Two-Phase Hybrid Stepping Motor Based Antenna Positioning Control System Using Proportional Integral and Derivative Controller

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***Abstract*—This paper has presented two-phase hybrid stepping motor (TPHSM) based antenna positioning control system using Proportional Integral and Derivative (PID) controller. The objective was to design a control system that will enable a satellite antenna to track a desired azimuth/elevation for effective line of sight operation. In order to achieve this, the dynamic of TPHSM based antenna was obtained and a PID controller was designed using the MATLAB PID Tuner. The result of the developed system showed that a desired position in terms of step input was achieved.**

***Index Terms*—Antenna, Controller, PID, Line of Sight**

I. INTRODUCTION

In satellite communication system, the role of antenna is to convert electrical signals to electromagnetic waves during transmitting and do the opposite during receiving. Antenna is the most visible part of a satellite communication system. The types of antennas used in satellite communication are the parabolic reflector antennas, often called dish antennas, whose structures are parabolic. They are used to achieve high gain when used for frequencies in the range of microwave (Ahmed et al, 2014). As a result of this property, these antennas are suitably applied in satellite links, radio relay links, and radar systems (Balanis, 2005; Ahmed et al, 2014). There are various types of antennas related to satellite communication from these antennas; the parabolic reflector is used for signal reception (Sugandhi et al, 2016). Thus to make parabolic antennas used in communication efficient in maintaining good satellite tracking, they are designed and mounted with servomotor control system.

In this paper, a two-phase hybrid stepping motor (TPHSM) based antenna positioning control system using a real Proportional Integral and Derivative (PID) controller is designed.

II. SYSTEM DESCRIPTION AND MODELLING

A. Two-phase Hybrid Stepping Motor

Stepping motors are electromagnetic mechanic devices that are able to transform discrete impulses typically of square wave pulses, into linear or angular displacement (Attiya et al., 2016). Two-phase hybrid stepping motors (TPHSM) are special type of synchronous motors designed to rotate through fixed angle called a step for each electrical pulse received from control unit (Nagrath and Gopal, 2005). They are often applied in control and measurement systems due to the advantage of easy open loop control and no error accumulation that they provide. These motors are ideal choice for applications with small power (less 100 W) and maintains fast and efficient positioning control for robotic, machine tool, servos, aerospace, printer and scanner systems (Attiya et al., 2016; Bellini et al., 2004).

B. Mathematical Description

A typical mathematical representation of a TPHSM consists of the dynamic equations of the shaft and stator coils. The shaft maintains a mechanical dynamic as it rotates within the stator coil which provides the electrical components of the process. The components of the electrical dynamics are given by (Baldha et al., 2015):

$$\frac{dI_a}{dt} = \frac{\left[V_a - RI_a + K_m \omega \sin(N\theta)\right]}{L} \tag{1}$$

$$\frac{dI_b}{dt} = \frac{\left[V_b - RI_b + K_m \omega \cos(N\theta)\right]}{L} \tag{2}$$

The mechanical equations are (Baldha et al., 2015):

$$\frac{dI_a}{dt} = \frac{\left[-KmI_a \sin(N\theta) + K_m I_a \cos(N\theta) - B\omega - T_L - K_d \sin(4N\theta)\right]}{J} \quad \text{…. (3)}$$

$$\frac{d\theta}{dt} = \omega \tag{4}$$

where I_a and I_b are the currents in phases A and B respectively in ampere (A). V_a and V_b are the voltages in phases A and Bin volt (V) respectively. ω is the rotor speed (rads^{-1}), θ is rotor position (rad), R is the resistance of the phase winding in (Ω), L is the self-inductance constant (Nm/A), B is the viscous friction constant (Nms^2/rad), J is the rotor inertia (kgm^2), T_L is the load torque (N/m).

C. System Configuration and Transfer Function

Figure 1 shows a model of two-phase hybrid stepping motor-based antenna positioning control system. The parameters of the system are presented in Table 1.

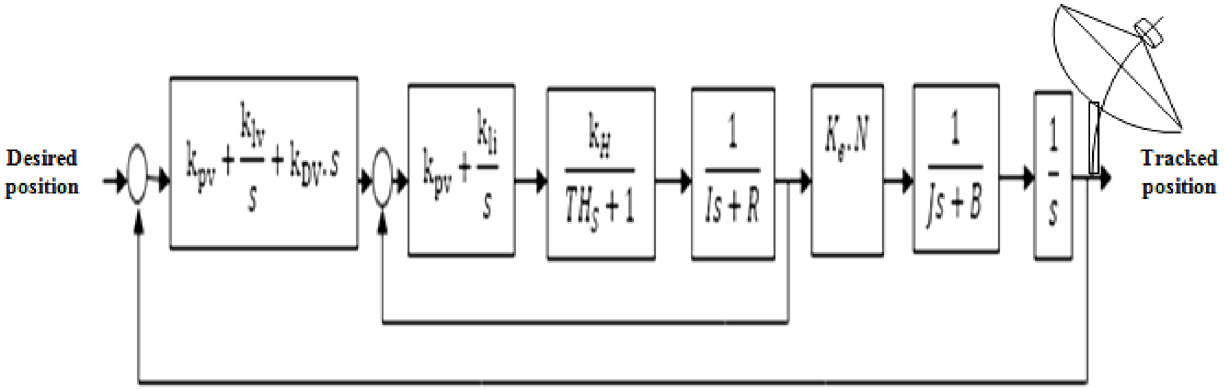


Fig.1 Block diagram of two-phase hybrid stepping motor-based antenna control system

Table 1 System parameters (Al-Yasiri et al., 20)

Parameter	Description	Value
R	Armature resistant	2.96Ω
L	Armature inductance	150mH
J	Moment of initial	42.3×10^{-6} kgm^2
B	Viscous friction coefficient	48.6×10^{-6} Nms
K_e	Torque constant	13.5×10^{-3}Nm/A
K_b	Back EMV constant	13.5×10^{-3}Vs/rad
N	Number of teeth	180
β	Beta gain	1
K_H	-	15
K_{PV}	Voltage gain	500
K_{IV}	Voltage integrator parameter	0
K_{DV}	Voltage differentiator parameter	100
K_{Ii}	Current integrator parameter	500
K_{Pi}	Current Gain	5

The open loop transfer function G(s) of two-phase hybrid stepping motor-based antenna positioning control system is given by (Al-Yasiri et al., 20):

$$G(s) = \frac{A(s)}{B1(s) + B2(s)} \tag{5}$$

where

$$A(s) = \left(K_{PV} + \frac{K_{IV}}{s} + K_{DV}s\right)\left(K_{Pi}s + K_{Ii}\right)K_e N K_H$$

$$B1(s) = JLs^4 + \left(JR + \beta L + JK_{Pi}K_H\right)s^3$$

$$B2(s) = \beta K_{Pi}K_H s + \left(JK_{Pi}K_H + \beta R + \beta K_{Pi}K_H\right)s^2$$

Replacing the variable in Eq. (1) with the parameters in Table 1, gives the transfer function of the control system as follows (Al-Yasiri et al., 20):

$$T(s) = \frac{13500}{6.345s^2 + 132.498s + 326.106} \qquad (6)$$

Equation (2) is the open transfer function of THHSM based antenna positioning control system.

III. Design of Controller

An appropriate controller used in industrial control systems for three-term control-loop feedback mechanism is the Proportional Integral Derivative (PID) controller. The PID controller reduces system error by adjusting the process through the use of a manipulated variable. It ensures optimum control dynamics including zero steady state error, fast response (short rise time), minimized overshoot, no oscillations and higher stability. The use of PID controller in higher order processes is the main advantage it has over some other linear controllers. Figure 2 shows a block diagram of a PID control model.

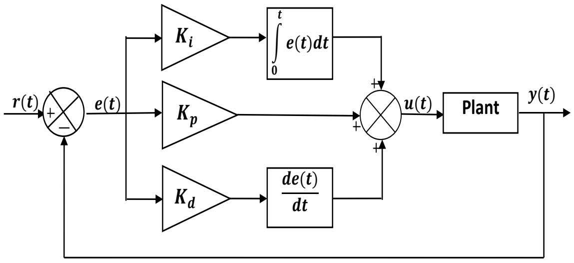


Fig. 2 Block diagram of PID control system

The mathematical representation of PID control algorithm can be obtained by analyzing Fig. 2. The quantities $r(t), e(t), u(t)$ are the reference input (voltage in this case), error (or deviation of the terminal voltage from the reference voltage), and controller output. Also K_p, K_i, K_d are the parameters of the PID controller called the proportional, integral and derivative gains, and $y(t)$ is the output (generator output voltage in this case).

$$e(t) = r(t) - y(t) \qquad (7)$$

With the error fed into the PID, proportional, integral and derivative computations are performed on the error and the resulting mathematical expression of the controller output is given by:

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt} \qquad (8)$$

Equation (3.6) is the expression for continuous time ideal PID controller expressed in time domain and can as well be represented as a Laplace transform equation in complex frequency domain assuming zero initial condition as:

$$U(s) = K_p E(s) + K_i \frac{1}{s} E(s) + K_d sE(s) \qquad (9)$$

Or in simplified form as:

$$C(s) = K_p + K_i \frac{1}{s} + K_d s \qquad (10)$$

where $C(s) = U(s)/E(s)$ and is called the PID controller.

Equation (10) represents the three parameters in-parallel for and stands as the resulting effect of the PID controller as the sum of the effects of the three components (Eze et al., 2020). However, in practice the real PID controller is often implemented. It has a pre-filter implemented along with the derivative component to solve the problem of noise disturbance that may go into the controller through derivative part. Hence, the real PID is given by:

$$C(s) = K_p + K_i \frac{1}{s} + K_d \left(\frac{sN}{s + N} \right) \qquad (11)$$

Equation (11) is the PID control algorithm implemented in this work and *N* is the filter coefficient. The gains of the controller were obtained by employing fast and robust turning of the MATLAB/Simulink PID tuner in continuous time domain. The values of the tuned parameters are given in Table 2.

Table 2 Controller Parameters

Gain	Definition	Tuned
K_p	Proportional gain	1.07
K_i	Integral gain	3.19
K_d	Differential gain	0.0372
N	Filter coefficient	0.00324

Substituting the tuned parameters of the real PID in Table 2 into Eq. (11), gives:

$$C(s) = 1.07 + \frac{3.19}{s} + 0.0372\left(\frac{0.00324s}{s + 0.00324}\right) \qquad (12)$$

Equation (12) is the designed controller for the system. Adding the PID into the control loop gives:

$$T_1(s) = \frac{1.693\times10^5 s^2 + 4.502\times10^6 s + 1.33\times10^7}{6.345s^4 + 2090s^3 + 4.121\times10^4 s^2 + 1.006\times10^5 s} \quad \ldots\ldots (13)$$

The closed loop block diagram of the system is shown is shown in Fig. 3.

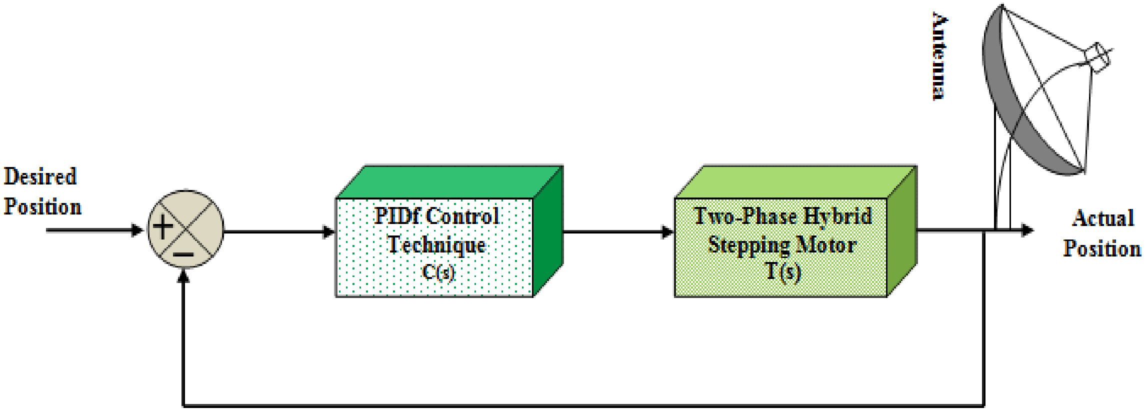


Fig. 3 PID controlled motorized antenna system

IV. SIMULATION RESULTS AND DISCUSSION

In this section, the results obtained from simulation conducted in MATLAB are presented in Figures 4, 5, 6 and 7 respectively. The performance analysis of the system in open and closed loop (with PID controller) is presented in Table 3.

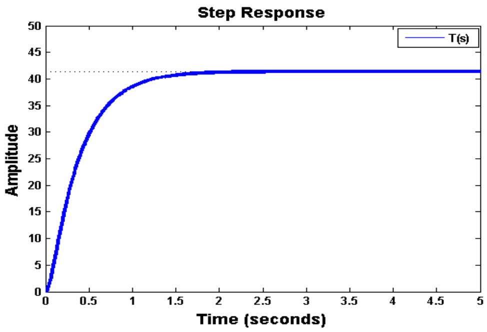


Fig. 4 Step response of open-loop system

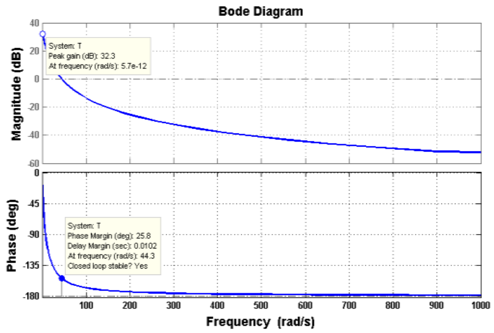


Fig. 5 Stability plot of open-loop system

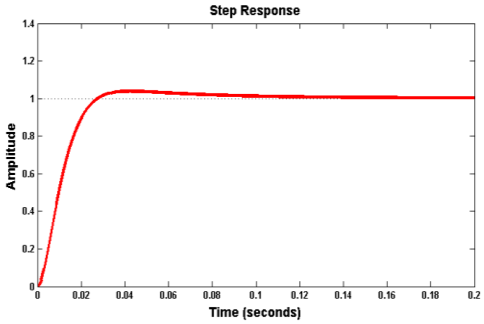


Fig. 6 Step response with PID controller (closed-loop system)

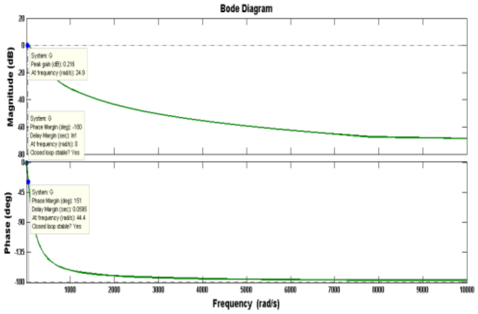


Fig. 7 Stability plot of compensated system

Table 3-time domain performance analysis

System	t_r (s)	t_p (s)	Os (%)	t_s (s)
Open-loop	0.80	8.23	0.06	1.64
Closed-loop (with PID)	0.02	0.04	3.89	0.08

From Table 2 t_r, t_p, t_s are the rise time, peak time, settling time in seconds respectively.

The step response of the open-loop in Fig. 5 showed that for a step forcing input applied to the system, the actual position with respect to unit input was not achieved even though the time domain performance parameters seem promising. The stability performance plot of the open-loop shown in Fig. 6 indicated that the system was stable with peak gain of magnitude of 32.3 dB at frequency of 5.7×10^{-12} rad/s and phase margin of 25.8 deg at frequency of 44.3rad/s.

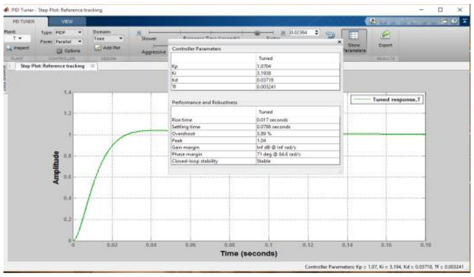
With the introduction of the PID controller, the actual output was able to track the desired input in terms of unit step forcing signal as shown in Fig. 7. The time domain transient response parameters outperformed those of the open-loop (or uncompensated) system as shown in Table 3. The stability plot in Fig. 7 revealed that compensated system is stable with peak gain magnitude 0.216 dB at frequency of 24.9 rad/s and phase margin of 151 deg at frequency of 44.4 rad/s.

Generally, with the PID compensated system, the satellite antenna positioning control system based on two-phase hybrid stepping motor will be able to track desired azimuth/elevation demanded for effective line of sight operation.

CONCLUSION

The application of PID controller with robust and fast tuning technique for efficient positioning of a dish antenna assembly aided by two-phase hybrid stepping motor has been studied. The results obtained from the simulations conducted in MATLAB environment indicated the designed PID was able to guarantee effective transient response performance to unit step input.

APPENDIX



Plant: T
Type: PIDF
Form: Parallel
Domain: Time
0.02364

Controller Parameters

	Tuned
Kp	1.0704
Ki	3.1938
Kd	0.03718
Tf	0.003241

Performance and Robustness

	Tuned
Rise time	0.017 seconds
Settling time	0.0796 seconds
Overshoot	3.89 %
Peak	1.04
Gain margin	Inf dB @ Inf rad/s
Phase margin	71 deg @ 84.6 rad/s
Closed-loop stability	Stable

Controller Parameters: Kp = 1.07, Ki = 3.194, Kd = 0.03718, Tf = 0.003241

PID tuning graphical user interface

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