POSITION TRACKING PERFORMANCE OF AC SERVOMOTOR BASED ON NEW MODIFIED REPETITIVE CONTROL STRATEGY

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ABSTRACT

This work focuses on the design and implementation of a New Modified Repetitive Control Strategy (NMRCS) for position control in real-time AC servo motor system. The dynamic second order transfer function model of the system is derived and the model parameters are identified using experimental data. Based on the model parameters, the conventional PD controller parameters are computed by optimization tool in MATLAB platform. The real-time runs are carried out with NMRCS based PD controller for a periodic reference tracking. The Repetitive Control Strategy (RCS) based PD controller and conventional PD controller are taken for comparative studies. The performance measures of the above said controllers are analyzed in terms of tracking error. A robustness of the proposed control strategy is also tested. The real-time results confirm the supremacy of NMRCS based PD controller.

Keywords: *NMRCS, RCS, Conventional PD, AC Servomotor*

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/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 main advantages of NMRCS are: (a) its tracking ability can adapt itself (b) in the real time implementation it has robustness against noises (c) it does not require difficult theories of control, knowledge of system, or other environment models.

The repetitive control strategy is illustrated in [8]. It can decrease the error subsequent to the first epoch [9]. The novelty of RCS is motivated by a power supply regulation problem in proton synchrotron accelerator [10] and a high accuracy trajectory control in servomechanism [11].Currently a different application of repetitive control has sprung up, including high-speed motion tracking problem of visual servoing [12], speed control of ultrasonic motors [13], accurate position control of piezoelectric actuators [14] and control of rotation mechanisms [15].

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 mathematical model of the system is developed. Here AC servo motor, optical sensor and an inertia disc representing the load are considered for model identification. The proposed scheme is explained in section 3; Real time outcomes are analyzed in Section 4 to illustrate the better tracking of the proposed NMRCS in closed loop. Finally, conclusions are drawn in Section 5.

2. REAL-TIME SYSTEM

The real-time system consists of a permanent magnet two phase AC servo motor with gear box and servo drive. The key parameters required in model of this servomotor are identified by conducting suitable experimental test as shown in Figure 1.

The closed loop hardware configuration of the real-time AC servo motor system is shown in Figure 2. It consists of PC based motion control card (VMAT 01). This card is capable of running the real time control algorithms in simulink tool of MATLAB platform directly and it provides a multifunction, high speed analog to digital converter (ADC) and digital to analog converter (DAC).

Figure 1. Experimental setup

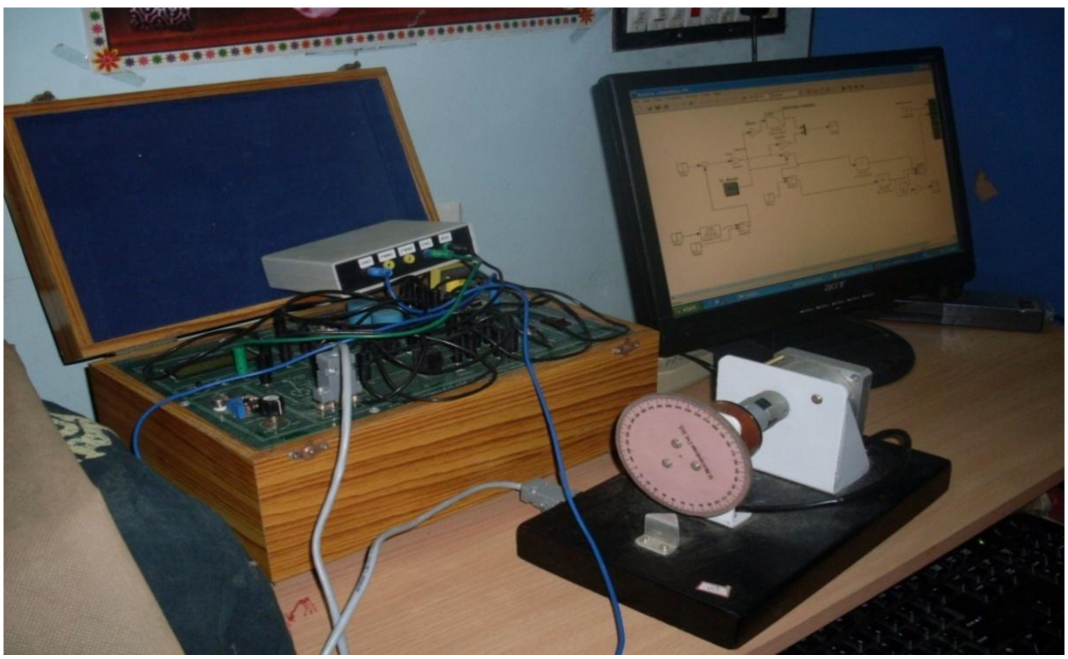

Figure 2. Closed loop hardware configuration of AC servo motor

3. IDENTIFICATION OF MODEL PARAMETERS AND CONTROLLERSETTINGS

3.1 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 (T_c) for the two phase AC servo motor is described as

$$T_C = k_1 E(t) - k_2 \dot{\theta}(t) \quad (1)$$

Where T_C = Control torque (Nm)

k_1 & k_2 = motor constants (Nm/V, Nm/rad/s) - identified parameters from experimental test.

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

E = rated input voltage (v)

The dynamic equation of the mechanical system is given by

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

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.cm^2)

By equating (1) and (2)

$$J\ddot{\theta} + B\dot{\theta} + T_L = k_1E(t) - k_2\dot{\theta}(t) \quad (3)$$

Taking laplace transform the above equations becomes

$$K_1E(s) - k_2s\theta(s) = Js^2\theta(s) + Bs\theta(s) + T_L(s) \quad (4)$$

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

$$\frac{\theta(s)}{E(s)} = \frac{K_1}{Js^2+K_2s+Bs} = \frac{K_m}{s(\tau_m s+1)} \quad (5)$$

Where $K_m = \frac{K_1}{K_2+B}$ and $\tau_m = \frac{J}{K_2+B}$

Km = Motor gain constant

τ_m = Motor time constant

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.cm^2
Friction coefficient (B)	0.01875
GB ratio	36
Radius of the output shaft	0.0175m

3.2 PD Controller Design

A proportional derivative (PD) controller is designed to control the position of AC servo system. The PD controller parameters (Kc and Kd) are tuned using signal constraint block of simulink optimization tool in MATLAB platform [16]. The signal constraint is a block where response signals can be graphically constrained and model parameters are automatically optimized to get the performance requirements (refer table.2).

Based on the model parameters and performance requirements, the optimized PD controller settings are identified as Kc = 2.0203 and Kd = 1.8826.

Table 2. Performance specification for PD control system

Rise time (t_r)	20
Settling time (t_s)	22.2
Over shoot (Mp)	20%

4. REPETITIVE CONTROL STRATEGY (RCS)

Repetitive control strategy [17] 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 [18]. 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 3.

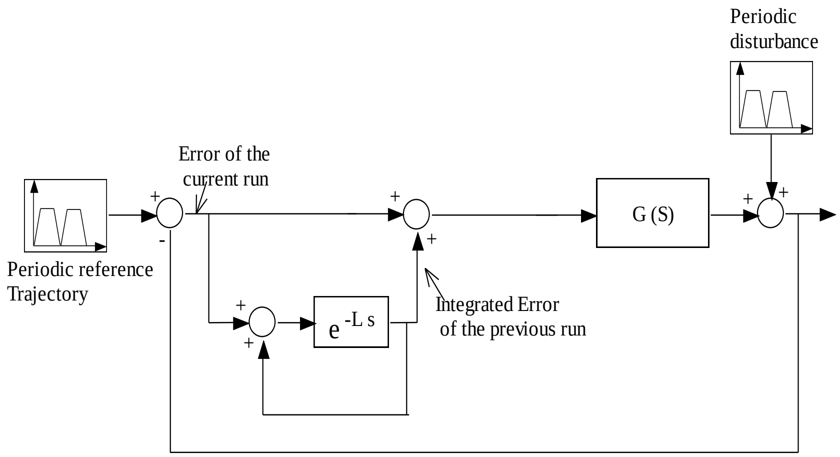

Figure 3. Repetitive Control Strategy

5. 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 [17]. 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 4. 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.

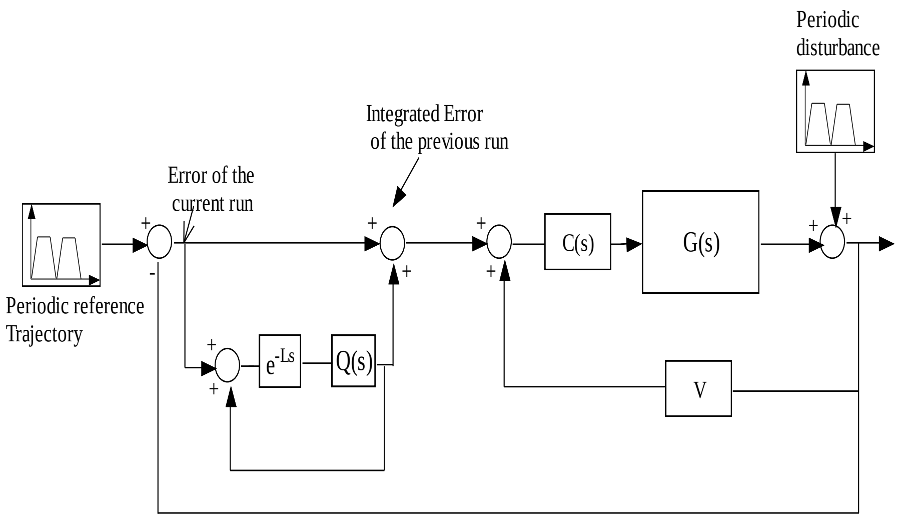

Figure 4. New Modified Repetitive Control Strategy

5.1 Sensitivity

From the above figure, the sensitivity function of the proposed scheme is derived as

$$s(jw) = \frac{e}{d} = \frac{-1}{1+\frac{PC}{1-PCV}\left[1+\frac{e^{-jwTd}}{1-e^{-jwTd}}\right]} \quad (6)$$

5.2 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.

5.3 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 ω_c 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 5).

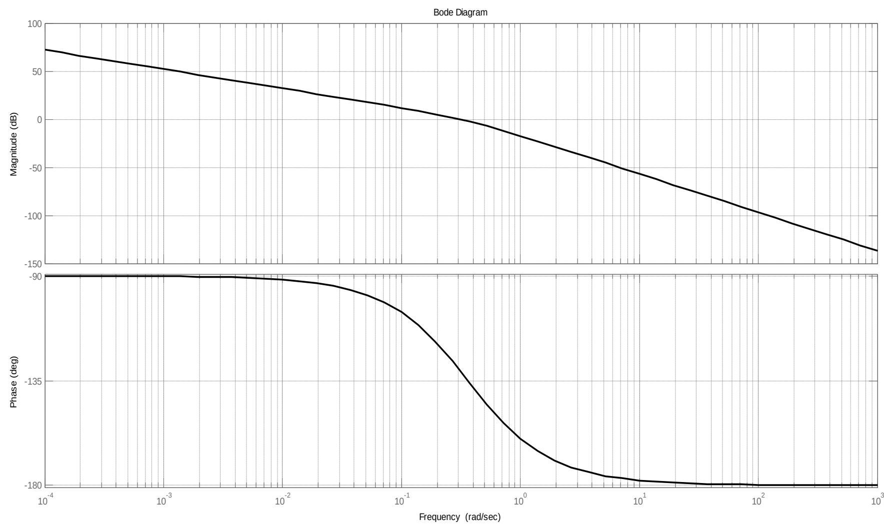

Figure 5. Bode plot of the AC servo motor system

6. RESULTS AND DISCUSSIONS

6.1 Real-Time Run

An input reference periodic signal with known period (L = 62) and amplitude (V_{pp} = 5) is generated and is applied to AC servo motor system with NMRCS based PD controller. The tracking response is recorded in Figure 6. In addition, an experimental runs of RCS based PD control strategy and conventional PD mode control strategy are carried out and responses are traced in Figure 7 and Figure 8. In all the cases the nominal operating point of 40% position angle is maintained. From the Figures 6-8, the tracking errors are calculated with respect to time and results are charted in Figure 9. It is observed that NMRCS in control loop is capable of tracking dynamic periodic reference trajectories with minimum error. To check the robustness 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,Vpp= 6) & (L= 45,Vpp = 5) are carried out. Figures (10 to 17) justify the robustness of NMRCS in AC servo motor system.

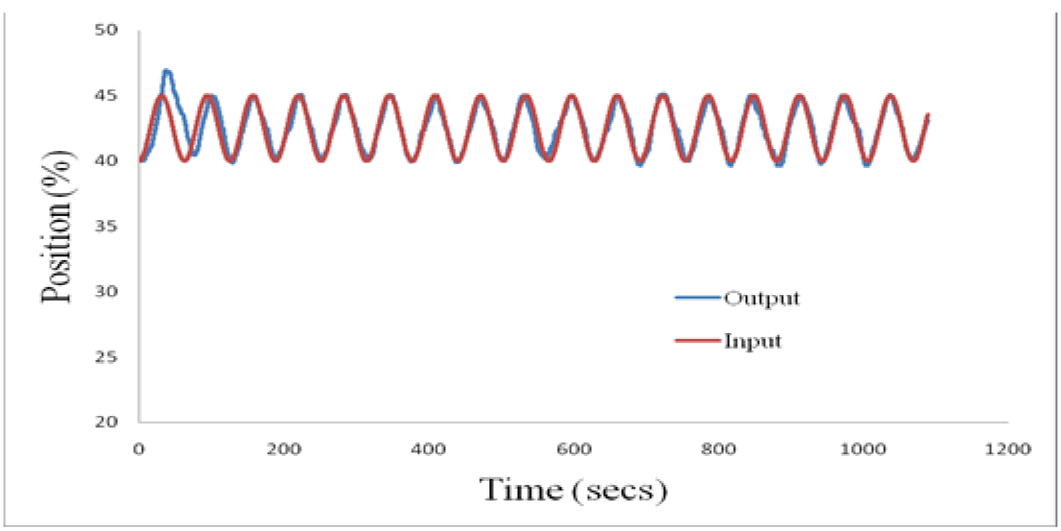

Figure 6. Tracking response of periodic reference trajectories [Period (L) =62, amplitude (V_{pp}) =5, Operating point = 40%] with NMRCS based PD mode

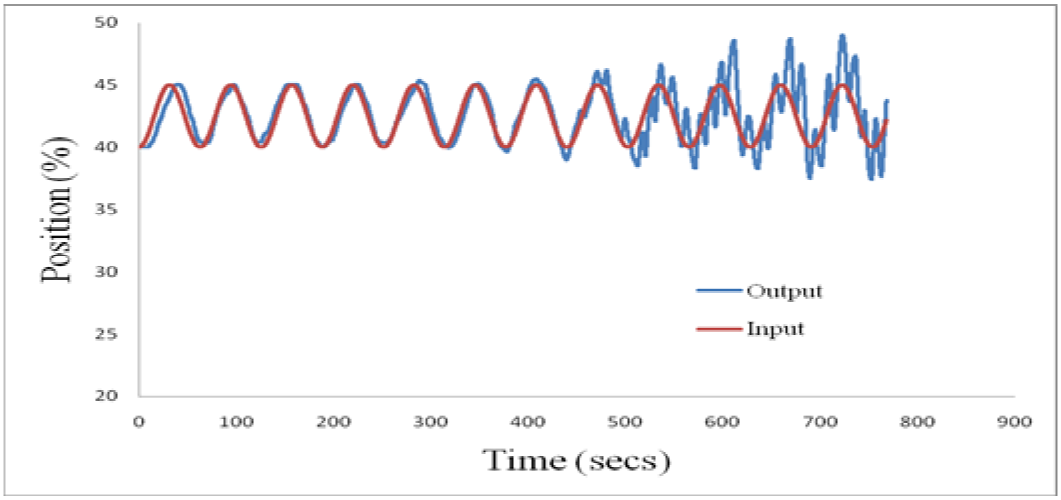

Figure 7. Tracking response of periodic reference trajectories [Period (L) =62, amplitude (V_{pp}) =5, Operating point = 40%] with RCS based PD mode

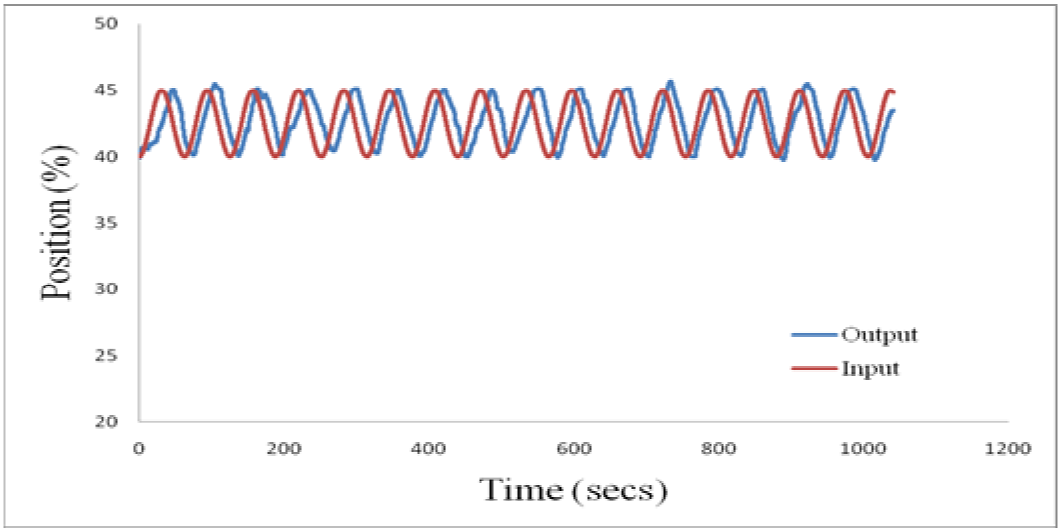

Figure 8. Tracking response of periodic reference trajectories [Period (L) =62, amplitude (V_{pp}) =5, Operating point = 40%] with Conventional PD mode

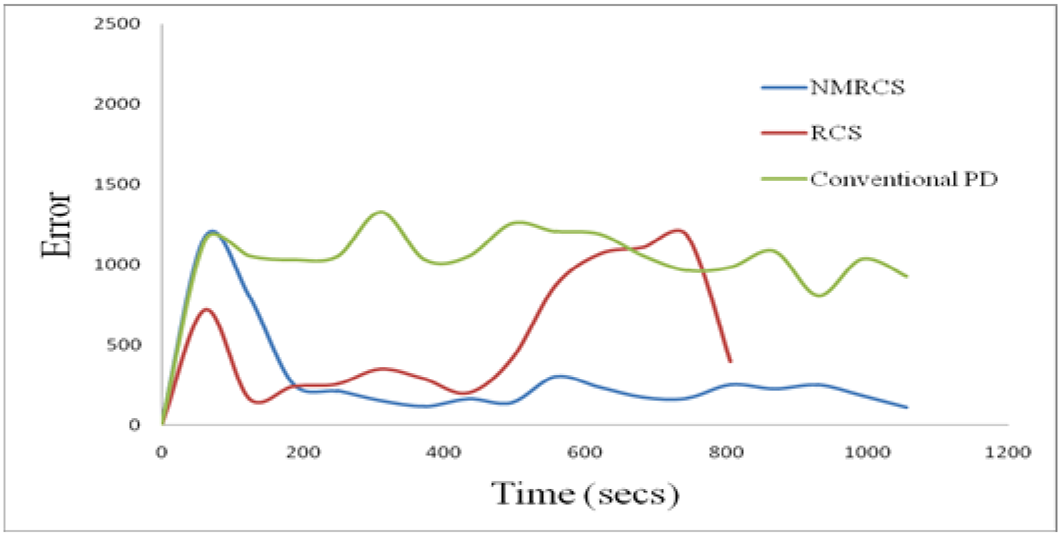

Figure 9. Tracking error response for NMRCS, RCS and PD control strategies [Period (L) =62, amplitude (V_{pp}) =5, OP = 40%]

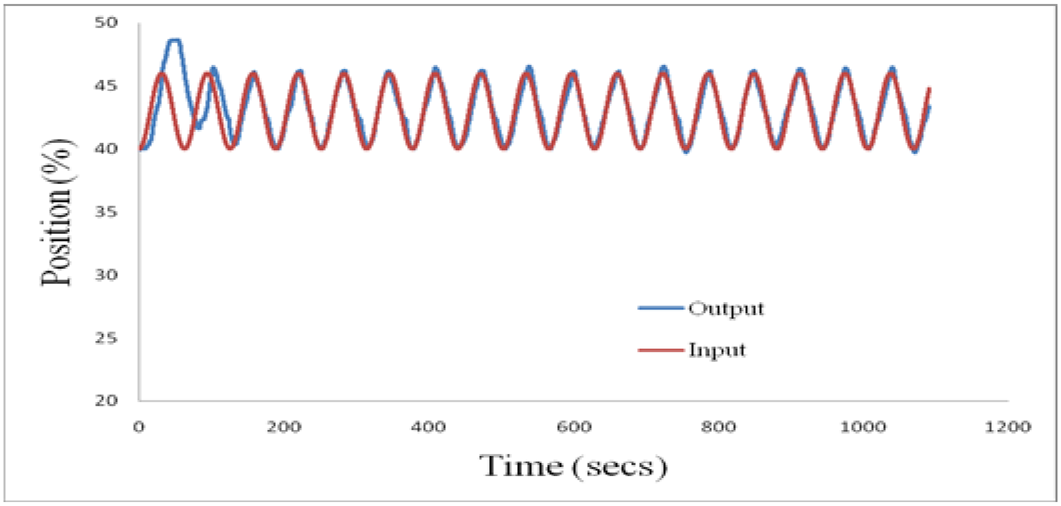

Figure 10. Tracking response of periodic reference trajectories [Period (L) =62, amplitude (V_{pp}) =6, Operating point = 40%] with NMRCS based PD mode

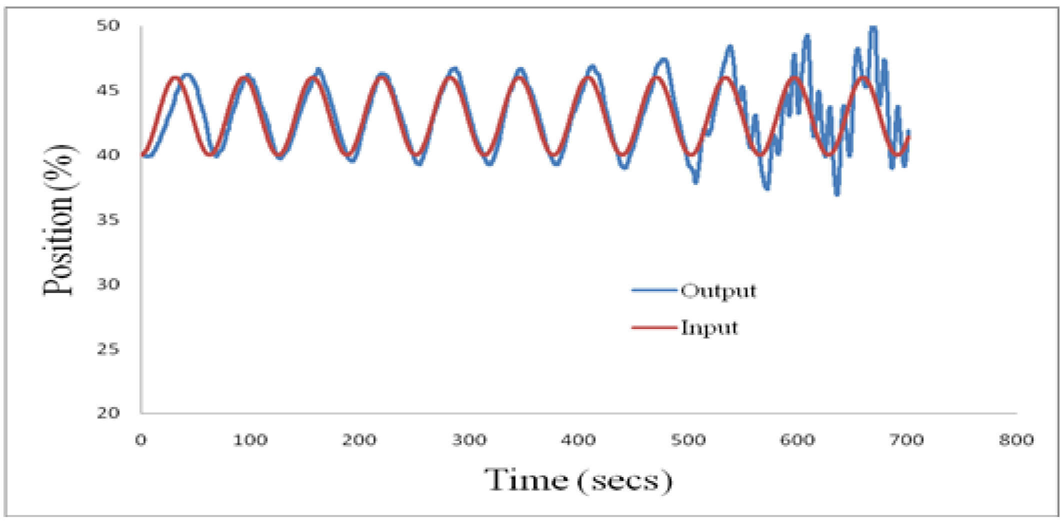

Figure 11. Tracking response of periodic reference trajectories [Period (L) =62, amplitude (V_{pp}) =6, Operating point = 40%] with RCS based PD mode

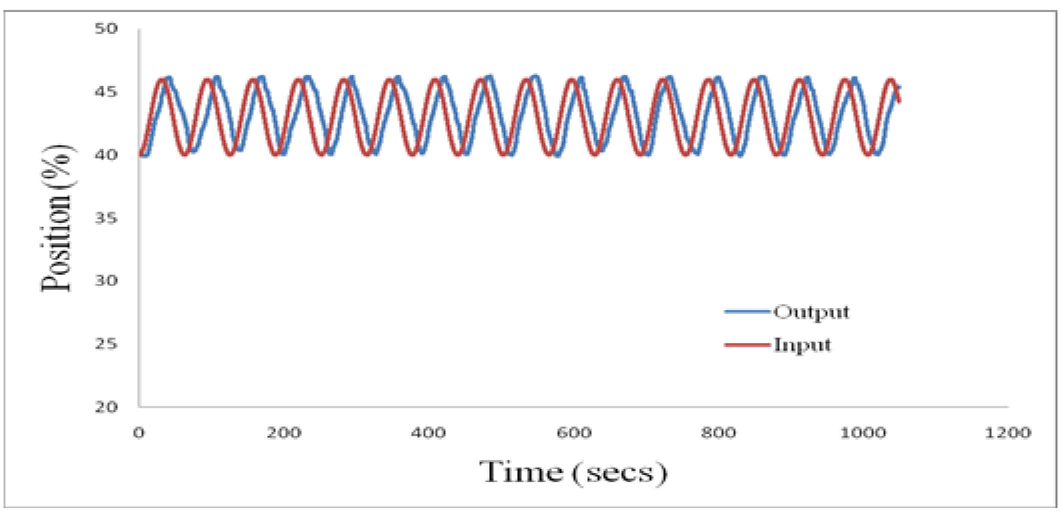

Figure 12. Tracking response of periodic reference trajectories [Period (L) =62, amplitude (V_{pp}) =6, Operating point = 40%] with Conventional PD mode

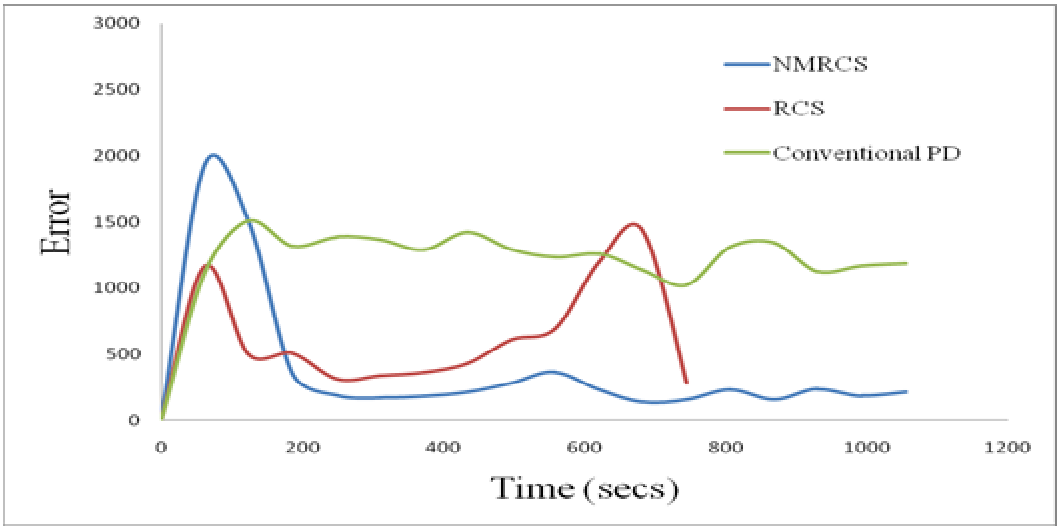

Figure 13. Tracking error response for NMRCS, RCS and PD control strategies [Period (L) =62, amplitude (V_{pp}) =6, OP = 40%]

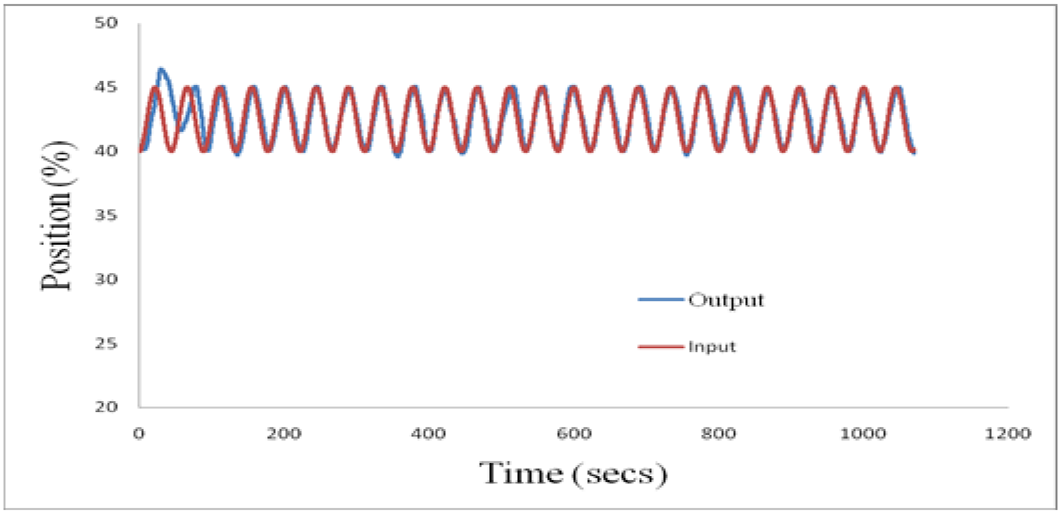

Figure 14. Tracking response of periodic reference trajectories [Period (L) =45, amplitude (V_{pp}) =5, Operating point = 40%] with NMRCS based PD mode

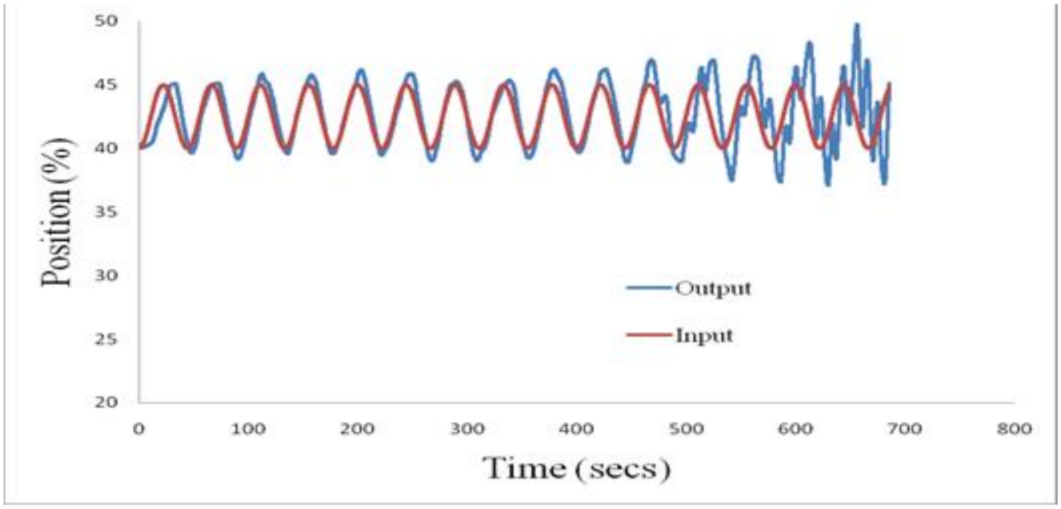

Figure 15. Tracking response of periodic reference trajectories [Period (L) =45, amplitude (V_{pp}) =5, Operating point = 40%] with RCS based PD mode

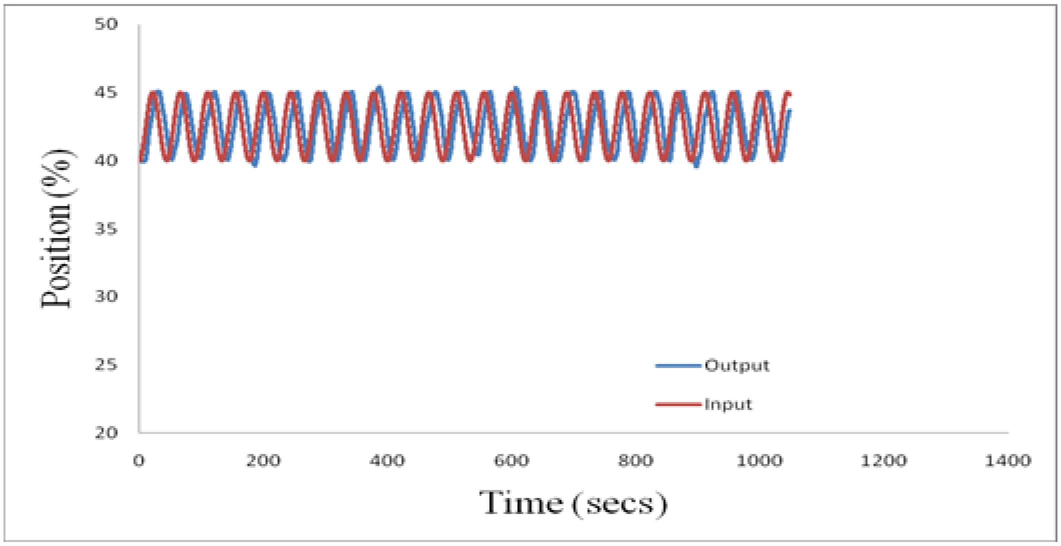

Figure 16. Tracking response of periodic reference trajectories [Period (L) =45, amplitude (V_{pp}) =5, Operating point = 40%] with Conventional PD mode

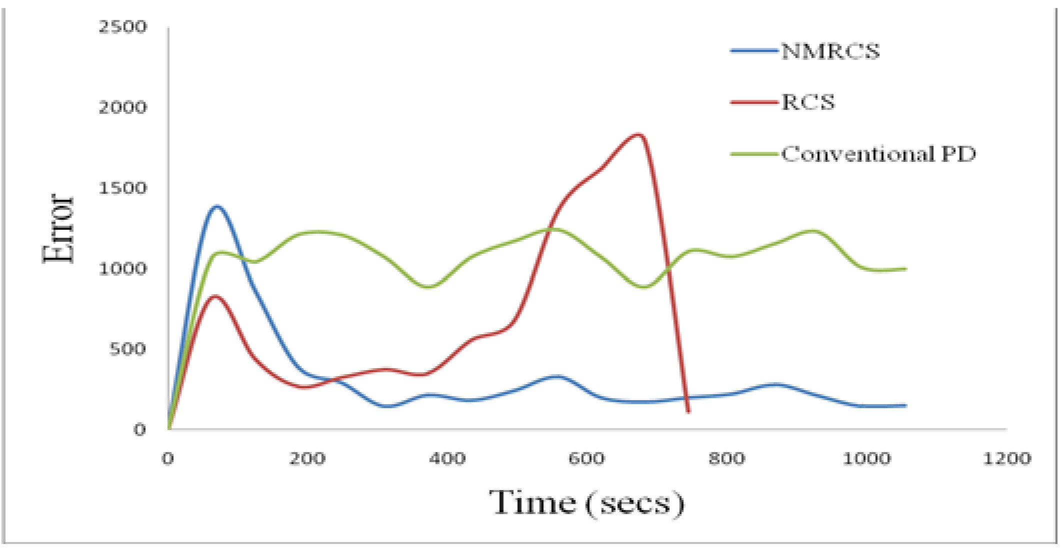

Figure 17. Tracking error response for NMRCS, RCS and PD control strategies [Period (L) =45, amplitude (V_{pp}) =5, OP = 40%]

6.2 Sensitivity Analysis

Figure 18 shows the magnitude of sensitivity function for all the two control strategies such as RCS and NMRCS. It seems that the sensitivity at the period frequencies is smaller in NMRCS configuration as compared to RCS configuration. It clearly indicates that in NMRCS errors are minimized at period frequencies and shows the good tracking performance.

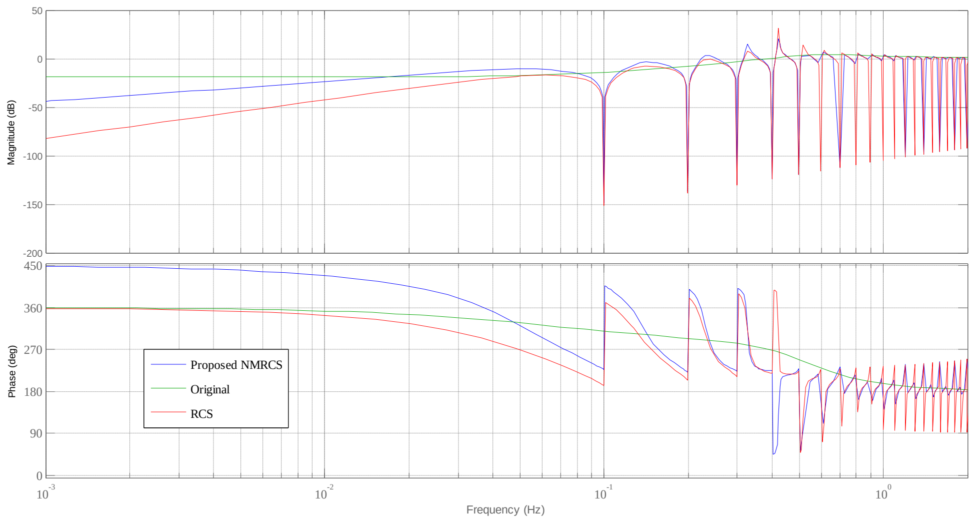

Figure 18. Magnitude of the sensitivity function

7. CONCLUSION

A new modified repetitive control strategy is proposed in this work for a AC servo motor system. Real-time implementation of the proposed strategy in AC servo motor system is done and tracking of periodic signal with this new control strategy is analysed. Performance analysis is identified in terms of tracking error. A comparative analysis with another control strategy (RCS) is also carried out. The result clearly shows the supremacy of the proposed NMRCS in Ac servo motor system.

8. ACKNOWLEDGEMENT

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