this period, press and hold the tool loosening button, and then look at the claw of spindle whether it is aligned with the slot cutter head; if not, the orientation angle parameter No.4077 [4] needs to be adjusted. If the value of the parameter is greater, the orientation angle deflect to the inside, otherwise the angle deflect to the outside. According to debugging step by step, the angle has reached the optimal state.

(3) After the completion of the spindle orientation, debugging tool-change point can be started. In the hand wheel manner the spindle moves slowly toward the cutter head, when the spindle claw moves into the slot about 3mm of the cutter head, and the spindle claw cannot touch the slot rim of cutter head, then the angle parameter needs to be adjusted again. At the moment, read the Z axis coordinate displayed in CNC system, the coordinate values is entered put into the
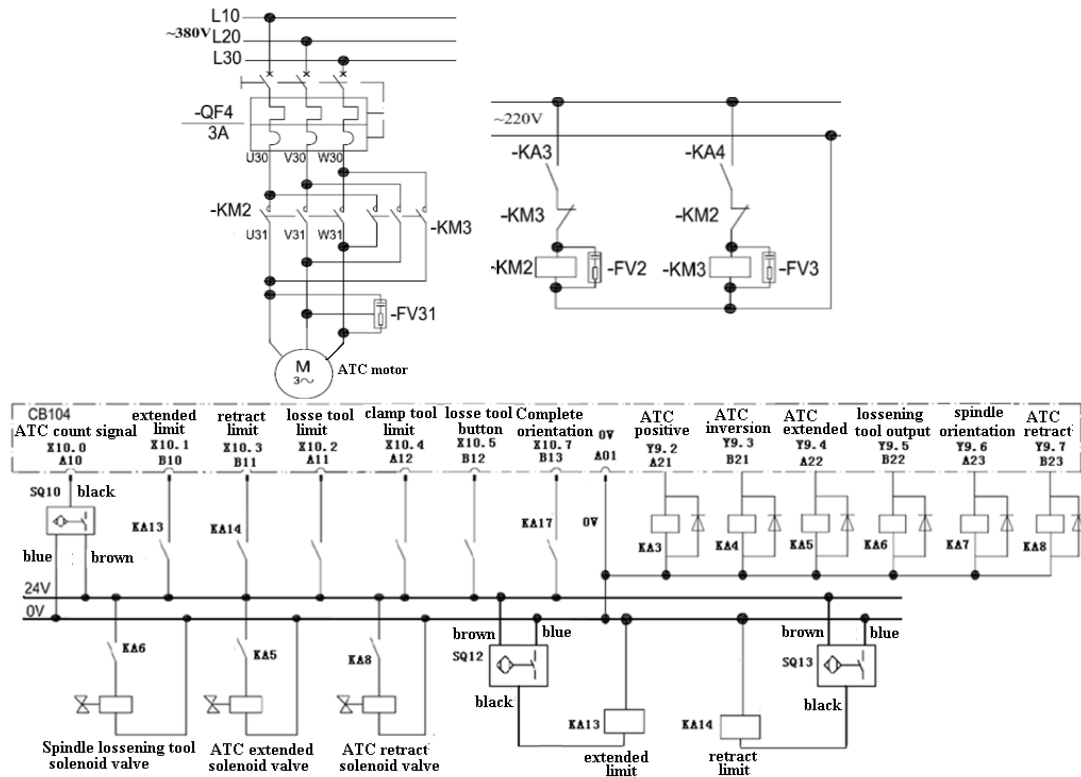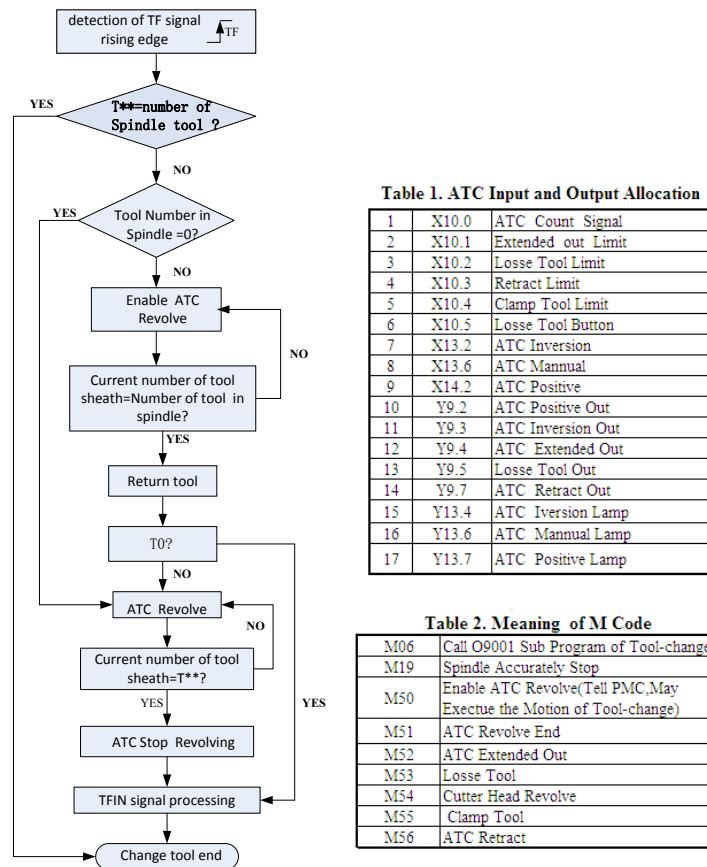
Fig. (3). ATC electrical principle diagram.

Table 1. ATC Input and Output Allocation

1	X10.0	ATC Count Signal
2	X10.1	Extended out Limit
3	X10.2	Losse Tool Limit
4	X10.3	Retract Limit
5	X10.4	Clamp Tool Limit
6	X10.5	Losse Tool Button
7	X13.2	ATC Inversion
8	X13.6	ATC Mannual
9	X14.2	ATC Positive
10	Y9.2	ATC Positive Out
11	Y9.3	ATC Inversion Out
12	Y9.4	ATC Extended Out
13	Y9.5	Losse Tool Out
14	Y9.7	ATC Retract Out
15	Y13.4	ATC Iversion Lamp
16	Y13.6	ATC Mannual Lamp
17	Y13.7	ATC Positive Lamp

Table 2. Meaning of M Code

M06	Call O9001 Sub Program of Tool-change
M19	Spindle Accurately Stop
M50	Enable ATC Revolve(Tell PMC,May Exectue the Motion of Tool-change)
M51	ATC Revolve End
M52	ATC Extended Out
M53	Losse Tool
M54	Cutter Head Revolve
M55	Clamp Tool
M56	ATC Retract

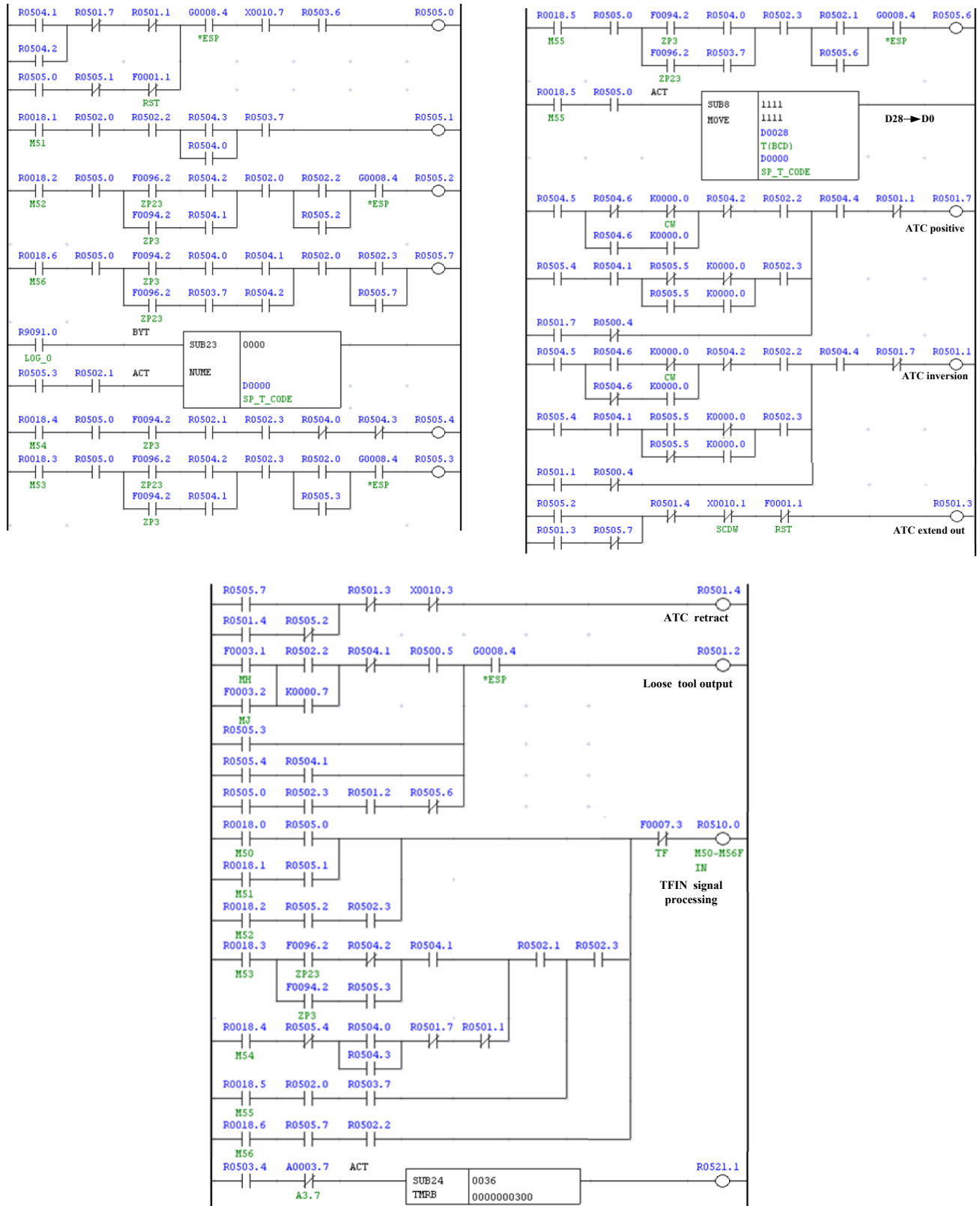**Fig. (4).** The Flow chart of tool-change.

Fig. (5). Ladder program.

parameter corresponding to the second reference point (PRM.1241). By debugging repeatedly and the optimization of the parameter, setting the tool-change point is completed.

(4) It is advisable that the above debugging process must be in the hand wheel manner and operates slowly; otherwise the cutter head or even the ATC may be damaged.

(5) Before operating the ATC, the tool-change macro program named after 9001 was fed into CNC system, and the system parameter (PRM.6071) needs to be set to 6.

2. Debugging the Process of Tool-change

Press "PROG" button, switch to the program editing images (MDI images), input "M06T**;" press "INSERT" key, press the "cycle start" button, the process of tool-change will start. If the process of tool-change is not normal, the following operations will be performed:

(1) In the CNC system, setting "counter" parameters, "data" parameters and "K" parameters. The specific operation is: press "SYSTEM" key, press three times "+" key namely the right extended soft key, then press "PMCMNT" key, press "+" key, thus, we can find the following parameters:

(2) Set the counter parameter. The first column parameter of the counter C0 is the tools capacity of ATC (if a certain ATC has 16 tools, then the first column parameter automatically is displayed as 16, the data is determined by the PMC program). The second column is the tag number of the current tool. The parameter can be modified in real time in the tool-change incorrect or disorder situation (*i.e.* the data corresponding to the number of the tool on cutter head, otherwise there will be a phenomenon of finding tool disorder).

(3) Set the data parameter. To set the parameter in the parameter setting screen; the "data" soft key is pressed, then press the "zoom" soft key. The number of current tool in spindle is displayed in the D0 column, if there is no tool in spindle, the D0 column should be set to "0"; if there is one tool in spindle, the D0 column should be set to the current tool number. The data in D28 is the number of the tool that is meant to change, namely the tool number which is fed in the MDI screen. In addition, the data in the D34 should be set to "1", the specific meaning is required by the PMC program.

(4) Set the K parameter. The K parameter is holding type relay, maintaining the status of the cutter head rotation for finding tool in the PMC program, until the tool is found, the status will be maintained again. If it suddenly stopped running in the process of finding tool, the value of K0.0 or K0.1 is "1" or their value is all "1". K0.0 and K0.1 need to be set to "0", before executing the tool-change command again.

(5) After the above parameters are all set, the correct operation of tool-change can be executed. These parameters can be saved automatically upon power failure (unless the power is off during the process of tool-change, leading to these data disorder). If the macro program of tool-change runs smoothly to finish, then the process of tool-change is correct and will normally end.

It is important that the machine tool must return to the reference point before tool-change. Once the tool-change is done, the above parameters are no longer maintained. Only when tool-change is not in normal circumstances, the above three parameters can be modified. These parameters can't usually be modified, otherwise it will lead to arbitrary tool or tools collision phenomenon.

CONCLUSION

To realize the PMC control function of bamboo hat ATC, the NC system variable, parameter settings, the NC macro program and PLC/PMC program cooperate with each other. At the time of implementing M06 directive, the execution sequence of macro program of instructions was considered, in order to avoid error that PMC caused and appearance of arbitrary tool phenomenon. The debugging method and the PMC control of bamboo hat ATC can be used in CNC milling machine for upgrading to full function machine center, based on different numerical control systems. Different parameters are required for different tasks, such as setting tool-change point namely the third reference point, FANUC 0iMateMD need to set the parameter 1242, while MITSUBSHI M70 machining center sets the parameter 2039.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

ACKNOWLEDGEMENTS

Declared none.

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