

Proportional Integral and Derivative Control of Brushless DC Motor

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Abstract

Brushless DC (BLDC) motors are one of the electrical drives that are rapidly gaining popularity, due to their high efficiency, good dynamic response and low maintenance. In this paper, the modeling and simulation of the BLDC motor was done using the software package MATLAB/SIMULINK. A speed controller has been designed successfully for closed loop operation of the BLDC motor so that the motor runs very closed to the reference speed. The simulated system has a fast response with small overshoot and zero steady state error.

Keywords: PID Controller; BLDC motor; Mathematical model;

1. Introduction

Since the late 1980's new design concept of permanent magnet brushless motors has been developed. The permanent magnet brushless motor can be classified upon to the back-EMF waveform, where it can be operated in either brushless AC (BLAC) or brushless DC (BLDC) modes. Usually the BLAC motors have a sinusoidal back-EMF waveform and BLDC motors have a trapezoidal back-EMF. In modern electrical machines industry productions the brushless direct current (BLDC) motors are rapidly gaining popularity. BLDC motors are used in industries such as Appliances, HVAC industry, medical, electric traction, road vehicles, aircrafts, military equipment, hard disk drive, etc. Comparing BLDC motors with DC motors, the DC motor have high starting torque capability, smooth speed control and the ability to control their torque and flux easily and independently. In the DC motor, the power losses occur mainly in the rotor which limits the heat transfer and consequently the armature winding current density, while in BLDC motor the power losses are practically all in the stator where heat can be easily transferred through the frame, or cooling systems can be used specially in large machines. In general the induction motor has many advantages as: their simplest construction, simple maintenance, low price and reliability. Furthermore, the disadvantages of induction machines make the BLDC motors more efficient to use and become more attractive option than induction motors. Some of the disadvantages of induction machines are poor dynamic characteristics, lower torque at lower speeds and lower efficiency

It is assumed that the BLDC motor is connected to the output of the inverter, while the inverter input terminals are connected to a constant supply voltage, as shown in Fig.1. Another assumption is that there are no power losses in the inverter and the 3-phase motor winding is connected in star.

Applying Kirchhoff's voltage law for the three phase stator loop winding circuits yields:

$$v_c = R_c i_c + L_c \frac{di_c}{dt} + M_{ca} \frac{di_a}{dt} + M_{cb} \frac{di_b}{dt} + e_c \quad (3)$$

$$e = K_e \omega_m \quad (4)$$

Where K_e is the back-emf constant.

So the BLDC motor mathematical model can be represented by the following equation in matrix form:

$$\begin{bmatrix} L_a & M_{ab} & M_{ac} \\ M_{ba} & L_b & M_{bc} \\ M_{ca} & M_{cb} & L_c \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} - \begin{bmatrix} R_a & 0 & 0 \\ 0 & R_b & 0 \\ 0 & 0 & R_c \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} - \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (5)$$

If we assume that the rotor has a surface-mounted design, which is generally the case for today's BLDC motors, there is no saliency such that the stator self inductances are independent of the rotor position, hence:

$$L_a = L_b = L_c = L$$

And the mutual inductances will have the form:

$$M_{ab} = M_{ac} = M_{ba} = M_{bc} = M_{ca} = M_{cb} = M$$

Assuming three phase balanced system, all the phase resistances are equal:

$$R_a = R_b = R_c = R$$

Rearranging the equation (5) yields;

$$\begin{bmatrix} L & M & M \\ M & L & M \\ M & M & L \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} - \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} - \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (6)$$

The electromechanical torque is expressed as

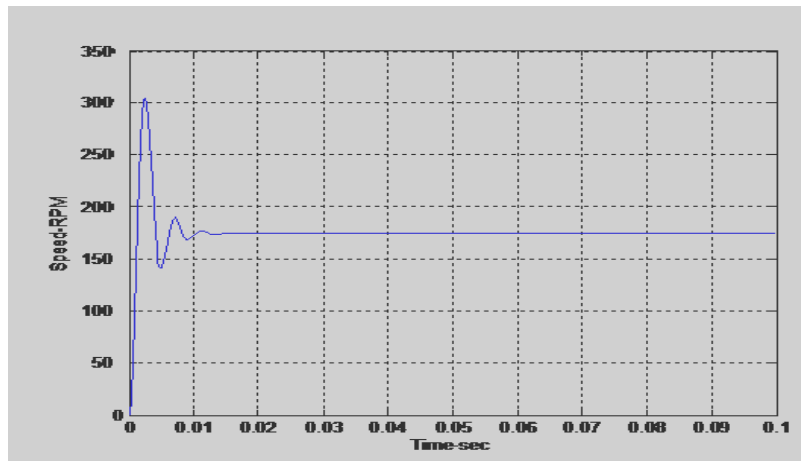
$$T_{em} = J \frac{d\omega_r}{dt} + B\omega_r + T_L \quad (7)$$

But the electromagnetic torque for this 3-phase BLDC motor is dependent on the current, speed and back-EMF waveforms, so the instantaneous electromagnetic torque can be represented as:

$$T_{em} = \frac{1}{\omega_m} (e_a i_a + e_b i_b + e_c i_c) \quad (8)$$

The simulation of the BLDC motor was done using the software package MATLAB/SIMULINK. After running the simulation, the speed, torque, current, waveforms were recorded and analyzed. Fig. 3 shows the open loop response of the motor.

Figure 3: Open loop response



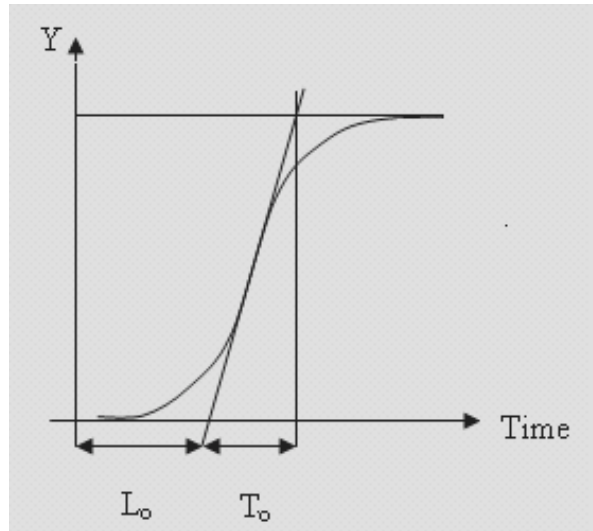
3. PID Controller

PID control is a proportional integral plus derivative controller whose transfer function is:

$$G_{PID}(s) = K_p \left(1 + \frac{1}{T_i s} + T_d s \right) \quad (9)$$

The selection of the Proportional Integral and Derivative (PID) controller parameters can be obtained using the Ziegler-Nichols methods. Depending on the values of as shown in fig. 4 and using the Ziegler-Nichols tables, we can find the PID parameters.

Figure 4: Ziegler-Nichols PIS Parameters



Now, using the following equations, the PID parameters can be derived:

$$K_p = 1.2 \frac{T_o}{L_o} \quad (10)$$

$$T_i = 2L_o \quad (11)$$

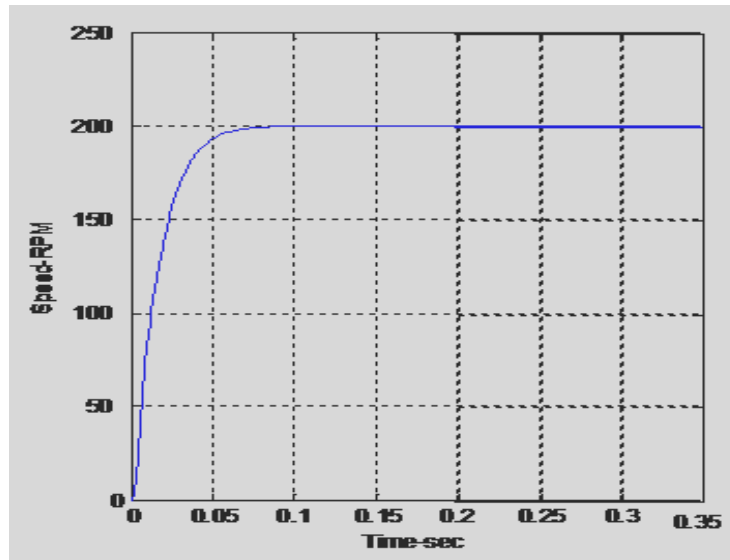
$$T_D = 0.5L_o \quad (12)$$

4. Simulations and Results Analysis

A simulation of a brushless DC motor system with the PID gains calculated using the above equations was performed using MATLAB. The calculated gains of PID control are provided in Table 1. The speed response is shown in Figure 5. So it can be concluded that a direct PI tuning method is suitable to designate self-tuning technique for BLDC motor, where the overshoot in the motor speed response approximately zero and the error steady state is also go to zero.

Table 1: PID Parameters

PID GAINS	Values
K_p	9
T_i	0.04
T_D	0.01

Figure 5: The motor response using PI controller

5. Conclusions

In this paper, a mathematical model of brushless DC motor is developed. The simulation of the brushless DC motor was done using the software package MATLAB/SIMULINK. Also PID control based on the Ziegler-Nichols method is presented and applied to brushless DC motor. This method is feasible due to the unique and simplified structure of this motor. The PID controller designed has been simulated and observed to have good performance, where the results show that the overshoot before adding the PI control was 71% but after adding PI control the maximum overshoot was approximately zero which is a good result. So a speed controller has been designed successfully for closed loop operation of the BLDC motor and the motor runs very closed to the reference speed.

References

- [1] J. R. Hendershort Jr and T. J. E. Miller, Design of Brushless Permanent-Magnet Motors, Oxford, U.K.: Magana Physics/Clarendon, 1994.
- [2] Microchip Technology, "Brushless DC (BLDC) motor fundamentals", Application note, AN885, 2003.
- [3] S. Lin, C. Bi, Q. Jiang, and H. N. Phyu, " Analysis of Three Synchronous Drive Modes for the Starting Performance of Spindle Motors", IEEE Transactions on Magnetics, Vol. 43, No. 9, 2007
- [4] Abdullah Al Mamun, GuoXiao Guo, Chao Bi, Hard disk drive mechatronics and Control, CRC Press, 2007
- [5] Ben M. Chen, Tong H. Lee, Kemao Peng and Venkatakrishnan Venkataramanan, Hard Disk Drive Servo Systems, Springer-Verlag London Limited, 2006
- [6] Jacek F. Gieras, Rong-Jie Wang and Maarten J. Kamper, Axial Flux Permanent Magnet Brushless Machines, Springer Science and Business Media B.V, 2008
- [7] Tae-Sung Kim, Byoung-Gun Park, Dong-Myung Lee, Ji-Su Ryu, and Dong-Seok Hyun, " A New Approach to Sensorless Control Method for Brushless DC Motors", International Journal of Control, Automation, and Systems, August 2008
- [8] J. X. Shen, K. J. Tseng, " Analyses and Compensation of Rotor Position Detection Error in Sensorless PM Brushless DC Motor Drives", IEEE Tran. On energy conversion, Vol. 18, No. 1, March 2003
- [9] Gunhee Jang and M. G. Kim (2005), a Bipolar-Starting and Unipolar-Running Method to Drive a Hard Disk Drive Spindle Motor at High Speed With Large Starting Torque, IEEE TRANSACTIONS ON MAGNETICS, VOL. 41, NO. 2, 2005
- [10] Quan Jiang, Chao Bi, and Ruoyu Huang, 2005, a New Phase-Delay-Free Method to Detect Back EMF Zero-Crossing Points for Sensorless Control of Spindle Motors IEEE Transactions on Magnetics, VOL. 41, NO. 7, JULY 2005