RESEARCH OF CONTROL SYSTEM OF ROBOTIC WELDING POSITIONER

Yu Shi, Ding Fan
State Key Lab of Gansu Advanced Non-ferrous Metal Materials
Gansu University of Technology (China)
E-mail: shiy@gsut.edu.cn

ABSTRACT

The development of a numerically controlled (NC) robotic positioner is of vital importance to the design of a welding flexible manufacturing center (WEMC) of an arc-welding robot. The control system has taken a 2-axis servo motor control card as its core and used a two-mode controller that was based on the Fuzzy and PID control method as its position controller. In the two-mode controller, the outputs of the Fuzzy and PID controllers acted on the object at the same time, but the weights of the Fuzzy and PID controllers differed in their value of error. This structure avoided concussion effectively when switching from one controller to the other controller. The two-mode controller provided precise control over the position of the welding positioner. This paper provides a detailed theoretical analysis of the constitution design and real-time control software and describes the design and fulfilment method of a multi-task real-time control software of highly precise and numerically controlled welding positioner, which has a good result in practice.

IIW-Thesaurus keywords: *Numerical control; Automatic control; Controls; Manipulators; Welding accessories; Arc welding; Robots.*

1 INTRODUCTION

A numerically controlled (NC) welding positioner is the key component of the welding flexible manufacturing center (WEMC) for the arc welding robot that requires a high quality control system. The potential qualities of the control system include reasonable structure, powerful computing and processing ability, excellent information management function, and open interface of software and hardware.

In the position control of the AC servo robotic welding positioner, intervals between gears of system transmission chains can produce nonlinearity between displacements and instructions of the positioner. Sometimes, creep can also cause nonlinearity between output and input of the system. Therefore, the control target of this system presents nonlinearity and uncertainty.

The control system of a robotic welding positioner consists of many function modules. It is important to make all modules concerned work, so this paper has made a detailed theoretical analysis of the design and real-time control software and brought up the design and fulfilment method of multi-task real-time control software of a high precision NC welding positioner.

2 OUTLINE OF THE SYSTEM

The welding positioner has two axes, one is to rotate in the horizontal direction within 360°, and the other is to tilt in the vertical direction within 110°. The positioner rotation is driven by AC servomotors. According to the demands of welding process, the welding positioner should be able to stop at any position within the range of 0°-360° and keep uniform motion synchronized with the welding robot. Thus, it demands closed-loop control of speed and position. The system hardware structure is shown in Figure 1.

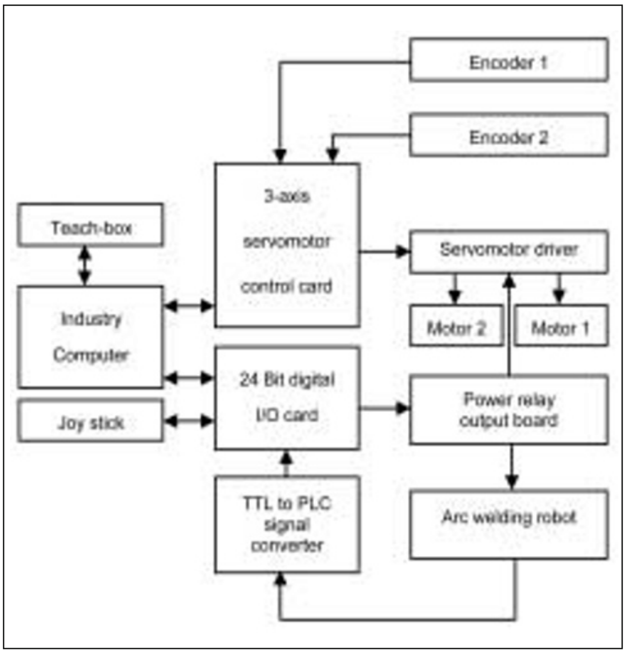

Figure 1 – System structure of hardware

Doc. ICRA-2003-01

3 STRUCTURE AND ARITHMETIC OF CONTROLLER

3.1 Structure of position controller

The servo control system can be divided into open-loop feedback control system, half closed-loop feedback control system, and closed-loop feedback control system. For the closed-loop feedback control system, the displacement sensor is installed on the main shaft, so that it can eliminate mechanical error, such as the error resulting from gear gap, and achieve high position precision, so the closed-loop feedback control system was employed in the NC welding positioner.

3.2 Two-mode intelligent coordinating controller

An improved fuzzy controller is good for large errors, but when the error is in a small range, it is hard to fix an accurate position and easy to cause oscillation. The control effect is not as precise as PID control. Thus, a two-mode controller has been designed [1, 2], one of which was a variable PID controller and the other was the improved fuzzy controller.

The two-mode controller using the variable PID controller and fuzzy controller was designed, but the switch point between the two controllers was difficult to select, and the switch between the two controllers was easy to cause a sudden change of control. Suppose the fuzzy controller was named as A and PID controller as B; the error was divided into six levels. When the error was very large, only A controller was used, and when the error was very small, only B controller was adopted. Otherwise, both controllers were used. But when the error was quite large, the control effect caused by A was stronger than that caused by B. On the contrary, when the error was quite small, the control effect caused by B was stronger than that caused by A. They were decided by the fuzzy membership degree. The structure of the two-mode coordinating control system is shown in Figure 2.

Because a simple normal function such as a convex function could not satisfy the demands of monotonously decreasing or increasing pattern, an S-type function was adopted here.

The expression of the membership function is:

$$\mu_B(x) = \left\{\frac{1 - e^{-ax}}{1 + e^{-ax}}\right\} \qquad 0 \le x < 6$$

$$\mu_B(x) = 1 \qquad x \ge 6 \qquad (1)$$

$$\mu_A(x) = 1 - \mu_B(x)$$

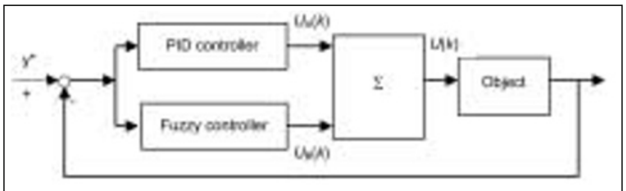

Figure 2 – Two-mode intelligent coordinating controller

To determine the discrete values of the membership function established to separate from the different errors at seven points, let $\alpha = 0.4$, and the weight of the two controllers for different errors is shown in Table 1.

Table 1 – Weight value of each controller

E	6	5	4	3	2	1	0
A	0	0.16	0.33	0.46	0.62	0.80	1
B	1	0.84	0.67	0.54	0.38	0.20	0

3.3 Speed control

During each control cycle, the computer output pulse sequenced to every axis. For every pulse output, the servomotor driver would advance the servomotor one step. One pulse therefore represented one position-command. The frequencies of the pulse sequence represented the movement speed of the axis, while the quantity of pulse represented the displacement. During the control process, mainly two factors affected the movement speed. First was the interval of the control cycle. Second was the quantity of the pulse in each control cycle. According to the requirement of the control precision, the interval of the control cycle was fixed at 5 ms, so, in the system, the factor that affected the movement speed was the number of the pulse in every control cycle, so, the movement speed could be controlled by controlling the number of the pulse in each control cycle. As the period of the control cycle was very short (ms level), even if in every control cycle, the movement speed was varying with the deflection, but the executing result macroscopically was a smooth movement speed.

4 THE SOFTWARE STRUCTURE OF THE CONTROL SYSTEM

The software of the NC positioner was programmed in an object-oriented environment [3]. The whole system consisted of the initialization module, communication module, error disposal module, I/O control module, display module, tech module, editor and document processing module, command explanation module, two-model control module, interpolation computing, and servo electric machine controlling module and so on. These different modules represented different tasks. They could be divided into two sorts, real time task module and unreal time task. The real time task modules could be divided into different priorities according to degree of importance. Figure 3 shows the module types define.

In a traditional mechanism of single task control system, the single loop is the main structure, and all modules run as a whole. But in practice, each module has its executing frequency that differs from the others. It is difficult to satisfy this complex time-sharing requirement in such a structure.

Main software	
Real-time task	Unreal-time task
Communication Error checking I/O control Data display Movement Control	Initialization Teaching Programs edit Files manage Zero point local

Figure 3 – Module types defined

Considering that the control system of the NC positioner could be divided into some modules, which could be defined as sub tasks, then the multi-task mechanism could be used to manage these tasks. Under the multi-task control system, each module returns to the system scheduler after execution, the executive sequence of tasks is flexible, and it could dynamically change in the process of execution. The priority of each sub task determines its executive frequency. The task with high priority has high executive frequency. Each task runs in its own time slice. The complex timing requirement of control system could be satisfied by setting a reasonable time slice and the priority of each task.

5 EXPERIMENT RESULT

5.1 Simulating result of the two-mode controller

In order to check the control effect of the two-mode controller, a lot of simulations and experiments were made in the welding positioner; for contrast, the PID controller, fuzzy controller, and the two-mode controller were put together. Figure 4 shows the simulating result of the system step-response. From Figure 4, it can be seen that the PID controller caused some over-shoot, and the adjusting time was longer, which after the reference input had little change, and the response could not track the change in time. The fuzzy controller responded rapidly but the static error was a little high. The two-mode controller responded quickly with low static error.

5.2 The experimental result of the position control

Figure 5 shows the curve of the position error, which was obtained by checking the difference between the position feedback from the encoder and the reference input value. The pulses of the encoder were selected as 25 000 pulses/r; after quadruple frequency, it could reach 100 000 pulses/r. From the curves, it could be found that the error changed greatly when the reference input changed abruptly and oscillation was easily generated. In fuzzy control, although the error curve changed abruptly, it could be stabilized quickly. The change for PID control was less apparent than fuzzy control, but it took more oscillation to stabilize. The error curve for the two-mode control was less abrupt, and the final static error could be controlled within 5 pulses. Therefore, theoretically, the position error can be calculated as follows:

Relative error is 5/10 000 = 0.005 % (within 360^o).

Absolute error is $5 \times 3.14 \times 1\ 000/100\ 000 = 0.157$ mm (the diameter of turntable of positioner is 1 000 mm).

In order to test the precision and reliability of the control system, experiments for typical weldments were carried out. The results show that the control system can guarantee the precision of both the position and speed control when cooperating with an arc welding robot.

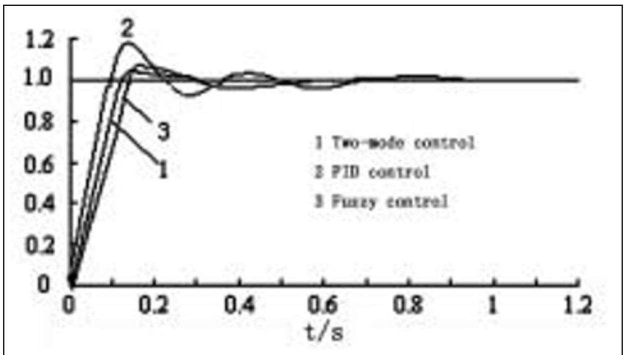

Figure 4 – Step-response curve

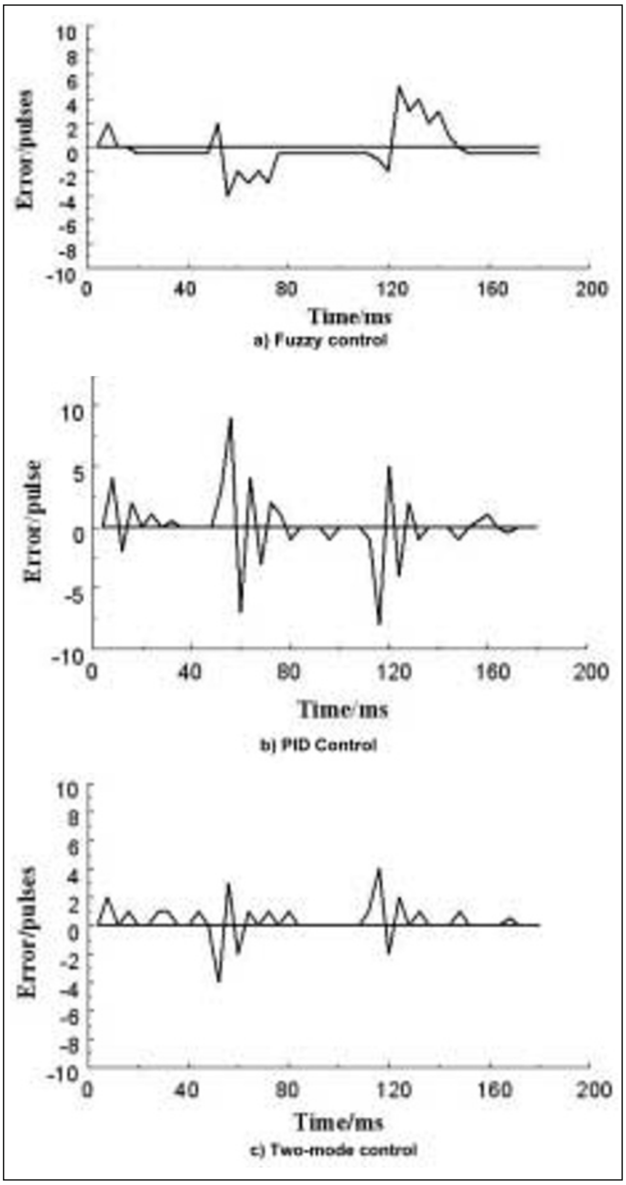

Figure 5 – Error curve of position control

5.3 Results of speed control

Figure 6 a) shows the experimental relationship between the number of pulses and the rotational speed of the tilted shaft in each control cycle. Figure 6 b) shows the experimental relationship between the number of pulses and rotational speed of the rotated shaft. The results show that the number of pulses in each control cycle is strictly proportional to the rotational speed under fixed cycling time. In the range of the designed speed of the positioner, the maximum relative speed error of the tilted shaft is within 0.309 %. While the maximum relative error of the rotated shaft is within 1.827 %, it can completely meet the speed requirement of the weld process.

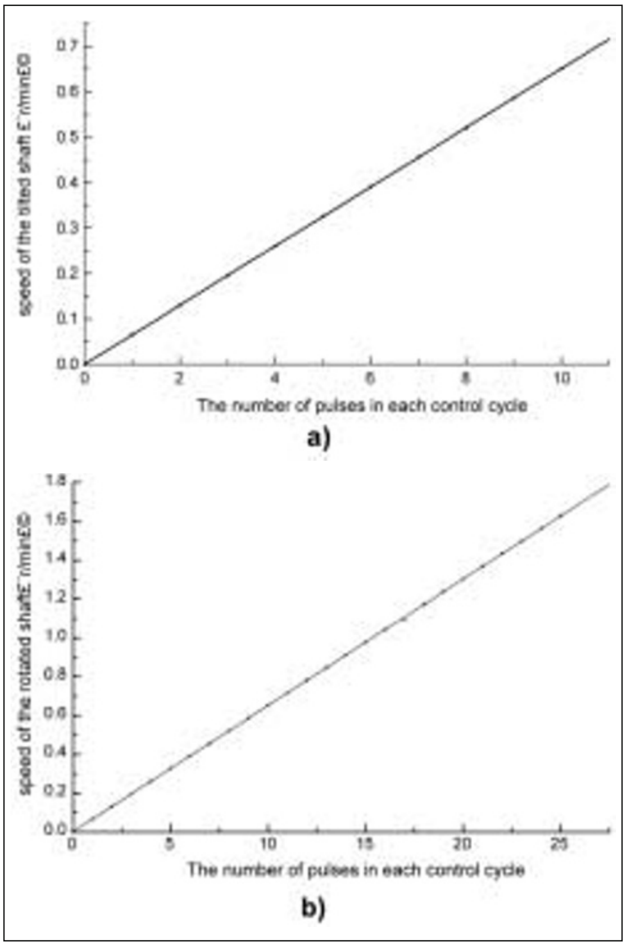

Figure 6 – Results of speed control

6 CONCLUSIONS

1. The two-mode controller developed in this paper combines the advantages of both fuzzy control and PID control. The fuzzy control can respond fast when the control error is larger. The PID control can achieve high control precision when the control error is smaller. Therefore, the responding speed of the positioner with high precision by using the two-mode controller can be increased and the position precision improved.

2. Real-time multi-task structure improved the quality of control system greatly, enhanced real-time control ability, and met the requirement of a complicated system.

3. The proposed control system for the NC robotic positioner has a reasonable structure of software and hardware, and high reliability and precision. It showed excellent performance in practical applications.

REFERENCES

[1] Fan D., Zhou W.: Two-mode intelligent coordinating control of position for the welding positioner, China Welding, 1998, 7 (1), 47-52.

[2] Li Y.F., Lau C.C.: Application of fuzzy control for servo system, In IEEE International Conference on robotics and automation, 1990, 8, 1511-1519.

[3] Shi Y., Fan D.: Investigation of design method for Dos-based real-time multi-task control software, Journal of Gansu University of Technology, 2001.