A Comparative Analysis of PI, PID and Anti-Windup PI Schemes for PMDC Motors

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ABSTRACT

Orthopedic surgical simulators are used by the trainee surgeons to drill the bones and place the screws. These simulators use PMDC motors for bone drilling. In this paper the performance of a closed loop chopper controlled drive is evaluated. The chopper controlled drive has an inner current control loop and an outer speed control loop. The outer control loop employs a PI, PID and anti-windup PI controller for the speed control of the PMDC motor. A comparative study is made between conventional PI, PID and the anti-windup PI controllers. The system is simulated using Matlab/Simulink and the properties of these controllers were measured and tabulated. The simulation results inferred that the proposed closed loop system with anti-windup PI controller gives better performance and the system can be used for the control of the PMDC motor in orthopedic surgeries.

Keywords

Anti-Windup PI controllers, Back Calculation, Chopper, Dead Zone, Maximum peak overshoot, Orthopedic surgical simulator, PI, Tracking, PMDC Motor, Rise time, Steady state error, Settling time.

1. INTRODUCTION

Novice surgeons practice drilling and screw placements in cadaver bones rather than live patients. The use of orthopedic surgical simulators for practicing drilling and screwing can help for such practices [1], [2] & [3]. The drilling and screwing of bones depends on the resistive force offered by the bones and the screw geometry respectively [3], [4], [5] & [6]. The resistive force offered by the un-fractured bones will be more while that of the fractured will be less. The screwing of the bones is done in three phases namely insertion, tightening and stripping [1], [2], & [6]. Different torque and speed combinations are needed for optimal placement of screws.

In the surgical simulators PMDC motors are used, because of their linear speed torque characteristics. The mathematical model of the motor is derived [7] & [8]. The speed control of the motor is employed with P, PI and PID controllers for various applications which include rock drilling and robotics [6-10]. A closed loop chopper control drive using PI controller was developed and analysed for various speed and torque values. [11]. The conventional PI controller doesn't have any magnitude limiter. This causes the integral windup phenomenon. This windup problem can be reduced by using anti-windup scheme. In this scheme the integrator output is limited within a specific range. [12-13]. The performance of the modified system using anti-windup PI controller is evaluated. [14]. The PID controller based closed loop drive was simulated and analysed [15].

In this paper, a comparative study is attempted on the performance of the drive system with PI, anti-windup PI and PID controllers.

2. MATHEMATICAL MODEL OF THE PMDC MOTOR

The advantages of PMDC motor include linear speed – torque characteristics with high stalling torque and reduced power loss. Due to these advantages the PMDC motors are widely used in orthopedic surgical simulators. The mathematical model of the motor is derived from the following equations [7-10].

$$V=E+IaRa+La\frac{dIa}{dt} \quad (1)$$

$$E=K_1\omega \quad (2)$$

$$T_E=T_L+B\omega+J\frac{d\omega}{dt} \quad (3)$$

$$T_E=K_2Ia \quad (4)$$

Where,

R_a = Armature Resistance in Ohms
L_a = Armature Inductance in H
I_a = Armature Current in A
E = Back EMF in Volts
K_1 = Voltage Constant in volts sec/rads
ω = Angular Speed in rads/sec
T_E = Electromagnetic torque developed in Nm
T_L = Load torque in Nm
J = Moment of Inertia in kg.m^2/s^2
B = Damping Coefficient in Nms
K_2 = Torque Constant in Nm/A

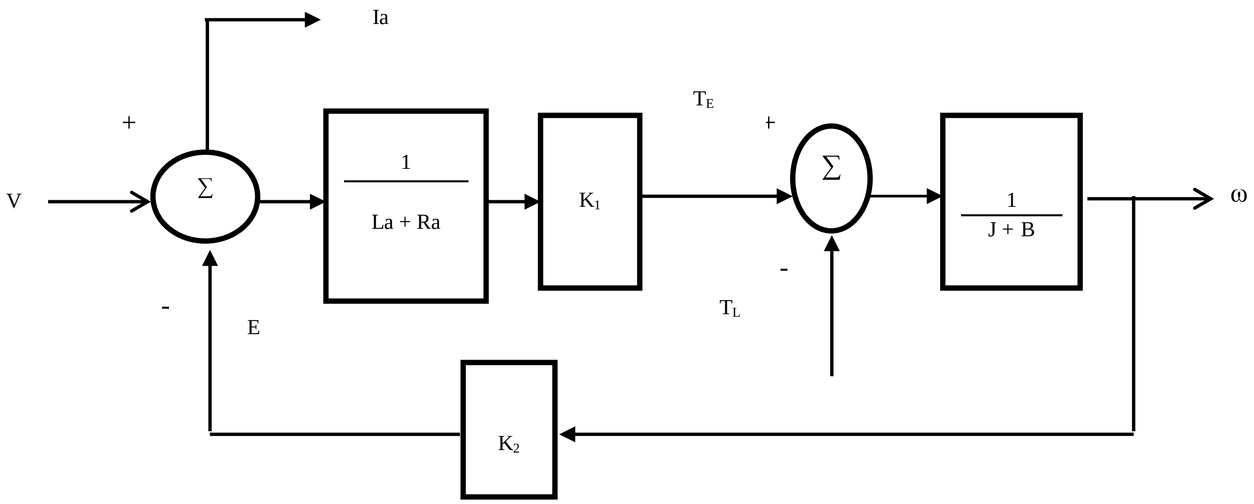

Fig.1: Mathematical Model of PMDC Motor

3. PROPOSED SYSTEM

3.1. Inner Current Control loop

The block diagram of the proposed closed loop chopper controlled system is shown in figure 2. The system consists of an inner current control loop and an outer speed control loop, with two power electronic switches S1 and S2. The inner current control loop is meant for ON/OFF control of the switch S2. The torque required for drilling and the screw placements differs for fractured and un-fractured bones. The un-fractured bones have good strength and so the resistive force required by them increases. This in-turn increase the torque required to drill them. During surgery the un-fractured bones should not be drilled. In PMDC motors torque is a function of current. Here torque is measured in terms of current and compared with the set value. The difference between the set value and the present values drives the hysteresis controller and the controller controls switch S2. During drilling or screwing when the drill bit reaches or touches the un-fractured bone the torque required increases. This increase in torque is sensed and compared with the set value and the error is processed by the hysteresis controller. As the torque value is increased, the controller generates appropriate pulse to switch off the switch S2.

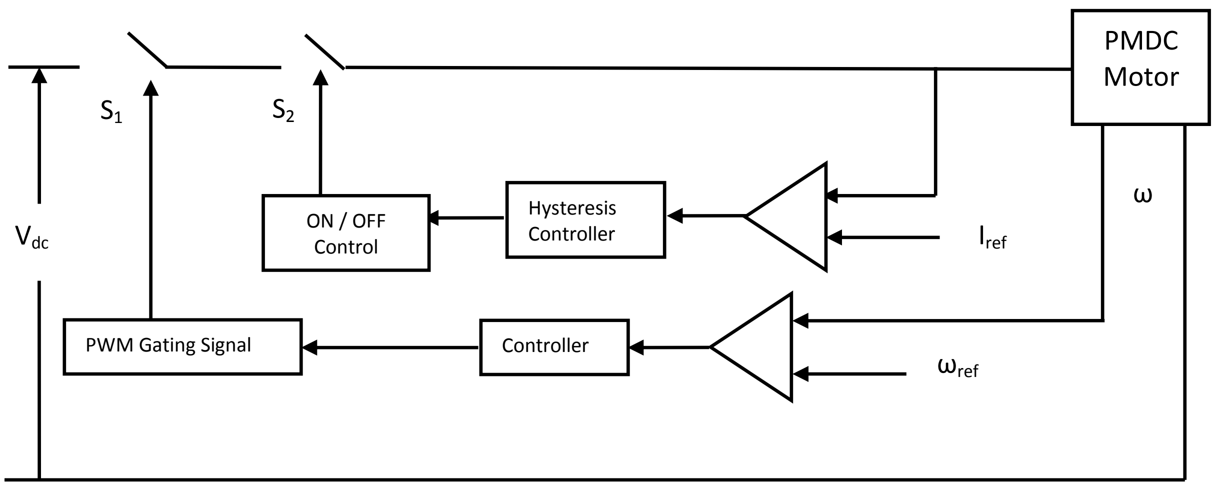

Fig.2: Block Diagram of the Proposed System

3.2 Outer Speed Control Loop

The three phases of screwing such as insertion, tightening and stripping needs three different levels of speed in the motor. Based on the operation the value of speed is set. The current speed of the motor is sensed and is compared with the set value. The error is processed by PI, anti-windup PI or PID controllers, which in-turn generates the required PWM signal for the switch S1. The switch S1 generates the required voltage for the motor and thus the speed of the motor is controlled.

4. SIMULATION MODEL

The Matlab Simulink model of the proposed system 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 propotional gain and integral gain values are fixed by Zeigler-Nichols method of tuning the PI and PID controllers. The hysteresis controller acts as an ON/OFF controller for switch S2 based on the torque values.

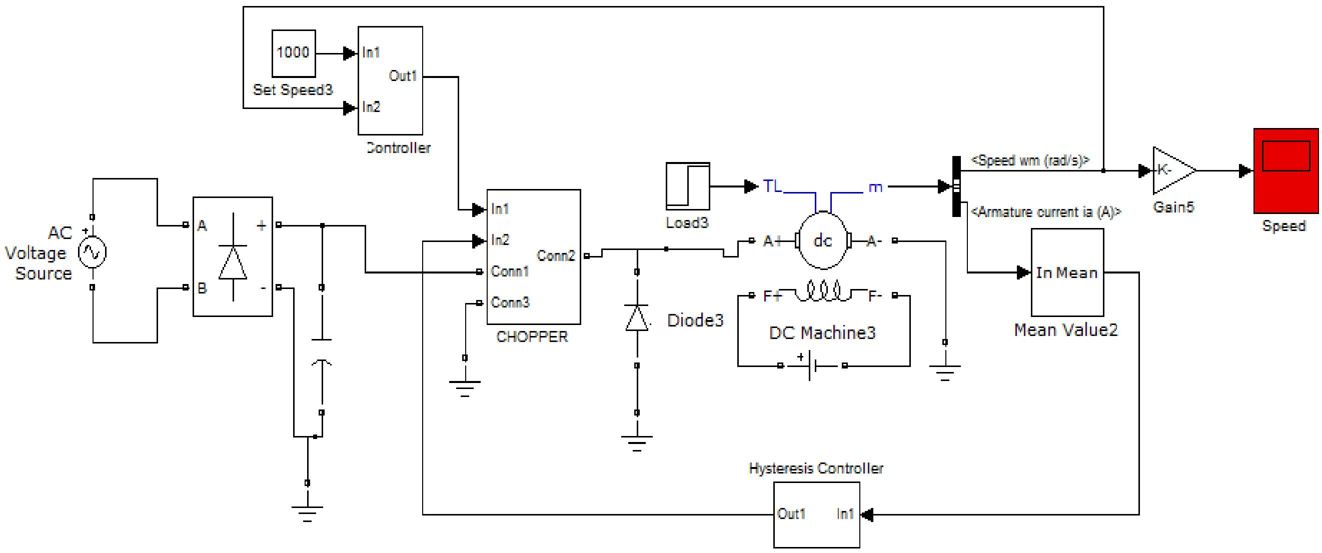

Fig.3: Matlab / Simulink Model of the System

5. SIMULATION RESULTS

The model of the PMDC motor and the control circuit is developed and simulated using Matlab/Simulink. To examine the performance of the inner current control loop, the torque is varied over a period. When there is a sudden increase in torque, the hysteresis controller switches off S2 and the speed becomes zero. This makes the drilling to be stopped. The outer speed control system is employed with PI, anti-windup PI and PID controllers. The set speed values were varied and the performance for different speed ranges were analysed. The same speed ranges were used for the three controllers and their transient state performances were studied.

The response of the system with PI controller is shown in figure 4. The comparative response of the PI and anti-windup PI controllers is shown id figure 5. From the comparative analysis it is clear that the maximum peak overshoot of the system is reduced with the anti-windup PI controller. From the simulation results the transient state parameters are tabulated as given in table 1. The tabulated values show that there is a reduction in the maximum peak overshoot and also in the steady state error of the system in case of anti-windup PI compared to conventional PI and PID controllers.

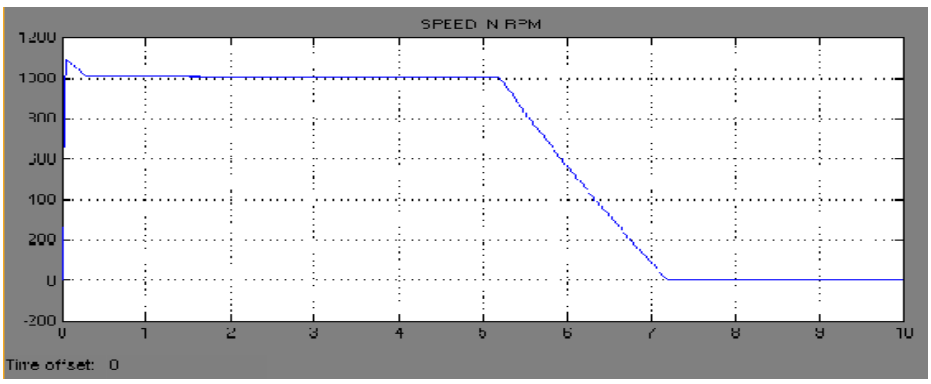

Fig. 4: Response of the system with PI Controller

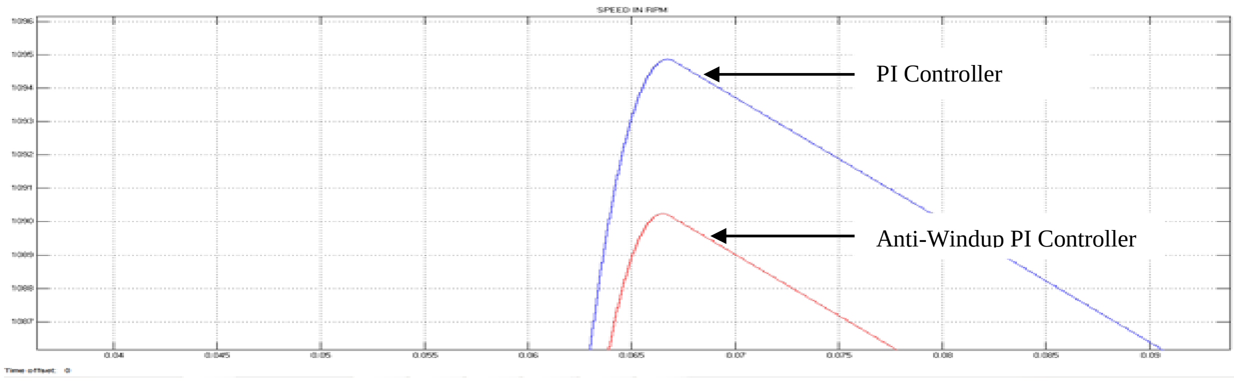

Fig. 5: Comparison of PI and Anti-Windup PI Controllers Response

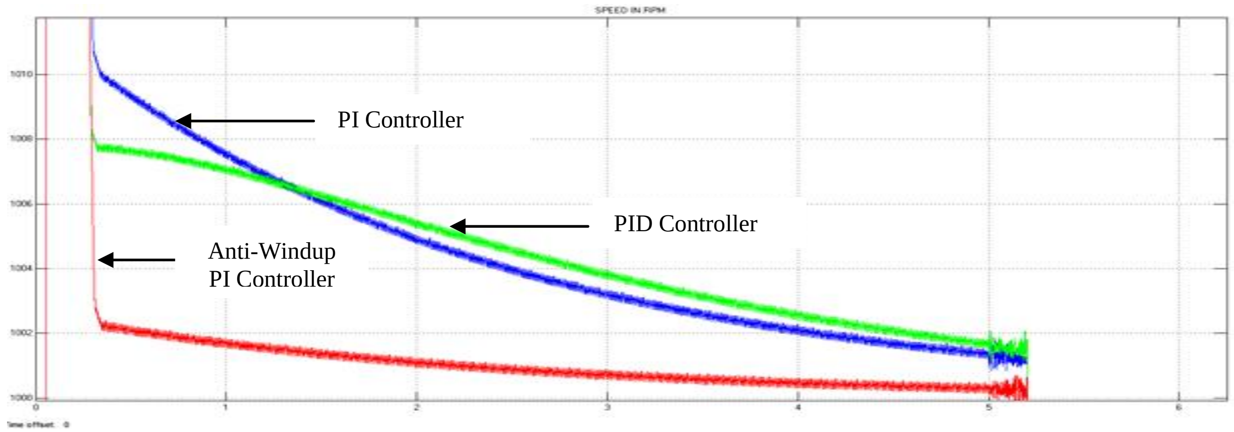

Fig. 6: Comparison of Steady State Response of PI, PID and Anti-Windup PI Controllers

Table 1. – Performances of PI and PID Controllers

Parameter	Speed = 900 rpm			Speed = 1000 rpm			Speed = 1200 rpm		
	PI	PID	AWPI	PI	PID	AWPI	PI	PID	AWPI
Maximum Peak Overshoot (%)	9.9	9.7	9.3	9.5	9.2	8.9	7.2	6.9	6.7
Steady State Error (%)	1	0.3	0.22	1.1	0.3	0.16	1.2	0.21	0.16

6. CONCLUSION

The closed loop chopper controlled PMDC motor system with inner current control and outer speed control loops are presented. The simulation results implicit that the speed becomes zero as soon as the torque is increased beyond the set value. The performance of the outer speed loop with PI and PID techniques are simulated and the results were compared. The comparative results show that using PID controller the transient response is improved with reduced maximum peak overshoot and steady state error. It is concluded that, the system with inner current loop and outer speed loop with PID controller can be used with improved transient state performance in orthopedic surgical simulators.

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