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 (Nagrat 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):

\[
\frac{dl_a}{dt} = \frac{[V_a - RI_a + K_m \cos(N\theta)]}{L}
\]
\[
\frac{dI_b}{dt} = \frac{[V_b - RI_b + K_m \cos(\theta)]}{L} \\
(2)
\]

The mechanical equations are (Baldha et al., 2015):
\[
\frac{dI_a}{dt} = \left[ -KmL_1\sin(\theta) + K_mL_2\cos(\theta) - B_0 - T_L - K_d\sin(4\theta) \right] / J \\
\ldots (3)
\]
\[
\frac{d\theta}{dt} = \omega \\
(4)
\]

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 B in volt (V) respectively. \( \omega \) is the rotor speed (rads\(^{-1}\)), \( \theta \) 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.

![Block diagram of two-phase hybrid stepping motor-based antenna control system](image)

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( R )</td>
<td>Armature resistant</td>
<td>2.96Ω</td>
</tr>
<tr>
<td>( L )</td>
<td>Armature inductance</td>
<td>150mH</td>
</tr>
<tr>
<td>( J )</td>
<td>Moment of initial</td>
<td>( 42.3 \times 10^{-6} ) kgm(^2)</td>
</tr>
<tr>
<td>( B )</td>
<td>Viscous friction coefficient</td>
<td>( 48.6 \times 10^{-6} ) Nms</td>
</tr>
<tr>
<td>( K_e )</td>
<td>Torque constant</td>
<td>( 13.5 \times 10^{-3} ) Nm/A</td>
</tr>
<tr>
<td>( K_b )</td>
<td>Back EMV constant</td>
<td>( 13.5 \times 10^{-3} ) Vs/rad</td>
</tr>
<tr>
<td>( N )</td>
<td>Number of teeth</td>
<td>180</td>
</tr>
<tr>
<td>( \beta )</td>
<td>Beta gain</td>
<td>1</td>
</tr>
<tr>
<td>( K_H )</td>
<td>-</td>
<td>15</td>
</tr>
<tr>
<td>( K_{PV} )</td>
<td>Voltage gain</td>
<td>500</td>
</tr>
<tr>
<td>( K_{IV} )</td>
<td>Voltage integrator parameter</td>
<td>0</td>
</tr>
<tr>
<td>( K_{DV} )</td>
<td>Voltage differentiator parameter</td>
<td>100</td>
</tr>
<tr>
<td>( K_{II} )</td>
<td>Current integrator parameter</td>
<td>500</td>
</tr>
<tr>
<td>( K_{PI} )</td>
<td>Current Gain</td>
<td>5</td>
</tr>
</tbody>
</table>

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):
\[
G(s) = \frac{A(s)}{B_1(s) + B_2(s)} \\
(5)
\]

where
\[
A(s) = \left( K_{PV} + \frac{K_{IV}}{s} + K_{DV} \right) \left( K_{PI} + K_{II} \right) K_e N K_H \\
B_1(s) = J L s^4 + \left( J R + \beta L + J K_{PI} K_H \right) s^3 \\
B_2(s) = \beta K_{PI} K_H s + \left( J K_{PI} K_H + \beta R + \beta K_{PI} K_H \right) s^2
\]

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):
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](image)

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).

\[
e(t) = r(t) - y(t) \quad (7)
\]

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:

\[
u(t) = K_p e(t) + K_i \int_0^t e(t) dt + K_d \frac{de(t)}{dt} \quad (8)
\]

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:

\[
U(s) = K_p E(s) + K_i \frac{1}{s} E(s) + K_d s E(s) \quad (9)
\]

Or in simplified form as:

\[
C(s) = K_p + K_i \frac{1}{s} + K_d s \quad (10)
\]

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:

\[
C(s) = K_p + K_i \frac{1}{s} + K_d s + \frac{sN}{s + N} \quad (11)
\]

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 tuning of the MATLAB/Simulink PID tuner in continuous time domain. The values of the tuned parameters are given in Table 2.

<table>
<thead>
<tr>
<th>Gain</th>
<th>Definition</th>
<th>Tuned</th>
</tr>
</thead>
<tbody>
<tr>
<td>( K_p )</td>
<td>Proportional gain</td>
<td>1.07</td>
</tr>
<tr>
<td>( K_i )</td>
<td>Integral gain</td>
<td>3.19</td>
</tr>
<tr>
<td>( K_d )</td>
<td>Differential gain</td>
<td>0.0372</td>
</tr>
<tr>
<td>( N )</td>
<td>Filter coefficient</td>
<td>0.00324</td>
</tr>
</tbody>
</table>

T(s) = \( \frac{13500}{6.345s^2 + 132.498s + 326.106} \) \quad (6)
Substituting the tuned parameters of the real PID in Table 2 into Eq. (11), gives:

\[ C(s) = 1.07 + \frac{3.19}{s} + 0.0372 \left( \frac{0.00324s}{s + 0.00324} \right) \]  

(12)

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

\[ T_1(s) = \frac{1.693 \times 10^5 s^2 + 4.502 \times 10^6 s + 1.33 \times 10^7}{6.345 s^4 + 2090 s^3 + 4.121 \times 10^4 s^2 + 1.006 \times 10^5} \]  

..... (13)

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

![PID controlled motorized antenna system](image)

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.

![Step response of open-loop system](image)

Fig. 4 Step response of open-loop system

![Stability plot of open-loop system](image)

Fig. 5 Stability plot of open-loop system

![Step response with PID controller (closed-loop system)](image)

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

REFERENCES

