International Journal of Engineering Innovation & Research
Volume 4, Issue 2, ISSN: 2277 – 5668

Position Control of AC Servomotor Using Internal Model Control Strategy

Ahmed S. Abd El-hamid and Ahmed H. Eissa
Corresponding Author email: Ahmednrc64@gmail.com

Abstract: **This paper focuses on the design and simulation of an Internal Model Control (IMC) Strategy for position control in AC servo motor. The dynamic second order transfer function model of the AC servo motor is derived. Based on the model parameters, the internal model controller parameters are computed and simulated in MATLAB Simulink. The performance measures of the controller are analyzed in terms of tracking error. A robust stability analysis of the proposed control strategy is also tested. Lastly, the simulated results of IMC are compared with PID controller results and main conclusion; by using IMC the best results may be achieved and also there is no need to effort for tuning PID parameters.**

Keywords: **AC Servo Motor, Internal Model Control (IMC), Three Term Control (PID), Control Stability, Bode Diagram**

I. INTRODUCTION

AC servo motor is commonly employed in various control applications [1–3], such as robot actuator, machining centre, computer numerical control, and machine and precise industrial robot. Due to the presence of electrical, mechanical properties and a high efficiency, AC servo system is demand to have an accurate response for the position tracking and a rapid recovery for the external disturbances or load variations.

Typically, conventional PD/PID controllers are used in the position tracking in the presence of external disturbances or load variations. However, the reference trajectory or load disturbance is periodic in nature; the conventional controllers are not able to attain suitable tracking performance [4–7]. In order to overcome these problems, internal model control strategies are suggested.

Internal model controller is based on the Internal Model Principle (IMP). The main goal of internal model control is that the tracking error decreases with increasing number of trials. The major concept presented in this article is precisely in a position control of AC servo motor system and analysis of the tracking performance. In Section 2 the mathematical model of the AC servo motor is developed. The principle of internal model controller is presented in section 3. The proposed IMC controller scheme is explained in section 4. The results and discussions are drawn in Section 5. Finally, the conclusions are listed in section 6.

II. MODELING OF AC SERVO MOTOR

The model of the system consists of a motor coupled to a gear box and an inertia load rigidly fixed to output shaft. The control torque (*Tc*) for the two phase AC servo motor is described as [1]

$$T_c = K_1 E(t) - K_2 \dot{\theta}(t) \quad (1)$$

Where
T_c = Control torque (Nm)
K_1 & K_2 = motor constants (Nm/V, Nm/rad/s)
$\dot{\theta}$ = angular velocity of the AC servo motor (rad/s)
E = rated input voltage (v)

The dynamic equation of the mechanical system is given by

$$T_c = J\ddot{\theta}(t) + B\dot{\theta}(t) + T_L \quad (2)$$

Where
θ = angular position of the AC servo motor (rad)
$\ddot{\theta}$ = angular acceleration of the AC servo motor (rad/s^2)
B = Friction coefficient
J = Moment of inertia (Kg.cm2)
By equating (1) and (2)

$$J\ddot{\theta}(t) + B\dot{\theta}(t) + T_L = K_1 E(t) - K_2 \dot{\theta}(t) \quad (3)$$

Taking Laplace transform the above equations becomes

$$K_1 E(s) = Js^2\theta(s) + Bs\theta(s) + K_2 s\theta(s) + T_L(s) \quad (4)$$

The transfer function between (s) and E(s) is obtained by putting $T_L(s) = 0$

$$K_1 E(s) = Js^2\theta(s) + Bs\theta(s) + K_2 s\theta(s) \quad (5)$$

$$K_1 E(s) = (Js^2 + Bs + K_2 s)\theta(s) \quad (6)$$

$$\frac{\theta(s)}{E(s)} = \frac{K_1}{Js^2 + K_2 s + Bs} = \frac{K_m}{s(\tau_m s + 1)} \quad (7)$$

Where

K_m = Motor gain constant $= \frac{K_1}{K_2 + B}$

τ_m = Motor time constant $= \frac{J}{K_2 + B}$

The specifications of AC servo system, which has considered for simulation study, are given in below table. By using equation (7) and considering the numerical values in the table (1), the identified transfer function model for the AC servo system is given as:

$$G_P(s) = \frac{0.4}{s(2.7763s+1)} \quad (8)$$

Table (1) values of parameters of AC servo motors

Type	GSM62AE
Voltage	230 V
Power	100 W
Speed	50 rpm
Moment of inertia (J)	0.052 kg.cm^2
Friction of coefficient	0.01875
GB ratio	36
Radius of the output shaft	0.0175 m

III. The Internal Model Controller Principle

The internal model control (IMC) philosophy relies on the Internal Model Principle, which states that control can be achieved only if the control system encapsulates, either implicitly or explicitly, some representation of the process to be controlled. In particular, if the control scheme has been developed based on an exact model of the process, then perfect control is theoretically possible.

A controller $G_C(s)$ is used to control the process $G_P(s)$. Suppose $G_P^*(s)$ is a model of $G_P(s)$. By setting $G_C(s)$ to be the inverse of the model of the model of the process,

$$G_C(s) = G_P^*(s)^{-1}$$

If $G_P(s) = G_P^*(s)$, (the model is an exact representation of the process), it is clear that the output will always be equal to the set point. Notice that this ideal control performance is achieved without feedback. What this tells us is that if we have complete knowledge about the process (as encapsulated in the process model) being controlled, we can achieve perfect control. It also tells us that feedback control is necessary only when knowledge about the process is inaccurate or incomplete.

IV. Design of IMC of AC Servo Motor

Designing an internal model controller is relatively easy. Given a model of the process $G_P^*(s)$.

First the factor $G_P^*(s)$ divided into "invertible" and "non-invertible" components.

$$G_P^*(s) = G_P^*(+)(s)G_P^*(-)(s)$$

Where $G_P^*(+)(s)$, contains terms which if inverted, will lead to instability and reliability problems, e.g. terms containing right-half plane zeros and time delays, and also these lead to marginally stability (have real part equal to zero) and $G_P^*(-)(s)$ is the remaining part such that its inverse is stable

In addition, $G_P^*(+)(s)$ is required to have a steady-state gain equal to one in order to ensure that the two factors $G_P^*(+)(s)$ and $G_P^*(-)(s)$ are unique.

Next, set $G_C(s) = G_P^*(-)(s)$ and then $G_{IMC}(s) = G_C(s)\, G_f(s)$, where $G_f(s)$ is a low-pass filter of appropriate order. The transfer function model for the AC servo system is given as:

$$G_P^*(s) = \frac{0.4}{s(2.7763s+1)} \quad (9)$$

$G_{IMC}(s)$ is designed as follows; the factorization is

$$G_P^*(s) = G_P^*(+)(s)G_P^*(-)(s) \quad (10)$$

where

$$G_P^*(-)(s) = \frac{0.4}{(2.7763s+1)} \quad (11)$$

and

$$G_P^*(+)(s) = 1/ \quad (12)$$

Next, set $G_{IMC}(s)$ to be the inverse of $G_P^*(-)(s)$ in series with a low pass filter

$$G_f(s) = \frac{1}{(1+\tau_f s)^r} \quad (13)$$

where τ_f the filter parameter is and r is the order of the filter. That is,

$$G_{IMC}(s) = \frac{(2.7763s+1)}{0.4(1+\tau_f s)^r} \quad (14)$$

Parameter r is a positive integer, the usual choice is $r = 1$. A good rule of thumb is to choose τ_f to be twice as fast as the open loop response. Hence, this example $\tau_f = 1$; and the desired $G_{IMC}(s)$ becomes

$$G_{IMC}(s) = \frac{(2.7763s+1)}{0.4s+0.4} \quad (15)$$

IV. Simulation Study

The structure of feedback control using IMC and PID is depicted in Fig. 1. The performance of the controllers is evaluated on the simulation model of the above AC servo motor. The values of model parameters were taken from M. Vijayakarthick1 and P.K. Bhaba (2012). Figures (2-5) compares the four different set point tracking for PID performance and IMC performance. In this comparison, the responses with the IMC controller "the settling time, the rise time and the maximum overshoot" are better than the responses with PID controller. For example, table (2) shows the results of time of the two controllers.

Table (2) values of time response of the two controllers

	IMC controller	PID controller
Rise time (Tr)	Fast	slow
Settling time (Ts)	10 s	20 s
Overshoot (Mp)	Less	High

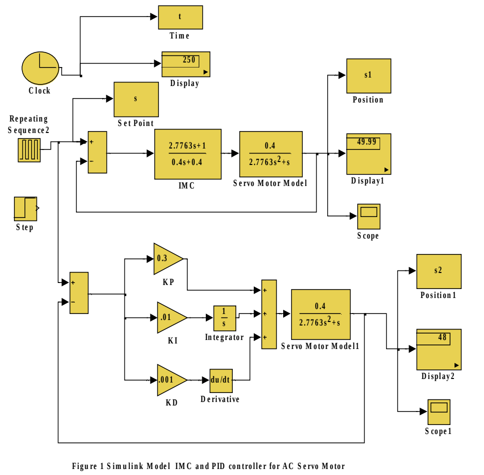

Fig.1. Simulink structure for AC servo motor, IMC controller and PID controller

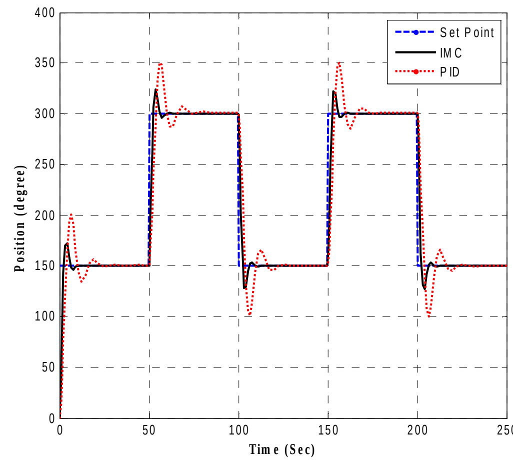

Fig.4. Set point tracking performance of two controllers

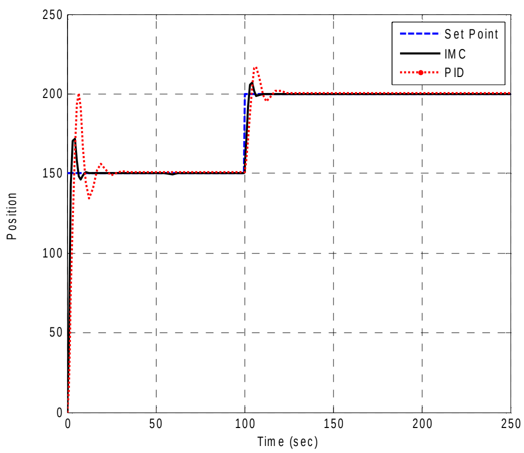

Fig.2. Set point tracking performance of two controllers

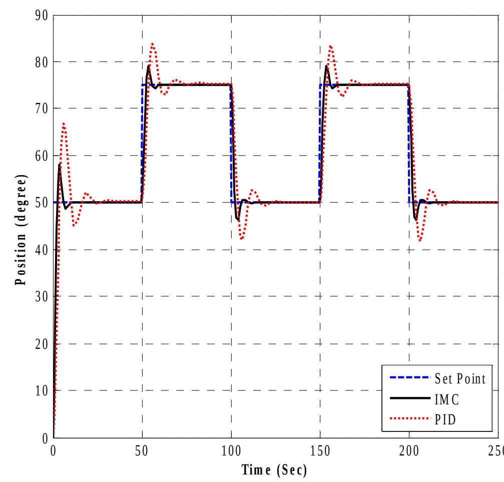

Fig.5. Set point tracking performance of two controllers

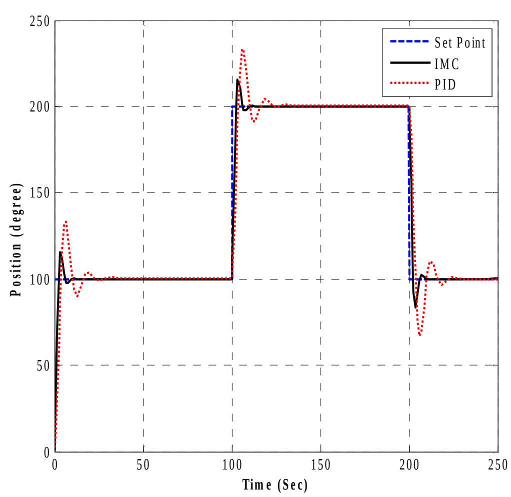

Fig.3. Set point tracking performance of two controllers

V. Stability Analysis "Bode Stability Criterion"

The Bode diagram represents the systems (AC servo motor) response in magnitude and phase to a sinusoidal input of any frequency through a log-log plot of the magnitude. It provides a sufficient condition for the closed-loop stability based on the properties of the open-loop transfer function. On a Bode diagram, a closed-loop system is marginally stable if the bode curves crosses the critical point i.e. a phase (angle) of -180° and an amplitude of 1 = 0 dB. The phase margin is the difference between the -180° and the actual phase angle of the frequency response function measured at the frequency where the gain is 0 dB (unity gain). The gain margin, on the other hand is the margin between the gain plot and the 0dB measured at the point where the phase angle reaches -180° crossing. The conclusions from the Bode plots were tested by simulating the system with MATLAB. Stability of the closed-loop transfer function of AC servo motor was analyzed by the application of Bode plot techniques. In general, we would like to have large gain and phase margins in order to improve the stability of the system.

In the below plots, the graph is plotted for AC servo motor without controller, and with IMC controller. The stability of the system is determined by the phase; the system is stable until the phase crosses the -180°. The frequency response curve shows a graph pattern of decreasing gain values with increasing frequencies with visible variations in the gain values around 10 to 20 dB. These decreasing gain values represent decreasing amplitudes of the power oscillations. At frequencies between 1 Hz and 10 Hz these oscillations become stable, however beyond 10 Hz the amplitudes continue to decrease. It can be observed that, the closed-loop transfer function is stable since its phase does not cross the -180° line.

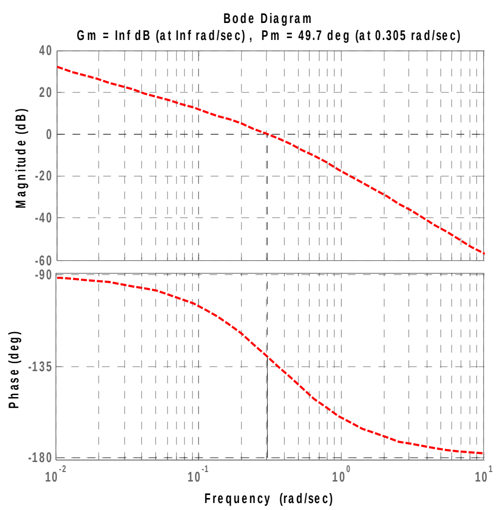

Fig.6. Bode diagram of AC servo motor model without controller

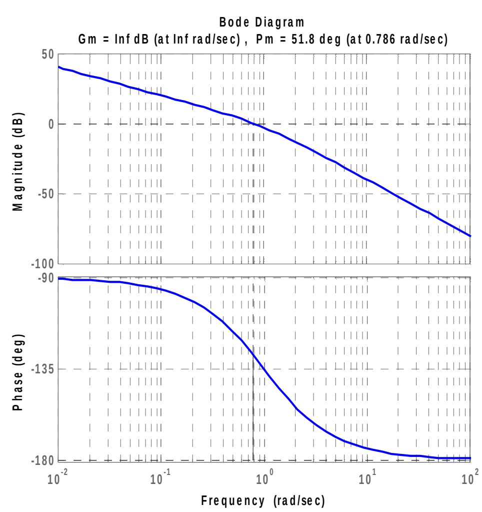

Fig.7. Bode diagram of AC servo motor model with IMC controller (closed loop)

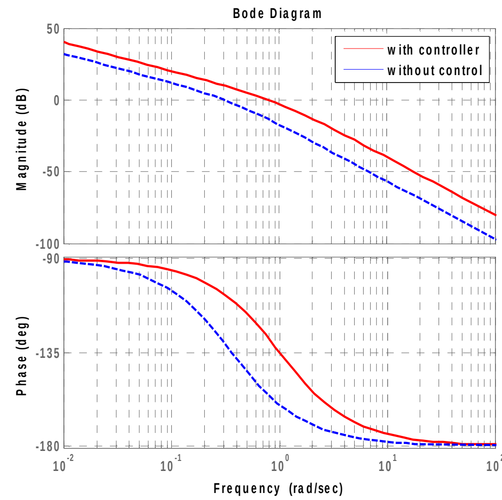

Fig.8. Bode diagram of AC servo motor model with IMC controller and without control

VI. Conclusion

In this paper, based on the mathematical model of servo AC motor PID and IMC controllers, are designed and compared to figure out a more convenient control method, PID controller. The simulation results show that all of these controllers are efficient and adequate for improving the time domain characteristics of system response, such as settling time and overshoot. The results show that IMC method give the better performance compared to PID controller by reducing overshoot, settling time and minimize the rising time. Also; the system with greater gain margins can withstand greater changes in system parameters before becoming unstable in closed loop

Reference

[1] M. Vijayakarthick1 and P.K. Bhaba "Position Tracking Performance of AC Servomotor based on New Modified Repetitive Control Strategy". IJRRAS 10 (1) -January 2012
[2] S.Sathishbabu and P.K.Bhaba "Tracking Position Control of AC Servo Motor Using Enhanced Iterative Learning Control Strategy" International Journal of Engineering Research and Development , Volume 3, Issue 6 (September 2012), PP. 26-33.
[3] L. Canan Dulger and Ali Kirecci "Motion Control and Implementation for an AC Servomotor System" Modelling and Simulation in engineering, Vol. 2007, Article ID 50586, 6 pages.
[4] Ahmed M. Kassem and Ali Mohamed Yousef "Experimental Setup and Robust Servo DC Motor Position Control Based on Gain Schedule Sliding Mode Controller" Research Journal of Applied Sciences, Engineering and Technology 4(10): 1320-1327, 2012
[5] Jeffrey E. Arbogast, Douglas J. Cooper "Extension of IMC tuning correlations for non-self regulating (integrating) processes" ISA Transactions 46 (2007) 303–311
[6] Ching-Tsai "A phase locked loop internal model adjustable speed control fol BLDC motors" IEEE transaction on industrial electronics, VOL.55, NO. 9, September 2008
[7] M. Saranya and D. Pamela "A real time IMC tuned PID controller for DC motor" IJRTE VOL. 1, Issue 1, April 2012
[8] Jeffrey E. Arbogast and Douuglas J. Cooper "Extension of IMC tuning correlation for non-self regulating (integrating) processes" ISA Transactions 46(2007) 303-311

International Journal of Engineering Innovation & Research
Volume 4, Issue 2, ISSN: 2277 – 5668

AUTHOR'S PROFILE

Ahmed S. Abd El-hamid was born in Port Said, Egypt, on October 17, 1964. I received the B.S. degree in Electrical Engineering from Suez Canal University, and Master and Ph.D. in Control Engineering from Cairo University in 1988, 1995, and 2000 respectively. From 1990 to 2006, I worked in Engineering Research Division, National Research Center, Egypt, and My promotion was "Assistant Researcher, "Researcher Assistant", Researcher", and lastly Associate Prof. from 2006 up to now. Most my research related with application of control systems on chemical and industrial processes.

Ahmed H. Eissa was born in Giza, Egypt, 1965. I received the B.S. degree in Electrical Engineering from Cairo University, and M.S and Ph.D. degrees in Control Engineering from Cairo University in 1987, 1994, and 1989 respectively. From 1989 to 2005, I promotion in jobs in Engineering Research Division, National Research Center, Egypt, "Assistant Researcher, Researcher Assistant, Researcher", and lastly "Associate Prof." from 2006 up to now. Most my research related with application of control systems on chemical and industrial processes.