Development of Closed Loop Chopper Controlled Drive for PMDC Motors Used in Orthopedic Surgical Simulators

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Abstract
PMDC motors are widely used in orthopedic surgical simulators. In this paper a closed loop chopper control scheme is developed for this motor. The drive circuit has two loops an inner current control loop and an outer speed control loop. The chopper drive is simulated using Matlab/Simulink. The inner current loop employs a hysteresis controller and the outer loop consists of a PI controller. The responses of both the loops were studied. The simulated results reveal that efficient control of the motor can be achieved by using the closed loop drive system.

Keywords
Chopper, Hysteresis Controller, Orthopedic Surgical Simulators, PMDC Motor, PI Controller

I. Introduction
Trainee surgeons use orthopedic surgical simulators to practice screw placements in fractured bones. They carry out their training in cadaver bones instead of live patients. The screw placement includes three phases namely insertion, tightening and stripping [1] & [2]. The simulator is used for bone drilling and screwing. The three phases need varying torque and speed combinations in the motor. The geometry of the screw and the bone density determines the torque required. For insertion phase torque required is less, whereas tightening needs more torque. [3-6]. Torque should be applied such that optimal tightening is obtained.

The simulators use PMDC motors for screw placements. These motors have high torque output and also quiet in operation. The mathematical model of the PMDC motor is derived already Shankar et al and Chandrasekar et al [7] & [8]. The speed control of the motor can be achieved by varying the armature voltage and the torque control by varying the armature current [9]. Various conventional and fuzzy based control schemes for PMDC motors were studied [9] & [10]. In this paper, a simple closed loop chopper controlled scheme employing both current and speed control is presented. The proposed system uses hysteresis controller for current control and PI controller for speed control.

II. Mathematical Model of PMDC Motor
PMDC motors are characterised by their linear torque-speed characteristics. Their power loss is reduced as the electrical power need not be supplied to generate the stator flux. The simplified model of the motor is shown in fig. 1.

\[ V = E + I_a R_a + L_a \frac{dI_a}{dt} \]  
\[ E = K_v \omega \]  
\[ T_e = T_L + B \omega + J \frac{d\omega}{dt} \]  
\[ T_e = K_T I_a \]

Where,
- \( R_a \) is armature resistance in Ohms
- \( L_a \) is armature inductance in H
- \( I_a \) is armature current in A
- \( E \) is back EMF in Volts
- \( K_v \) is voltage constant in Volts sec/rads
- \( \omega \) is angular speed in rads/sec
- \( T_e \) is electromagnetic torque developed in Nm
- \( T_L \) is load torque in Nm
- \( J \) is Moment of Inertia in kg.m^2/s^2
- \( B \) is damping Coefficient in Nms
- \( K_T \) is torque constant in Nm/A

Fig. 1: Mathematical Model of PMDC Motor

III. Proposed System
The schematic diagram of the proposed system is shown in Fig. 2. The system uses two switches S1 and S2. The inner current control loop is used to control the switch S2 and the outer speed control loop controls switch S1. In PMDC motors, torque is a function of current. So the current value is measured and compared with the set value. The speed of the machine will be sensed and it is compared with the set speed. The error is processed by the PI controller and it generates appropriate pulses for driving the switch S1, which generates the required voltage for the motor.
IV. PI Controller

The Matlab Simulink model of the PI controller is shown in Fig. 3. In this system, the speed error is calculated from the set speed and current speed and is given to the controller, based on which the required pwm signal for the chopper is generated. The proportional gain and integral gain values are fixed by Zeigler-Nichols method of tuning the PI controller. As voltage and speed relationship in PMDC motor is linear, the PI controller is used to improve the transient state response of the system.

V. Simulation Results

The system is simulated using Matlab Simulink. When the torque exceeds exceed the set torque value, the inner current loop controls the switch S2 and stops the motor such that drilling is stopped. By varying the torque values over a period, the performance of the inner loop is studied. The transient state properties of the outer speed control loop using PI Controller are measured from the simulation results. The simulation results are shown in Fig. 4. To examine the robustness of the outer chopper control loop, various speed values are set and the corresponding values are tabulated in table 1.

VI. Conclusion

A closed loop chopper controlled system with inner current control loop and outer speed control loop is presented. The inner current control loop is tested for its effectiveness by varying the torque values and the results infer that the motor is stopped when there is sudden increase in torque. The outer speed control loop employed with PI controller is simulated and the properties of its transient state response are tabulated for various speed values. The results conclude that the response of the proposed system makes this system to be suitable and can be employed for the three phases of the screw placements in orthopedic surgeries.

References


Table: 1 Performance of PI Controller

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Speed = 600 rpm</th>
<th>Speed = 900 rpm</th>
<th>Speed = 1200 rpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Peak Overshoot (%)</td>
<td>10.2</td>
<td>9.9</td>
<td>7.2</td>
</tr>
<tr>
<td>Steady State Error (%)</td>
<td>0.8</td>
<td>1</td>
<td>1.2</td>
</tr>
<tr>
<td>Rise time (s)</td>
<td>0.067</td>
<td>0.065</td>
<td>0.065</td>
</tr>
<tr>
<td>Settling time (s)</td>
<td>0.35</td>
<td>0.33</td>
<td>0.33</td>
</tr>
</tbody>
</table>

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