Intelligent Learning Control Strategies for Position Tracking of AC Servomotor

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Abstract – *In this paper, a New Modified Repetitive Control Strategy is proposed for precision motion control of AC servo motor for applications which are inherently repetitive in terms of the motion trajectories. The dynamic second order transfer function model of the AC servo motor is derived and the model parameters are identified using experimental data. A New Modified Repetitive Control Strategy (NMRCS) based on zero-phase filtering is incorporated to the existing conventional PD feedback controller to enhance the trajectory tracking performance by utilizing the experience gained from the repeated execution of the same operations. The Iterative Learning Control Strategy (ILCS) based PD controller and conventional PD controller are taken for comparative studies. Experimental results are presented to reveal the practical appeal and efficiency of the proposed scheme.*

Key Words: AC Servomotor, NMRCS, MRCS, Conventional PD

1. INTRODUCTION

AC servo motor is commonly employed in various control applications [1–4], such as robot actuator, machining centre, computer numerical control, 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 and PID controllers are used in the position tracking in the presence of external disturbances or load variations [5–7]. However, the reference trajectory or load disturbance is periodic in nature, the conventional controllers are not able to attain suitable tracking performance .In order to overcome these problems, repetitive control strategies are suggested. Repetitive controller is based on the Internal Model Principle (IMP). As said by IMP, the output tracks a class of reference signals without error only if the generator for references is integrated in the stable closed-loop system. The main goal of repetitive control is that the tracking error decreases with increasing number of trials. In most cases the repetitive controller affect the stability of the system. To assure the stability of the repetitive control system, a New Modified Repetitive Control Strategy (NMRCS) is considered.

The repetitive control strategy is illustrated in [8]. It can decrease the error subsequent to the first epoch [9]. Presently a different application of repetitive control has sprung up, including high-speed motion tracking problem of visual servoing [10], speed control of ultrasonic motors [11], accurate position control of piezoelectric actuators [12] and control of rotation mechanisms [13]. The major concept presented in this article is precisely practical implementation of the New Modified Repetitive Control Strategy (NMRCS) in a position control of AC servo motor system and analysis of the tracking performance. In Section 2 the Real time model of the AC Servo motor is developed. The Conventional and proposed schemes are enlightened in section 3 and 4; Real time results are analyzed in Section 5 to illustrate the better tracking of the proposed NMRCS. Finally, conclusions are drawn in Section 6.

2.AC Servo Motor Dynamics

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

$$T_c = k1E(t) - k2\dot{\theta}(t) \qquad (1)$$

Where T_c= Control torque (Nm)

k1 & k2 = motor constants (Nm/V, Nm/rad/s)

$\dot{\theta}$ = angular velocity of the AC servo motor (rad/s)

E = rated input voltage (v)

The key parameters (k1 and k2) required in model of this servomotor are identified by conducting suitable experimental test.

The dynamic equation of the mechanical system is given by

$$T_C = J\ddot{\theta} + B\dot{\theta} + T_L \qquad (2)$$

Where = angular position of the AC servo motor (rad)

$\ddot{\theta}$ = angular acceleration of the AC servo motor (rad/s2)

B = Friction coefficient

J = Moment of inertia (Kg.cm2)

By equating (1) and (2)

$$J\ddot{\theta} + B\dot{\theta} + T_L = k1E(t) - k2\dot{\theta}(t) \qquad (3)$$

Taking laplace transform the above equations becomes

$$K1E(s) - k2s\,\theta(s) = Js2\,\theta(s) + Bs\,\theta(s) + TL(s) \qquad (4)$$

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

$$\frac{\theta(s)}{E(s)} = \frac{K_1}{Js^2+K_2\,s+Bs} = \frac{K_m}{s(\tau_m s+1)} \qquad (5)$$

Where K_m(Motor gain constant) $= \frac{K_1}{K_2+B}$ and τ_m(Motor time constant) $= \frac{J}{K_2+B}$

The specifications of AC servo system, which has considered for real-time study, are given in table.1. By using equation (5) and considering the numerical values in Table.1, the identified transfer function model for the AC servo system is given as

$$G(s) = \frac{0.4}{s(2.7763s + 1)}$$

Table 1. AC servo motor Specifications

Type	GSM62AE
Voltage	230V
Power	100W
Speed	50 rpm
Moment of inertia (J)	0.052 kg.cm2
Friction coefficient (B)	0.01875
GB ratio	36
Radius of the output shaft	0.0175m

3.Design of Conventional PD Controller

The Proportional Derivative controller parameters (Kc and Kd) are identified using signal constraint block of simulink optimization tool in MATLAB platform. Based on the model parameters and performance requirements (refer Table 2.), the optimized PD controller settings are obtained as Kc = 2.0203 and Kd = 1.8826.

Table.2. Performance requirements for PD control design

Rise time (tr)	20
Settling time (ts)	22.2
Over shoot (Mp)	20%

4. Intelligent Learning Control Strategies

4.1 Iterative Learning Control Strategy (ILCS)

Figure.1shows a block diagram [14] of the control configuration considered in this work. In figure 1, simple ILC control loop is connected with a feedback controller. The features of this control scheme are the design of learning filter 'L' and Lowpass filter 'Q'. The inverse of L is nothing but the process-sensitivity P= $\frac{G}{1+GC}$ i.e L = P-1. Due to the unstability and non-proper characterisitics of inverse complementary sensitivity,L can not be act as a filter. This problem is overcome by adapting Zero Phase Error Tracking Controller (ZPETC) algorithm [15]. Here Learning gain kl, which determines the rate of convergence of the error signal. The value of kl is preferred by executing the optimization program.

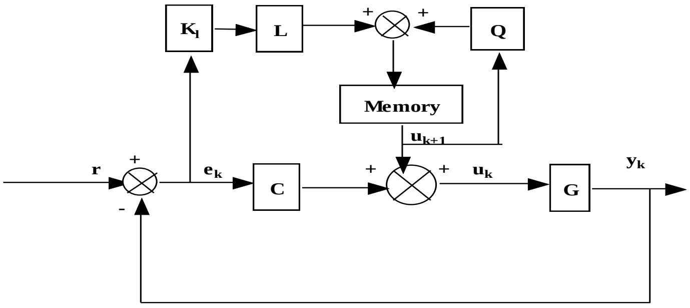

Figure.1 Simple ILCS

4.2 Repetitive Control Strategy (RCS)

Repetitive control strategy [16] is designed especially for tracking a periodic reference signal and rejecting a periodic load signal. The design of repetitive control strategy (RCS) is based on the Internal Model Principle (IMP) and it is proposed by Wonham and Francis [17]. The IMP states that if any exogenous signal can be regarded as the output of an autonomous system, the inclusion of the model of the signal in a stable closed-loop system can assure perfect tracking or complete rejection of the signal.

The RCS includes the factor $\frac{e^{-Ls}}{1-e^{-Ls}}$ which has poles at $jk\frac{2\pi}{L}$, k = 0,$\pm$1,…..,$\pm\infty$ (corresponding to the harmonic and sub harmonics of the basic period L), the controller can track any periodic signal and reject any disturbance of period L. Based on this concept, RCS is constructed with a model of $\frac{e^{-Ls}}{1-e^{-Ls}}$. The basic Repetitive control structure is given in Figure 2.

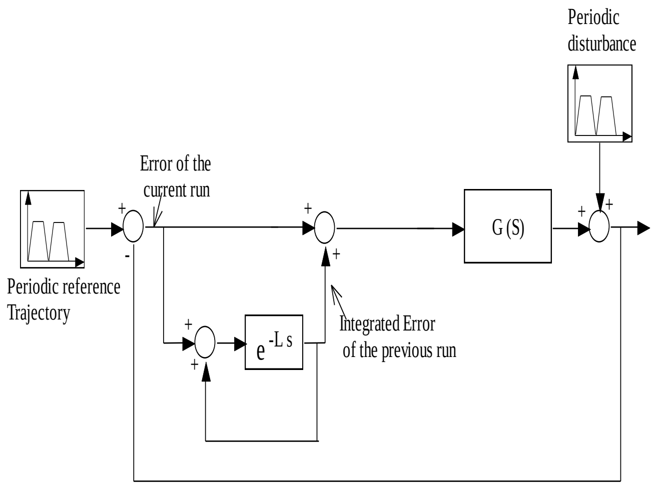

Figure 2. Repetitive Control Strategy

4.3. New Modified Repetitive Control Strategy (NMRCS)

For high frequency signals, certain uncertainty is present in the model of AC servo motor system. Due to this uncertainty, noise has a great influence on the response, which intern affects the stability of the system. To trounce this problem, a low-pass filter, Q(s) is added to the existing RCS control loop and to ensure system stability. This modified structure is known as Modified Repetitive Control Strategy (MRCS) as proposed by Hara et al. For further enhancement of stability in MRCS, a New Modified Repetitive Control Strategy is proposed in this work and the proposed structure is given in Figure 3. Since the stability is directly related to sensitivity, the sensitivity function is considered in this proposed structure. In addition, a rational factor is also incorporated in this new structure.

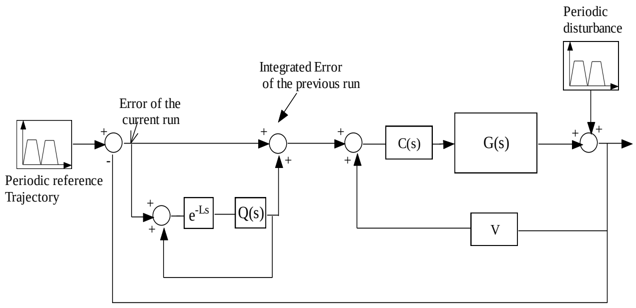

Figure 3. New Modified Repetitive Control Strategy

1) 4.3.1Design Parameters in ILCS and NMRCS

2) A. Rational Factor

By optimization technique, the stable rational factor (V) in equation (6) is identified by formulating minimum tracking error as objective function. The identified value of V for AC servo motor is 0.1.

3) B. Low pass filter design

A first order continuous time low pass filter is considered here. i.e $Q(s) = \frac{\omega_c}{s+\omega_c}$,where ωc is the cut-off frequency in rad /sec. The cut-off frequency (0.3), is obtained from the Bode plot of AC servo motor system (Ref: Figure 4).

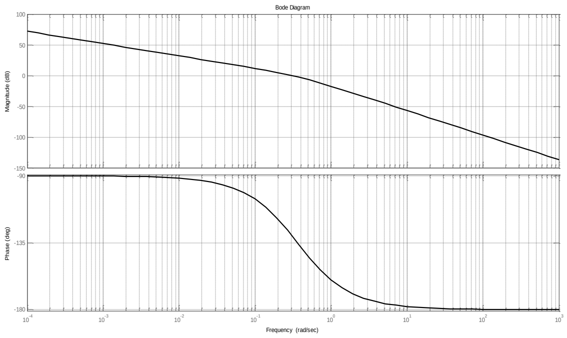

Figure 4. Bode plot of the AC servo motor system

5. Results and Discussions

A reference periodic signal with known period (L = 62) and amplitude (A = 5) is generated and is applied to AC servo motor system with NMRCS based PD controller. The tracking response is recorded in Figure 5. In addition, an experimental runs of ILCS based PD control strategy and conventional PD mode control strategy are carried out and responses are traced in Figure 6 and Figure 7. In all the cases the nominal operating point of 40% position angle is maintained. From the Figures 5 to 7, the tracking errors are calculated with respect to time and results are charted in Figure 8. It is observed that NMRCS in control loop is capable of tracking dynamic periodic reference trajectories with minimum error. To check the strength of the NMRCS, a real-time runs of the AC servo motor system for a periodic input signal having different known periods and amplitude (L= 62,A= 6) & (L= 45,A = 5) are carried out. Figures (9 to 16) validate the robustness of NMRCS in AC servo motor system.

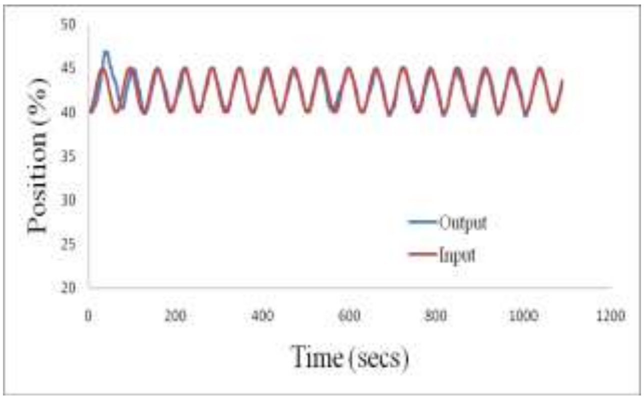

Figure 5. Tracking response of periodic reference trajectories [Period (L) =62, amplitude (A) =5, Operating point = 40%] with NMRCS based PD mode

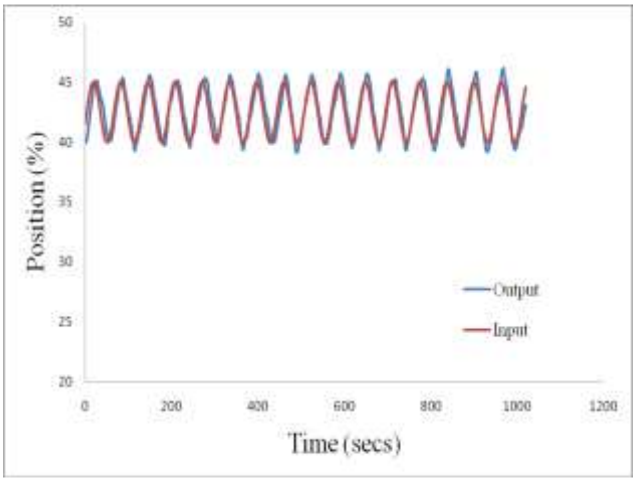

Figure 6. Tracking response of periodic reference trajectories [Period (L) =62, amplitude (A) =5, Operating point = 40%] with ILCS based PD mode

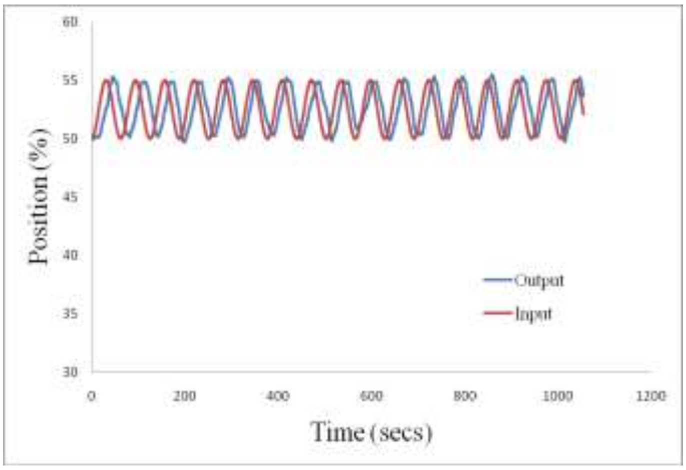

Figure 7. Tracking response of periodic reference trajectories [Period (L) =62, amplitude (A) =5, Operating point = 40%] with Conventional PD mode

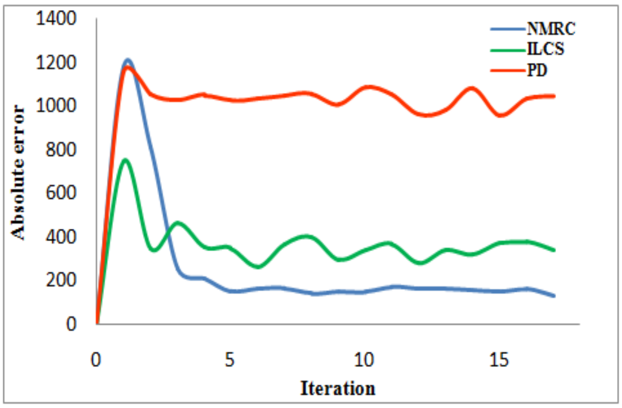

Figure 8. Tracking error response for all control strategies [Period (L) =62, amp.(A) =5, OP = 40%]

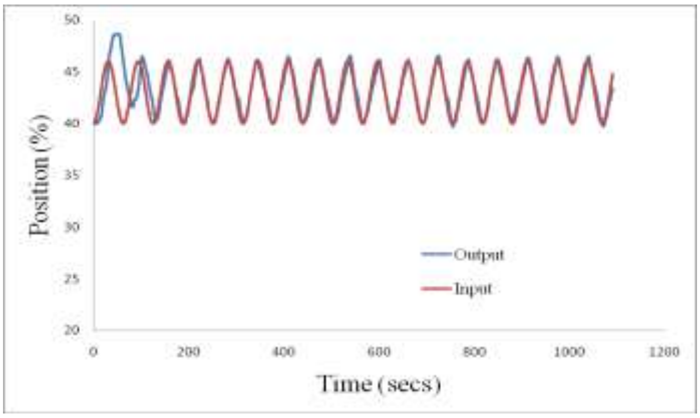

Figure 9. Tracking response of periodic reference trajectories [Period (L) =62, amplitude (A) =6, Operating point = 40%] with NMRCS based PD mode

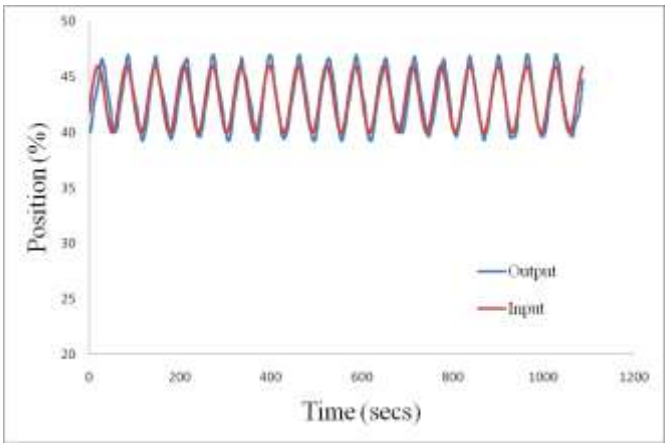

Figure 10. Tracking response of periodic reference trajectories [Period (L) =62, amplitude (A) =6, Operating point = 40%] with ILCS based PD mode

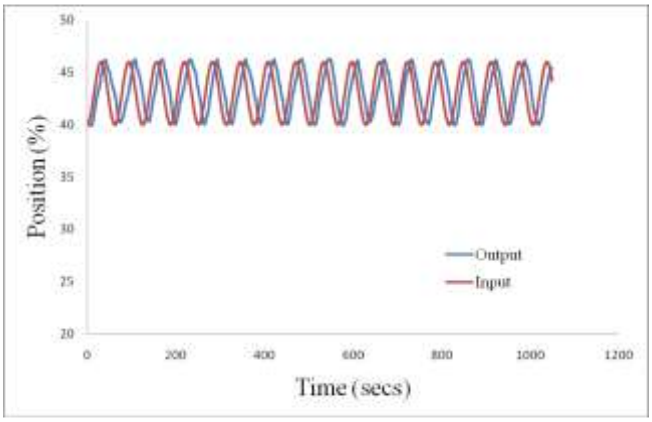

Figure 11. Tracking response of periodic reference trajectories [Period (L) =62, amplitude (A) =6, Operating point = 40%] with Conventional PD mode

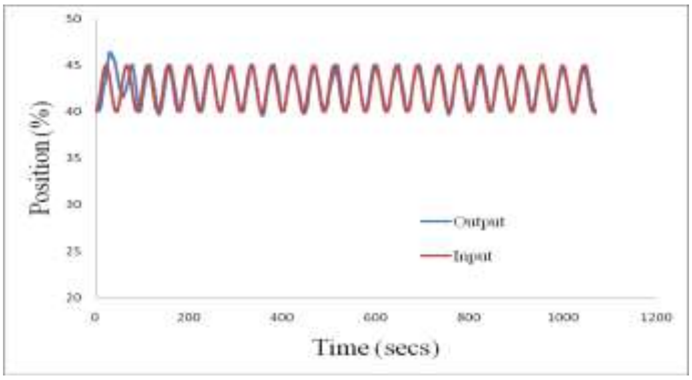

Figure 12. Tracking response of periodic reference trajectories [Period (L) =45, amplitude (A) =5, Operating point = 40%] with NMRCS based PD mode

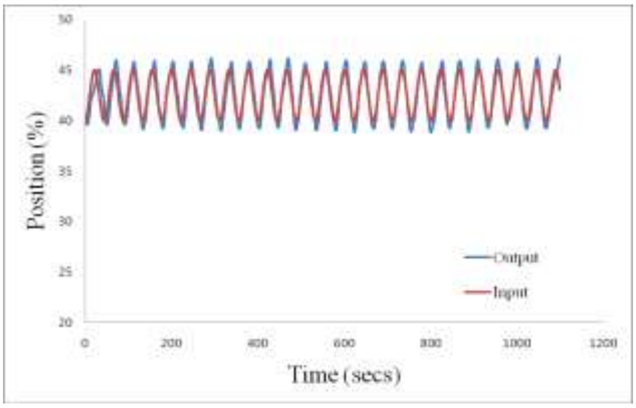

Figure 13. Tracking response of periodic reference trajectories [Period (L) =45, amplitude (A) =5, Operating point = 40%] with ILCS based PD mode

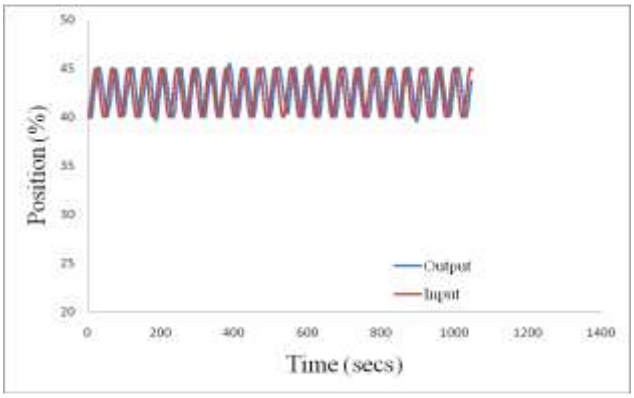

Figure 14. Tracking response of periodic reference trajectories [Period (L) =45, amplitude (A) =5, Operating point = 40%] with Conventional PD mode

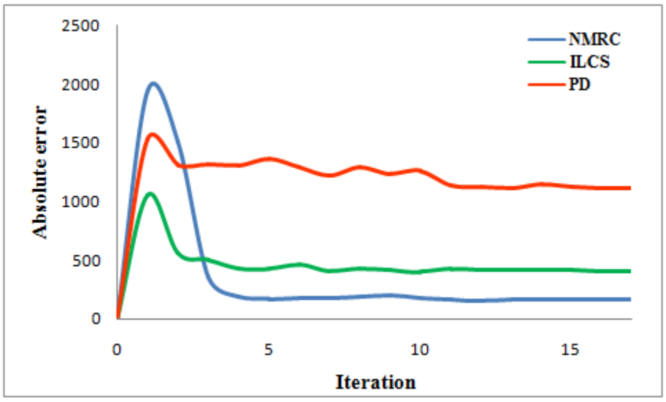

Figure 15. Tracking error response for all control strategies [Period (L) =62, amp.(A) =6, OP = 40%]

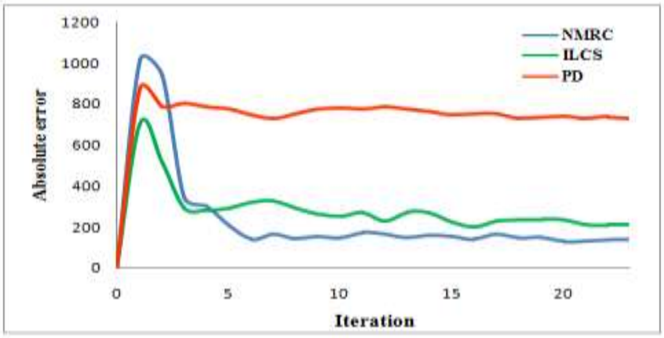

Figure 16. Tracking error response for all control strategies [Period (L) =45, amp.(A) =5, OP = 40%]

6. CONCLUSION

In this work, A New Modified Repetitive Control Strategy is proposed for a AC servo motor system. Real-time implementation of the proposed strategy in AC servo motor system is carried out and tracking of periodic signal with this new control strategy is analysed. A comparative study with another two control strategies (ILCS based PD and Conventional PD) are also carried out. Performance analysis is done in terms of tracking error. The result clearly shows the supremacy of the proposed NMRCS in Ac servo motor system.

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