International Journal of Engineering and Technical Research (IJETR)
ISSN: 2321-0869 (O) 2454-4698 (P), Volume-3, Issue-8, August 2015

Research on Fractional Order Adaptive Speed Control for Brushless DC Motor Drives

Wen Jianping, Cao Xiangang

Abstract—**in order to enhance the static and dynamic performances and robustness of the brushless DC motor (BLDCM) drives, this paper introduces a new control scheme for speed control. Fractional order integral and active disturbance rejection controller (ADRC) technology are applied to establish the speed loop controller. Fractional order integral replaces the nonlinear state error feedback control law that uses nonlinear function combination in ADRC, which can utilize the characteristics of fractional order calculus describing the physical object more nearly and spreading the stable domain of the system parameters. Simulation results verify that the proposed control method has given good dynamic response and robustness.**

***Index Terms*—Active disturbance rejection control, brushless DC motor, fractional order calculus, speed Servo.**

I. INTRODUCTION

BLDCM is increasingly used in high precise servo system and small power driving system due to its simple structures, speed conveniently, high power density and lower electromagnetic pollution [1-2]. These applications have raised higher requirements with fast dynamic response, robustness and stability precision of MLDCM speed control. PI control can hardly meet the requirement of high performances although it was widely used. Some new control strategieshave been developed and applied to the speed control of speed servo drives to obtain high driving performance. Predictive function control based on ARMAX model and fractional order PI is used to improve the performance of the BLDCM [3]. To depress influence of the disturbances to BLDCM, the variable structure controller having an extended state observer is presented [4]. In order to improve the PI control, fuzzy control is combined with PI control [5-6]. Variable structure control law and repetitive control law are synthesized to improve the rate smoothness of BLDCM driven systems [7]. Adaptive control exists complex adaptive control law. Chattering phenomenon can be caused in a conventional sliding mode control system. Active disturbance rejection control technique is applied in BLDCM speed servo system [8], which can design the controller of controlled object by using order of model, but not becoming dependent. It improves the response by using extended state observer to estimate and compensate disturbances.

Fractional order calculus extends integer order ones to non-integral order, which can model various real materials more nearly than integer order ones. This study introduces fractional order calculus into ADRC. Fractional order proportional integral control replaces the nonlinear state error feedback control law using nonlinear function combination in ADRC, which can synthesize the high performance of ADRC estimating disturbances with the characteristics of fractional order calculus spreading the stable domain of the system parameters. The bilinear transformation and continued fraction expansion are used to obtain discrete fractional order integral model. Simulation results verify that the proposed control scheme has given good speed response characteristics.

II. ADRC OF BLDCM DRIVES

The mathematical model of BLDCM can be obtained according to the following assumption.

Assumption 1: star connected windings, no neutral line,

Assumption 2: ignoring cogging effect, homogeneous distribution windings.

Assumption 3: ignoring saturation of magnetic circuit and eddy-current loss and magnetic hysteresis loss, no damping winding on rotor.

The voltage equation of stator windings is expressed as [9]:

$$\begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} = Z \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + pN \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \tag{1}$$

where, p is differential operator, u_a, u_b and u_c are phase voltages of three-phase stator windings, respectively, i_a 、i_b 、i_c are phase currents of three-phase stator windings, respectively, e_a, e_b and e_c are back-emf three-phase stator windings, respectively. Parameters Z and N are denoted as, respectively:

$$Z = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix}$$

$$N = \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix}$$

where R is resistance of the stator windings, L is self-inductance of the stator windings, M is mutual inductance of the stator windings.

Electromagnetic torque is given by:

$$T_e = \frac{2 p_n e_m i_m}{\omega_r} \tag{2}$$

where, e_m is amplitude of the back-emf; i_m is amplitude of phase currents, ω_r is angular velocity of the rotor; p_n is

Wen Jianping, School of Mechanical Engineering, Xi'an University of Science and Technology, xi'an, China

Cao Xiangang, School of Mechanical Engineering, Xi'an University of Science and Technology, xi'an, China

This study is supported by the Key Laboratory of Express-way Construction Machinery (Chang'an University), Shaanxi province, no. 310825151135.

number of pole pairs.

$$\frac{d\omega_r}{dt} = \frac{1}{J}(T_e - F\omega_r - T_L) \tag{3}$$

where, J is combined inertia of rotor and load; F is combined viscous friction of rotor and load; T_L is shaft load torque.

III. Design of Fractional Order ADRC

A. ADRC model of BLDCM

Let's plug (2) into (3) yields

$$\begin{aligned}\frac{d\omega_r}{dt} &= \frac{1}{J}\left(\frac{2p_n e_m}{\omega_r} i_m - F\omega_r - T_L\right)\\ &= F_k + w_d + \frac{1}{J\omega_r} i_m\end{aligned} \tag{4}$$

where, $F_k = -F\omega_r$; $w_d = -\frac{T_L}{J} + \frac{1}{J}\frac{2p_n e_m - 1}{\omega_r} i_m$.

The second-order ESO for ω_r is constructed as follows:

$$\begin{cases} e_d = z_{d1} - \omega_r \\ \dot{z}_{d1} = F_k + z_{d2} - \beta_{d1} fal(e_d, 0.5, \delta) + \dfrac{i_m}{J\omega_r} \\ \dot{z}_{d2} = -\beta_{d2} fal(e_d, 0.25, \delta) \end{cases} \tag{5}$$

where, ω_r is actual measured value; z_{d1} is estimate of ω_r; z_{d2} is estimate of w_d; β_{d1} and β_{d2} are adjustable parameters which are determined by sampling time; $\delta = 0.01$.

PI control law can be described as:

$$i_{od} = K_p(z_{d1} - \omega_r^*) + K_i \int (z_{d1} - \omega_r^*) dt \tag{6}$$

where, K_p and K_i are proportion coefficient and integral coefficient respectively.

The control input i_d for BLDCM drives is expressed as:

$$i_d = J\omega_r[i_{od} - (F_k + z_{d2})] \tag{7}$$

Substituting (7) into (4) yields

$$\dot{\omega}_r = i_{od} \tag{8}$$

B. Fractional order PI control law

Fractional order calculus can be expressed in calculus operator of fractional order and integral order [10]

$$D_t^{\lambda} = \begin{cases} d^{\lambda}/dt^{\lambda}, & \mathrm{R}(\lambda) > 0 \\ 1, & \mathrm{R}(\lambda) = 0 \\ \int_a^t (d\tau)^{-\lambda}, & \mathrm{R}(\lambda) < 0 \end{cases} \tag{9}$$

where a is lower bound of calculus operator; t is upper bound of calculus operator; λ is order number of calculus operator; order number of calculus equals to integral order when λ is integer; $R(\lambda)$ represents real number; D_t^{λ} indicates fractional differentiation when $R(\lambda)$ is greater than zero; D_t^{λ} indicates fractional differentiation when $R(\lambda)$ is less than zero.

The fractional order PI control law in ADRC can be expressed as

$$i_{od} = K_p(z_{d1} - \omega_r^*) + K_i D_t^{-\lambda}(z_{d1} - \omega_r^*) \tag{10}$$

To obtain discrete mathematical model of numerical control to be used, it is required that fractional order integral operator is discretized. Using bilinear transformation method, the fractional order system can be discretized into irrational equation of z, which is then transformed in the continued fraction expansion way to obtain discrete model of $s^{-\lambda}$. When λ equals to 0.4, sampling period equals 0.001 sec and the order of the polynomial function equals 6, the approximate discretized model of fractional order integral is obtained as follows

$$Z\left(s^{-0.4}\right) \approx \frac{nu}{de} \tag{11}$$

where nu and de are expressed as follows

$nu = -2.69 - 1.08z^{-1} + 3.48z^{-2} + 1.09z^{-3} - 1.09z^{-4} - 0.21z^{-5} + 0.05z^{-6}$

$de = -56.36 + 22.54z^{-1} + 72.75z^{-2} - 22.79z^{-3} - 22.73z^{-4} + 4.33z^{-5} + z^{-6}$

The block diagram of BLDCM drives is shown in Fig. 2.

IV. Simulation Analysis

In this section, the proposed control scheme is tested by means of simulations. The data of BLDCM are as follows: the stator inductances are 8.5 mH; the stator resistance is 0.2 Ω; the flux by magnet is 0.175 Wb; the number of poles is 4; the moment of inertia is 0.012 kg·m^2; sampling period of current loop is set to 2 μs.

To verify dynamic performance and robustness, a reference step input of 100 rad/s is applied at t = 0.01 s. A load disturbance of 30Nm is used at t = 0.6 s.

Fig. 2 shows speed response of BLDCM when no load is applied. The fractional order ADRC (FO ADRC) controller gives fast speed response and smaller overshoot.

Fig. 3 shows the speed response of BLDCM when load disturbance is applied. The designed algorithm has better performance to resist disturbance. The amplitude of undershoot is much lower and the time of speed adjustability is much lower.

Fig. 4 shows the phase current of motor stator when FO ADRC controller is applied to control the BLDCM drives. Fig. 4 shows the phase current of motor stator when PI controller is applied to control the BLDCM drives.

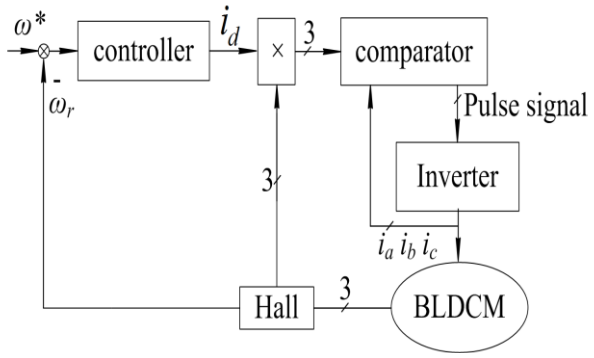

Fig. 1 The block diagram of BLDCM drives

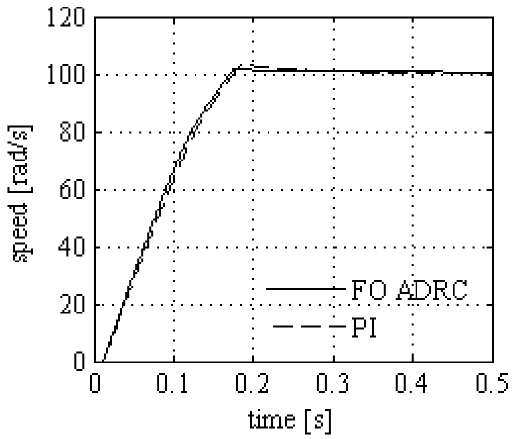

Fig. 2 speed step response in no-load

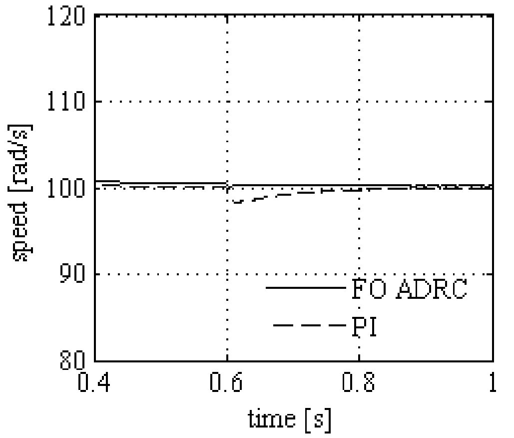

Fig. 3 speed response to load disturbances

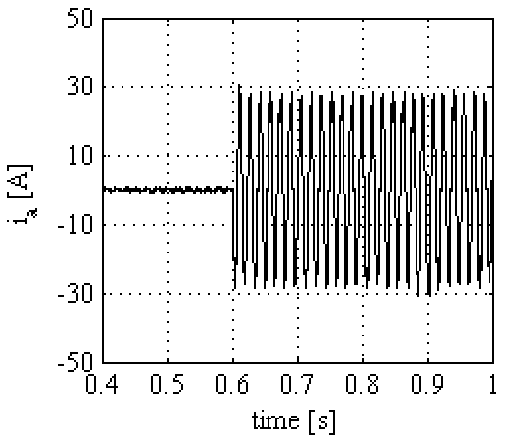

Fig. 4 the phase current curve (FO ADRC)

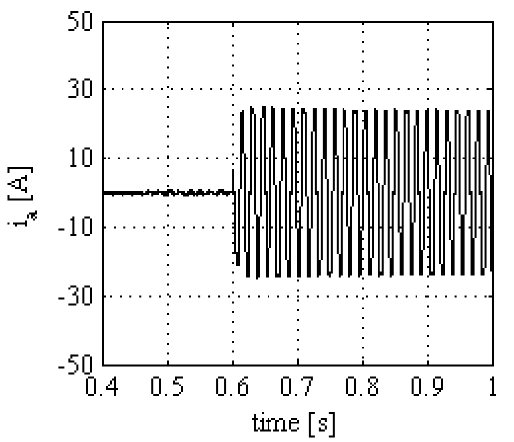

Fig. 5 the phase current (PI controller)

V. Conclusions

This paper proposes a new speed control algorithm for BLDCM drives. Fractional order integral is introduced to active rejection disturbance control to replace the nonlinear state error feedback control. The fractional order integral is discretized into irrational equation of *z* by using the bilinear transformation. Then, the irrational model is transformed in continued fraction expansion way to get discrete model. Simulation results show the effectiveness of the proposed algorithm.

References

[1] A. S. O. Al-Mashakbeh, "Proportional Integral Derivative Control of Brushless DC Motor," *European Journal of Scientific Research*, vol. 35, no. 2, 2009, pp. 198 - 203.

[2] F. Rodriguez, and A. Emadi, "A Novel Digital Control Technique for Brushless DC Motor Drives," *IEEE Trans. on Industrial Electronics*, vol. 54, no. 5, Oct. 2007, pp. 2365 – 2373.

[3] W. Guo, Y. Chen, L. Zhou, and J. Ni, "Fractinal-order PI Predictive Function Control Research of the Brushless DC Motor," *Journal of Wuhan University of Technology*, 2013, vol. 35, no. 4, pp. 130 - 135.

[4] C. Xia, J. Liu, W. Yu, and Z. Li, "Variable structure control of BLDCM based on extended state observer," *The IEEE International Conf. on Mechatronics and Automation*, vol. 2, Aug. 2005, pp. 568 – 571.

[5] Z. Ji, Y. Chen, and J. Jiang, "A Novel Fuzzy PI Intelligent Control Method of BLDCM Speed Servo System," *Electric Machines and Control*, vol. 7, no. 3, Sept. 2003, pp. 248 – 254.

[6] R. Arulmzhiyal, and R. Handiban, "Design of Fuzzy PID Controller for Brushless DC Motor," *the International Conf. on Computer Communication and Informatics*, Jan. 2012, pp. 1-7.

[7] Y. Liu, B. Su, and M. Zeng, "A Robust Repetitive Control Approach for Improvement of Rate Smoothness of BLDCM Driven Systems," *Proceeding of the CSEE*, vol. 25, no. 10, May 2005, pp. 144 – 148.

[8] Q. Dong, and Q. Li, "Current Control of BLDCM Based on Fuzzy Adaptive ADRC," *The Ninth International Conf. on Hybrid Intelligent Systems*, vol. 3, Aug. 2009, pp. 12 – 14.

[9] B. Abdi, H. Baharami, and S. Mirtalaei, "Simplified Design and Optimization of Slotless Brushless DC Machine for Micro-satellites Eelectro-mechanical Batteries," *Journal of Electrical Engineering and Technology*, vol. 8, no. 1, Jul. 2013, pp. 124 - 129.

[10] M. Kleinz, and T. J. Osler, "A Child's Garden of Fractional Derivatives," *The college mathematics journal*, vol. 31, no. 2, 2000, pp. 82-88.

Wen Jianping He received the Ph. D. degree in mechanical engineering from Xi'an Jiaorong University. His research interests in the areas of the technology on the control of drive for EV.

Cao Xiangang His research interests in the areas of equipment state monitoring and fault diagnosis technology.