Loading and Unloading Manipulator Controlled by Built-in PLC in CNC System

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Abstract: An increasing number of industrial robotic devices are appended to the computerized numerical control machine tools for higher efficiency and lower labor cost. At this point the most crucial technology is to create communications between the robot and the numerical control controller. The presentation would contribute to retrofitting numerical control machine tools into highly flexible and intelligent manufacturing systems. Firstly, the miscellaneous function handling mechanism was investigated in the case of Mitsubishi E60 numerical control system. Secondly, the control system of an experimental pneumatic manipulator was designed using the programmable logic controller built-in the numerical control system. Finally, an experiment was conducted to verify that the pneumatic manipulator and the numerical control machine could work cooperatively. Obviously, the presented method can be used to develop various process equipments to enhance the intelligence and flexibility of numerical control machine tools. Copyright © 2013 IFSA.

Keywords: Numerical control system, Miscellaneous function, Pneumatic manipulator, Programmable logic controller, Intelligent manufacturing system.

1. Introduction

For higher efficiency, lower labor cost and more flexibility, a growing number of industrial robotic devices are employed in modern manufacturing system, e.g. automatic tool changers, automatic pallet changer, flexible fixtures, industrial robots and so on [1, 2]. Consequently, more and more intelligent robots have been integrated with computerized numerical control (CNC) machine tools to execute loading, unloading, handling, clamping, measuring, monitoring, and assembling and so on [3, 4]. This not only just expands automation capabilities of the machine tool but also introduces intelligence into the machine tool. To achieve these, the real-time data communication between the robot control system and the CNC system must be created. Therefore, some new integrated CNC controllers or open architecture motion controllers have been developed for intelligent CNC solutions, enabling highly flexible work cells and innovative manufacturing processes. For example, Weike Song and coworkers [5] presented a multi-robot open architecture of an intelligent computer numerical control system based on parameter-driven technology. And the proposed CNC system has been successfully implemented on an H-beam steel-cutting task that requires flexible and accurate machining. Luis Morales-Velazquez et al. [6] put forward an open-architecture platform based on multi-agent hardware–software units, by developing a novel multi-agent distributed controller system. The hardware units of the proposed system...
integrate control and monitoring functions providing an FPGA-based open architecture for reconfigurable applications. Moreover, several international consortiums like OSACA in E.U., OMAC in U.S., and JOP, have been dedicated to overcoming the vendor-specific communication issues through standardization of open architecture controllers [6]. However, incompatibility between hardware and software architecture from different vendors, as well as high integration costs, hinder the application of such new technology in the conventional CNC systems. Meanwhile, for most manufacturers, it is an affordable and more convenient way to consider how to add robotic devices to existing CNC machine tools. At this point, the communication between the programmable logic controller (PLC) and the CNC controller would have a pivotal role. The objective of this presentation is to discuss the key technologies of a pneumatic manipulator controlled by built-in PLC of Mitsubishi CNC system. The remainder of the paper is organized as follows.

Section 2 introduces the CNC-PLC communication mode and the handling principle of the miscellaneous function (M code) in CNC system. Section 3 illustrates the design method of a pneumatic manipulator controlled by the built-in PLC in CNC controller. Section 4 presents a synergic control experiment to verify the pneumatic manipulator and the CNC machine could work cooperatively. Some conclusions and discussion of future work are given in Section 5.

2. CNC-PLC Communication Mode

2.1. Flow of Control Signals

As it is known, the CNC system is the heart of a CNC machine tool. On receiving standard NC programs, i.e. G&M codes, the CNC system firstly interprets and encodes NC codes into internal machine codes. The interpolator of the CNC system then calculates the intermediate positions of the motion in terms of the minimum resolution that can be handled by the controller. After data processing, the preparatory codes (G code) are converted into pulses to control the driving system to perform the required motions. Other functions such as the machine spindle ON/OFF, coolant ON/OFF, tool clamp ON/OFF are translated as Boolean logic signal for PLC unit. In general, the miscellaneous function is specified by an M code.

Evidently, PLC plays an important role in CNC system as an inter-mediator between CNC unit and machine tool. It reads in discrete information from both CNC unit and machine tool, and after doing some corresponding logical calculations, completes the control functions of Input/output (I/O). In Mitsubishi E60 CNC system, the signal transmission between the built-in PLC unit and machine tool, CNC unit is illustrated in Fig. 1. In this figure, the devices X and Y stand for PLC I/O bit type signal. The device R refers to data type I/O signal. Smaller quantities of special relay/register signals are also needed, such as overheat alarm signal.

It might also be noted that the PLC does not directly input or output these signals from or to hardware or controller. As shown in Fig. 2, it inputs or outputs the signals from or to I/O image memory. For the reading and writing with the hardware or controller, the controller will perform the I/O according to the level of the main process or high-speed process. Only the signals from or to machine can be performed with high speed. The high-speed processing program starts periodically with a time interval of 7.1 ms. But the main processing program runs constantly and its scan time depends on program size. The pointers P251 and P252 are separately reserved for starting PLC high-speed processing program and starting PLC main (ladder) processing program.

As shown in Fig. 2, when high-speed input designation signal is used in main processing, the input signal may change within one scan because high-speed processing whose level is higher than main processing interrupts. The hatched area is high-speed input designation part. Whenever the high-speed processing program runs, data is reset in the hatched area. Thus, the signal in the hatched area may change in main processing (A) and (B) because the high-speed process interrupts between (A) and (B) and re-reads the input signal in the hatched area.
2.2. Miscellaneous Function Handling Procedure

For any given type of CNC controllers, e.g. Siemens, FANCU and Mitsubishi, the procedure to perform a miscellaneous function completely involves three key steps: decoding, M function implementation and finish confirmation. In this sequence process, the following points must be observed [7]:

a) When the M function is commanded, the M function strobe (MFn) and M code data is output.
b) MFn is always the trigger in the sequence process to start the M function process.
c) When the designated M function process is completed, the "M function finish" signal is returned to the controller.
d) The controller waits for the rising of the M function finish signal and then turns MFn OFF.
e) MFn OFF is confirmed in the sequence process and then the "M function finish" signal is turned OFF.

This completes the series of M function processes. As shown in Fig. 3, in M decode circuit, the MFn (X230=1) and M code data (R20) are output and the auxiliary relay M1 is set to ON. When M function is specified, the value following address "M" can be identified. The M code data output from the controller is a maximum eight digit binary-coded decimal (BCD) code. Then the designated M function is processing. After the M function finished, the auxiliary relay M2 is set as ON and PLC outputs the signal Y226=1 to CNC controller.

There is another M function strobe, i.e. X231, which only can be specified in automatic operation program other than manual numerical command input. It should be noted that there are also two "M function finish" signals, namely, "M function finish 1" (Y226) and "M function finish 2" (Y227). Their only difference is if the next block is proceeded to at the falling edge or at the rising edge. These can be used separately per operation in one PLC. When too many signals FIN1 must be used, this signal FIN2 can be used instead of signal FIN1 to save time.

3. Pneumatic Manipulator Controlled by Built-in PLC in CNC System

3.1. Pneumatic Manipulator Configuration

When figuring out the development principle of miscellaneous functions, it is not quite difficulty to append a loading and unloading manipulator to act together with the CNC machine tool. To facilitate the interpretation of elementary methods, this paper only displays a relatively simple pneumatic manipulator whose actuators mainly consists of a rotary actuator, a guided air cylinder and an air gripper, as shown in Fig. 5.
The actions sequence of the pneumatic manipulator is defined as follows. 
Step 1: When the NC program reaches the new added M code (M80), the pneumatic manipulator would be activated. 
Step 2: The rotary actuator rotates 90 degree. 
Step 3: The guided air cylinder extends length up to 50mm. 
Step 4: The air gripper shrinks and grasps the part. 
Step 5: The guided air cylinder returns. 
Step 6: The rotary actuator rotates back 90 degree. 
Step 7: The air gripper loosens to put down the part. 
Step 8: All actions are completed and the rest of the NC program continues. 

The listed complex operations can be easily simulated using event-based motion analysis with SolidWorks simulation to validate the sequencing of the design to ensure correct operation. Especially, the timeout value between adjacent actions can be planned properly.

### 3.2. PLC Control Program

According the foregoing action steps, the PLC I/O signals firstly are defined and allocated to I/O addresses (Table 1). Then according to the aforementioned process of miscellaneous function handling, the PLC program was written in Mitsubishi GX Developer software as illustrated in Fig. 6. Here, the code M80 is defined to trigger the pneumatic manipulator. It was evident that the PLC program included three parts: decode M command, handle M code actions and inform the CNC system that the M code was accomplished. Afterwards the PLC program can be directly transmitted to the CNC controller via RS232 communication port.

<table>
<thead>
<tr>
<th>Input signal</th>
<th>Output signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal name</td>
<td>Address</td>
</tr>
<tr>
<td>#1 magnetic ring signal of guided air cylinder</td>
<td>X2B</td>
</tr>
<tr>
<td>#1 relay to make rotary actuator rotate</td>
<td>Y1E</td>
</tr>
<tr>
<td>#1 magnetic ring signal of air gripper</td>
<td>X3A</td>
</tr>
<tr>
<td>#2 relay to make guided air cylinder extend</td>
<td>Y1F</td>
</tr>
<tr>
<td>#2 magnetic ring signal of guided air cylinder</td>
<td>X3B</td>
</tr>
<tr>
<td>#3 relay to make air gripper shrink</td>
<td>Y20</td>
</tr>
<tr>
<td>#2 magnetic ring signal of air gripper</td>
<td>X3D</td>
</tr>
<tr>
<td>#4 relay to make guided air cylinder return</td>
<td>Y21</td>
</tr>
<tr>
<td>#5 relay to make rotary actuator rotate back</td>
<td>Y29</td>
</tr>
<tr>
<td>#6 relay to make air gripper loosen</td>
<td>Y1A</td>
</tr>
</tbody>
</table>

![Fig. 6. Ladder figure of PLC control system.](image)

All selected air cylinders have their own magnetic piston rings for position sensing. As illustrated in Fig. 8, magnetic cylinder sensors are attached directly to the cylinder body and detect a ring magnet in the piston through the housing wall made of non-magnetizable material, e.g. aluminum. Generally, the magnetic induction of pneumatic cylinders is between 5 and 25 mTesla. A response sensitivity of 3 mTesla is enough to ensure signal triggering. Apparently, the switch logic of magnetic cylinder sensors should be the normal opened type.

### 3.3. Pneumatic System

On the other hand, the pneumatic executing system can be built by the air compressor, solenoid directional control valves, magnetic induction sensors, relays and so forth. Certainly, they are essential to achieve automatic control of the designed pneumatic manipulator. The pneumatic circuit was drawn as presented in the Fig. 7.

![Fig. 7. Pneumatic system configuration.](image)
4. Synergic Control Experiment

4.1. Experimental Approaches

Using the built experimental setup, the synergic control experiment can be performed. Firstly, a NC program was written as follows.

```plaintext
O0022
N10 M03 S2000;
N20 M80;
N30 G01 X200, Z200, F100.;
......
N 80 M30;
```

Then run the program above in automatic operations model. It would be observed that when the NC program reaches M80, the manipulator would be triggered immediately. As soon as all actions are finished, the next line code would execute. Fig. 10 shows the experimental status. The result of experiment embodied that the pneumatic manipulator and the CNC machine could work cooperatively.

As has been argued, the defined M80 can also be specified by manual numerical command input because that the function strobe X230 other than X231 is used in the PLC program.

4.2. Discussions

Obviously, the whole experiment was successful. However, there are a few additional facts to add. Firstly, if the pneumatic manipulator may cause faults in the course of the M function handling, e.g. leakages in the pneumatic circuit, the NC program can pause in automatic operations model. After troubleshooting, the NC program can continue to run when the auto operation "start" command is lunched. To achieve this, the fault signal should be input into PLC and transferred into the CNC controller using the auto operation "pause" command (Y219). This would make the pneumatic manipulator more intelligent, on the other hand, it is also essential for the industrialized application.

Secondly, the PLC ladder program not only can be an M code in the NC program, but also can call a
NC macro program. This can be done by sharing the data set in the file registers (e.g. R74 and R76). The data set in file registers with the PLC can be referred to on the macro side with the macro system variables. Meanwhile the system parameter #1195 is set to 1, the M code can just call the macro program. Thereby the more complicated interactions between the machine tool and the robot can be accomplished.

Finally, because the presented paper mainly focused on the interaction between the PLC unit and CNC controller, the analysis and calculation in statics, kinematics, and dynamics were not discussed in detail. Factually, this work has been done using the simulation and motion analysis functions of the Solidworks software. The work in this aspect is undoubtedly important for the industry manipulators, especially for heavy duty, high-speed manipulators.

5. Conclusions

Undoubtedly, the intelligent manufacturing times has arrived. For most plants, to retrofit the existing CNC machine tool is the first step toward the smart factory of the future. The robots, machine tools, transducers and virtual worlds in computer are connected into a cyber-physical system, providing significant real-time quality, flexibility, self-adaptability and cost advantages in comparison with classic production systems. Maybe the presented manipulator looks simple enough. However, the core technology how to coordinate the robot and machine tool is fully shown. Obviously, we can use this method to develop various process equipments to enhance the intelligence, automation and flexibility of the CNC machine tools.

References