JOINT POSITION CONTROL SYSTEM FOR FARA ROBOTS OF SAMSUNG ELECTRONICS

Hyo-Kyu Kim, Dong-Il Kim, and Sungkuwn Kim

Robotics R/D Team, Production Technology Division,
Consumer Electronics Business, Samsung Electronics

Abstract

In this paper, attempts have been made to control AC synchronous servo motors used as actuators of joints of the FARA robot with high dynamic performance and precise positioning. The AC synchronous servo motors used in FARA robots have resolves as position sensors. Resolver to digital converters are used in order to obtain the information of rotor speed and position from resolver outputs. The proposed joint position control system consists of four speed controller and one position controller. Analog methods are used in the speed controller, while digital methods are used in the position controller. For precise position control, PID control algorithm and interpolation functions are executed in two 16 bit microprocessors with sampling rate 2ms. Experimental results show that the proposed joint position control system can be effectively applied to industrial robots in order to obtain high dynamic performance and precise positioning. The proposed joint position control system is being used in the control of FARA robots of Samsung Electronics.

Nomenclature

V_{as}, V_{bs}, V_{cs}	stator phase voltages
i_{as}, i_{bs}, i_{cs}	stator phase currents
ϕ_m	rotor flux
w_r	rotor speed
R_s	stator resistance
L_s	stator self-inductance
M	mutual inductance between the stator and the rotor
·	moment of inertia
B	damping coefficient
K_T	torque constant
p	number of pole pairs
x^s	steady state value of the variable x
P	=d/dt

1. Introduction

Active development of permanent AC servo motor drives has recently increased due to the inherent advantages of these motors such as rugged construction as well as easy maintenance, high efficiency, high power factor, and the precise synchronous operation. Accordingly, AC servo motors are widely used in the field of industrial robots, CNC machines, and other industrial machines which require high dynamic performance, high overload capability, and high positioning accuracy.

In this paper, the joint position control system is described which was developed in order to control AC servo motors used as actuators of joints in FARA robots of Samsung Electronics. The FARA robot is a SCARA robot which has four axes. The joint position control system is composed of four speed controllers, which are generally called servo drives, and one position controller. The speed controller consists of analog circuits for speed and current regulation and a one-chip microprocessor which provides protection functions and advances the phase angle in order to extend the limited current bandwidth. The position controller consists of two 16 bit microprocessors (8086-8MHz) which calculate the position control algorithm for all joints of a FARA robot, dual ported RAMs for communication with the main controller of FARA robots, counters receiving position feedback data from speed controllers, and D/A converters which output speed reference commands. For precise positioning, PID control algorithms and the interpolation based on position data from the main controller are executed in the microprocessor with sampling rate 2ms.

Experimental results are presented to verify that the proposed joint position control system can be effectively applied to industrial robots in order to obtain both high dynamic performance and high positioning accuracy.

2. Control scheme

1) Speed control

The dynamic equations of the permanent AC servo motor are expressed as

$$\begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} = \begin{bmatrix} R_s+PL_s & PM & PM \\ PM & R_s+PL_s & PM \\ PM & PM & R_s+PL_s \end{bmatrix} \begin{bmatrix} i_{as} \\ i_{bs} \\ i_{cs} \end{bmatrix} + \phi_m W_r \begin{bmatrix} \sin\theta_r \\ \sin(\theta_r+2\pi/3) \\ \sin(\theta_r+4\pi/3) \end{bmatrix}$$

$$PW_r = -BW_r/J + (T_e - T_L)/J, \qquad (1)$$

where V_{as}, V_{bs}, V_{cs} are the control inputs, θ_r is the angular displacement of the rotor with respect to the reference point, and T_e is the generated torque given by

$$T_e = K_T\phi_m(i_{as}\sin\theta_r + i_{bs}\sin(\theta_r+2\pi/3) + i_{cs}\sin(\theta_r+4\pi/3)) \qquad (2)$$

If the AC servo motor is being fed by impressed currents, where motor currents are essentially sinusoidal and are regulated within fixed bands, the dynamic equations of the AC servo motor given by (1), (2) can be further simplified. In practice, a high-gain or bang-bang current controller has been be employed in order to control the stator currents i_{as}, i_{bs}, i_{cs}. Here, we propose a saturation current controller for the current impressed scheme:

$$\begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} = \begin{bmatrix} K sat((u_1 - i_{as})/k) \\ K sat((u_2 - i_{ys})/k) \\ K sat((u_3 - i_{cs})/k) \end{bmatrix}. \quad (3)$$

where K, k are some positive constants, u_1, u_2, u_3 are the new inputs, and

$$sat(\eta) = \begin{cases} \eta, & |\eta| \le 1 , \\ \eta/|\eta| , & |\eta| \ge 1 . \end{cases} \quad (4)$$

V_{as}, V_{bs}, and V_{cs} are fed to the pulse-width modulators which control currents in the windings.

When the stator currents are directly controlled by the above saturation current controller in (3), (4), the dynamic equations of the induction motor in (1) and (2) can be approximated to

$$pw_r = -Bw_r/J + (\bar{T}_e - T_L)/J \quad (5)$$

where

$$\bar{T}_e = K_T\phi_m(u_1 \sin\theta_r + u_2 \sin(\theta_r + 2\pi/3) + u_3 \sin(\theta_r + 4\pi/3)) \quad (6)$$

When controlled by the saturation current controller (3), the resultant dynamic equations of the AC servo motor are expressed as (5). For the maximization of the generated torque in (6), the field orientation must be realized by using the following currents commands.

$$[u_1 \ u_2 \ u_3]^T = [I_m \sin\theta_r \ \ I_m \sin(\theta_r + 2\pi/3) \ \ I_m \sin(\theta_r + 4\pi/3)]^T \quad (7)$$

However, although the above currents commands are fed to the AC servo motor, the generated current in each winding lags the current command, as a function of rotor speed. This is due to the limited current loop bandwidth. The limitation of the current loop bandwidth can be overcome by advancing the phase angle in the current command. The advancing angle is a function of the rotor speed and the electrical time constant. At an electrical angular speed pw_r, the phase lag between the current command to each current loop and the developed current is:

$$\theta = \tan^{-1}(pw_r L_s / R_s) \quad (8)$$

From (5), (6), (7) and (8), the resultant dynamic equation of the AC servo motor is obtained as

$$pw_r = -Bw_r/J + (3K_T\phi_m I_m/2 - T_L)/J \quad (9)$$

In order to obtain desirable transient and steady state performances of rotor speed, the new input I_m is chosen as the following PI controller.

$$I_m = k_p(w_r^* - w_r) + k_i \int_0^t (w_r^* - w_r)dt \quad (10)$$

where the constants k_p, k_i are controller gains and w_r^* represents the command input for w_r.

2) Position control

The purpose of position controllers is to make axes follow trajectories obtained from trajectory generators. The position control algorithm is carried out through 16 bit microprocessors on the basis of the position command obtained from the trajectory generator and position feedback data. In order to obtain desirable transient and steady state performances of rotor position according to the position data, w_r^* is chosen as the following PID controller:

$$w_r^* = k_p'(\theta_r^* - \theta_r) + k_i' \int_0^t (\theta_r^* - \theta_r)dt + k_d' d(\theta_r^* - \theta_r)/dt, \quad (11)$$

where the constants k_p', k_i', k_d' are controller gains and θ_r^* represents the command input for θ_r.

3. Implementation

The microprocessor-based control system based on 16 bit microprocessors (8086-8MHz) is employed for the simultaneous control of four axes of a FARA robot. The main controller which consists of a 16 bit microprocessor (8086-8MHz) sends position commands to the joint position control system every 32 ms through dual ported RAMs. The joint position system consists of one position controller and four speed controllers. Fig.1 shows the block diagram of the FARA robot controller.

The speed controller consists of analog circuits and a one chip microprocessor 78C10. The speed and torque control loops are realized by analog circuits. The one chip microprocessor 78C10 executes the compensation algorithm advancing the phase angle in the current command every 5 ms and transmits the calculated value for compensation given as digital data to the counter, where it is combined with the information of the original current command to become the address of ROM for current commands. It also executes interrupt service routines for the fault state of the speed controller. The interrupt signals resulted from overcurrent, overvoltage, undervoltage, resolver output open/short, and overheat are initiated externally by hardware, while the interrupt signals resulted from overload, overspeed, are initiated internally through software. The overcurrent signal which is the most important is connected to the nonmaskable interrupt port.

The position controller is composed of two 16 bit microprocessor (8086-8MHz) where the interpolation is carried out on the basis of data obtained from trajectory planning in the main controller, 4 D/A converters which output velocity commands, and dual ported RAMs for communication with the main controller. It receives position feedback data as serial pulses or parallel data from the speed controllers and executes the position control algorithm every 2ms. 4096 pulses/rev. brushless resolvers are used for speed and position detection. In addition, the commutation signals for the AC servo motor are also generated based on the output of the resolvers. The flow chart of the joint position control algorithm is shown in Fig.2.

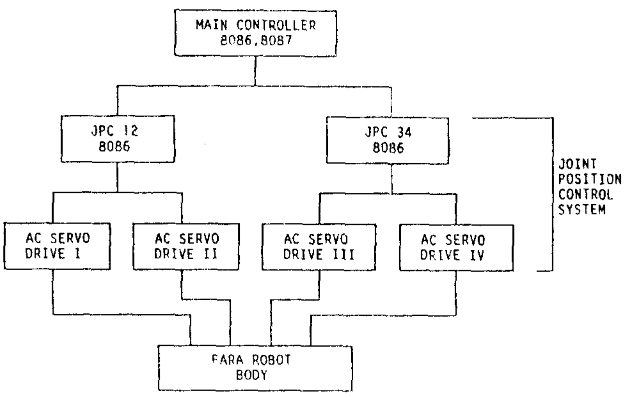


Fig.1 The block diagram of the FARA robot controller.

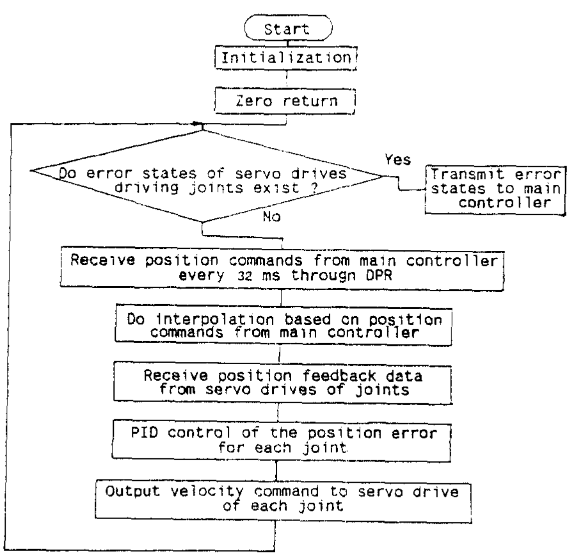


Fig.2. Flow chart of the joint position control algorithm.

4. Experiments

The performances of the proposed joint position control system described in the preceding sections were studied through experiments. For experimental works, the new version (version 3.0) of the FARA robot body developed recently has been equipped with the proposed joint position control system. Fig.3 shows the picture of the version 3.0 FARA robot body and controller. The main body specifications are listed in Table 1.

Two cases are examined in experimental works. In the first case, the robot is controlled to move in point to point motion where all axes start and end asynchronously. Fig. 4 shows the speed and torque responses of the first and second axes of the robot. In the second case, the robot is assigned to move in point to point motion where all axes start and end synchronously. Fig. 5 shows the speed and torque responses of the first and second axes of the robot.

The experimental results shown in Fig.4 and 5 demonstrate that the proposed joint position control system is useful in controlling industrial robots with high dynamic performance and precise positioning

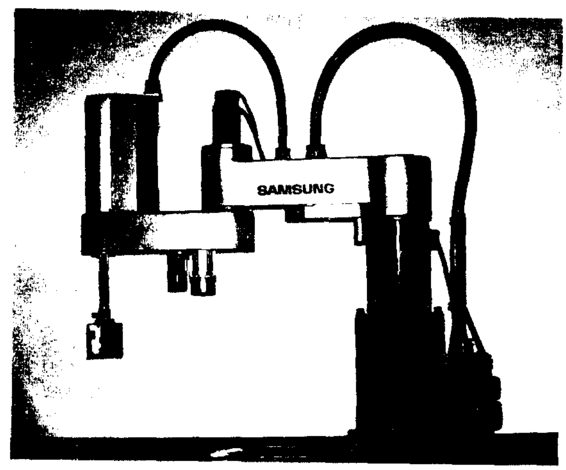


Fig.3a. The picture of the version 3.0 FARA robot body.

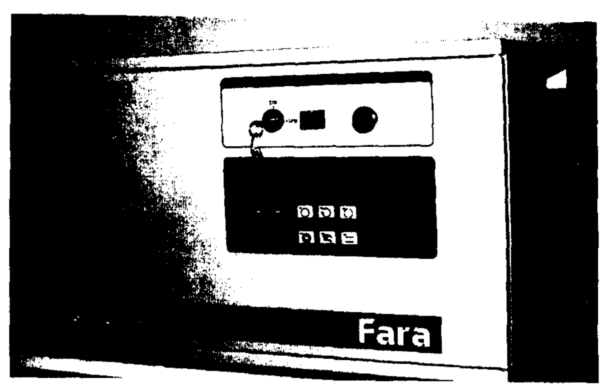
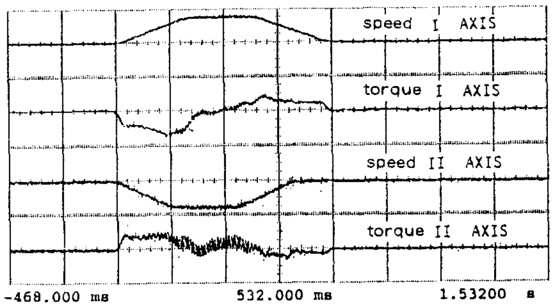
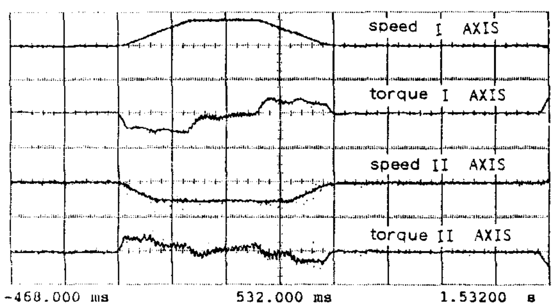


Fig.3b. The picture of the version 3.0 FARA robot controller.



Channel 1 =	10.00 Volts/div	Offset	=	0.000 Volts
Channel 2 =	10.00 Volts/div	Offset	=	0.000 Volts
Channel 3 =	10.00 Volts/div	Offset	=	-2.600 mVolts
Channel 4 =	10.00 Volts/div	Offset	=	0.000 Volts
Timebase =	200 ms/div	Delay	=	532.000 ms

Fig.4. Experimental results for asynchronous PTP motion.



Channel 1 =	10.00 Volts/div	Offset	=	0.000 Volts
Channel 2 =	10.00 Volts/div	Offset	=	0.000 Volts
Channel 3 =	10.00 Volts/div	Offset	=	-2.600 mVolts
Channel 4 =	10.00 Volts/div	Offset	=	0.000 Volts
Timebase =	200 ms/div	Delay	=	532.000 ms

Fig.5. Experimental results for synchronous PTP motion.

ITEM		SPECIFICATION	
TYPE		MULTIARTICULATED TYPE	
OPERATING AREA AND MAX. SPEED	I AXIS	240°, 360°/s	TOOL END COMPOSITE SPEED: MAX. 5.46M/S
	II AXIS	290°, 360°/s	
	III AXIS	150 mm	
		400 mm/s	
	IV AXIS	360°, 896°/s	
LOAD CAPACITY		HIGH SPEED : 2.5 Kg MEDIUM SPEED : 5 Kg LOW SPEED : 10 Kg	
POSITION REPEATABILITY		+ 0.05 mm	
WEIGHT		56 Kg	

Table 1. The main body specifications of a FARA robot

5. Conclusion

It has been shown that the proposed joint position control system can control industrial robots with excellent dynamic performances and precise positioning. The proposed joint position control system can be used for general automation, robotics, and machine tool applications requiring high dynamic performance and precise coordinate control. In addition, inherent versatility allows it to operate with AC, DC, variable (switched) reluctance and stepper motors. If necessary, more than four axes can be controlled simultaneously with the addition of a companion system.

However, because speed is the main performance criterion for real time motion control, it is recommended that further researches be directed toward the development of the joint position control system using digital signal processors. In Samsung Electronics, the joint position control system based on a 32bit floating point digital signal processor are under development.

References

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