Nonlinear Feedback Speed Control for Series Excited DC Motor Drives

Jian-Ping Wen, Le Xing

Abstract—**This paper introduces the nonlinear feedback speed control system of series excited DC motor based on auto disturbance rejection control technology to improve the performance of speed closed loop control, in which speed and current double closed loop structure containing outer speed loop and inner current loop are applied to regulate the motor speed. In the speed loop, the nonlinear dynamic changing process of speed and current of the motor is converted into linear function by using the extended state observer and nonlinear state error feedback control law. The current controller adopts pulse width modulation to produce pulse signal, which is used to control the DC chopper. In MATLAB/Simulink platform, the simulating model is established and implemented in the dynamic operating state. Compared with the conventional PI controller, the results show that the nonlinear feedback speed controller has the better robustness.**

Index Terms—**Series excited DC motor, auto disturbance rejection control (ADRC), speed control, nonlinear feedback**

I. INTRODUCTION

Series excited DC motor has been widely used in frequency starting and speed regulation fields because of its inherent advantages such as large starting torque, simple construction, strong overload ability, and AC-DC dual-purpose [1].

The torque-speed characteristic of series excited DC motor has a big change, which is likely to cause operating speed out of control in open-loop operating mode [2]. So, building the closed loop control is essential. The conventional PID controller plays an important role in the control system of many industrial applications [3]. But when the parameters variations, including control parameters, motor parameters, and load condition, occur, the PID controller causes the control effectiveness to fail and even lose balance. To achieve good dynamic response at the presence of external disturbances, some control strategies have been addressed. The three parameters of the PID controller can be specified. To reduce these parameter tuning efforts, the fuzzy control, the genetic algorithms, and artificial neural network (ANN) are proposed to adjust and optimize the three parameters [4-6]. The fuzzy logics have been adopted to enhance control performance because of its auto optimization function. The learning capability of ANN has been utilized to make PID controller self-tuning. Besides, the fuzzy neural network has been proposed in [7]. These intelligent optimization techniques seem to be effective in some applied situations, but they need sophisticated training. to fulfill the nonlinear system requirement, auto disturbance rejection control (ADRC) theory is developed [8-9], which fuses the conventional proportional integral derivative control technique, modern control theory and nonlinear control mechanisms,.

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In this paper, a novel approach is presented by applying the extended state and nonlinear state feedback with ADRC technology to design a outer speed loop control for enhancing control performance. a extended state is proposed to observe the disturbance of the series DC motor and compensate it. The first-order differential equation has been established, which describes the relationship of rotor speed and armature current. The simulation model is modeled in MATLAB/Simulink. Simulation studies are carried out to verify the controller.

II. MATHEMATICAL MODEL OF SERIES EXCITED DC MOTOR

The dynamic model for the series excited DC motor is given as follows [10]:

$$U_a = i_a R_s + L_s \frac{di_a}{dt} + e_b + e_r \tag{1}$$

where U_a is terminal voltage of the armature windings series the field windings, i_a is the armature current, R_s is a sum of the armature winding resistance and the field winding resistance, L_a is the armature winding inductance, L_f is the field winding inductance, M_{af} is mutual inductance, $L_s = L_a + L_f + 2M_{af}$, e_b is back-electromotive force, and e_r is electromotive force.

$$e_b = k_a i_a \omega \tag{2}$$

$$e_r = k_r \omega \tag{3}$$

where k_a is armature voltage factor, k_r is residual flux factor, ω is the angular speed of the rotor.

The electric torque is

$$T_{em} = J\frac{d\omega}{dt} + B\omega + T_L \tag{4}$$

where J is the moment of inertia, B is the damping coefficient, T_L is the load torque.

The armature current equals the field current. the equation can also be expressed as

$$T_{em} = k_a i_a^2 \tag{5}$$

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III. THE ADRC SPEED CONTROL OF SEIRES EXCITED DC MOTOR

A. ADRC

The ADRC consists of the tracking differentiator (TD), the nonlinear state error feedback control law (NLSEF), the extended state observer (ESO). The ADRC scheme of a second order system is shown Fig. 1. v is input signal, y is output signal, e_0 is error integral signal, e_1 is error signal, e_2 is error differential signal, u is controlled input, v_1 is approximately the input signal; v_2 is the differential signal of input signal; b is system parameter. z_1 and z_2 are observation of v_1 and v_2 respectively, z_3 is the extended state variable.

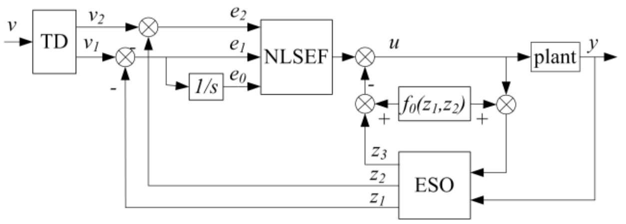


Fig. 1 The ADRC frame of second order system

B. Design of the ADRC Speed Controller

Applying (5) to (4) yields

$$\dot{\omega} = -\frac{1}{J}(B\omega + T_L) + \frac{1}{J}k_a i_a^2 \tag{6}$$

Now (6) is be written as follows

$$\dot{\omega} = w_d + \frac{1}{J}k_a i_a^2 \tag{7}$$

where w_d is the disturbances.

The second-order ESO for ω is constructed as follows

$$\begin{cases} e_d = z_{d1} - \omega \\ \dot{z}_{d1} = z_{d2} - \beta_{d1} fal(e_d, 0.5, \delta) + \dfrac{k_a i_a^2}{J} \\ \dot{z}_{d2} = -\beta_{d2} fal(e_d, 0.25, \delta) \end{cases} \tag{8}$$

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

The NLSEF is presented by

$$\begin{cases} \Delta\omega = z_{d1} - \omega^* \\ i_{oa} = k_d\, fal(\Delta\omega, 0.5, \delta) \end{cases} \tag{9}$$

where ω^* is angular speed reference, k_d is adjustable parameter.

The control input i_a is expressed as

$$i_a = \sqrt{\frac{k_a}{J}(i_{oa}^2 - z_{d2})} \tag{10}$$

Substituting (10) into (7) yields

$$\dot{\omega} = i_{od}^2 \tag{11}$$

The estimator of the extended state is fed back to the control input via disturbance compensation which makes speed model into a linear integral model.

IV. RESULTS AND DISCUSSION

The proposed control scheme is implemented in this section. A simulation model of the series excited DC motor is modeled and implemented using Matlab/Simulink to verify the proposed ADRC control method, as well as in comparison with standard PI controller.

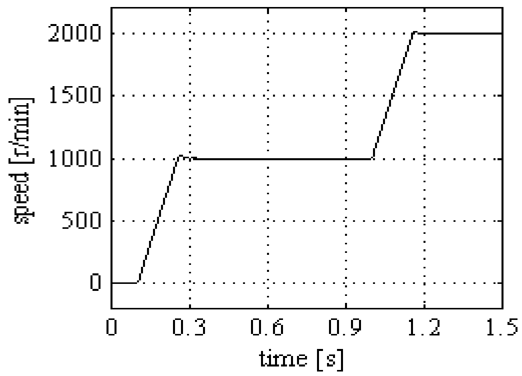
The parameter values of series excited DC motor are given as follows, nominal power is , nominal voltage is 48V, nominal current is 72A, nominal speed is 2800 r/min, nominal torque is 10Nm. Sampling time is 1ms,

The dynamic performance is tested under load 2Nm. A reference step input of 1000 r/min is first applied at t = 0.1 s. Then, the step input from 1000/min to 2000r/min is used at t = 1 s. The results are shown in Fig. 2.

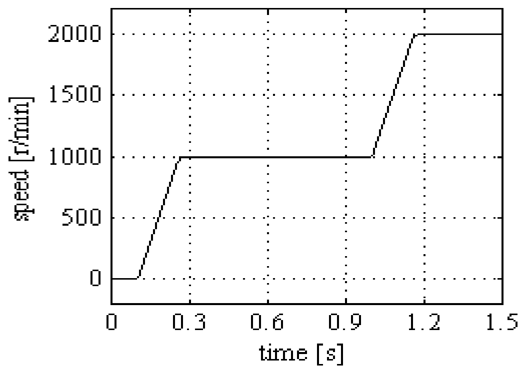
The ADRC controller gives fast speed response and smaller overshoot.

When the motor runs at stable operation of 1400 r/min (half of the nominal speed), a load disturbance of 10 Nm is used at t = 0.8 s. the results are shown fig. 3.

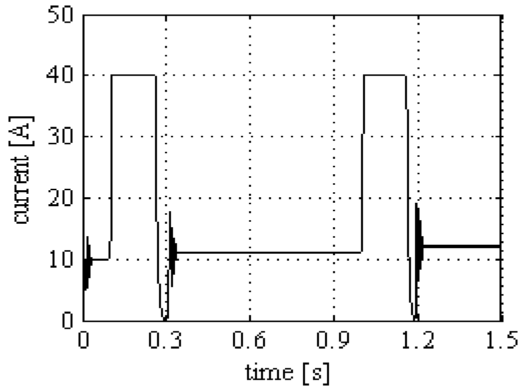
The designed algorithm, ADRC controller, has better performance to resist disturbance. The amplitude of undershoot is much lower and the time of speed adjustability is much lower.



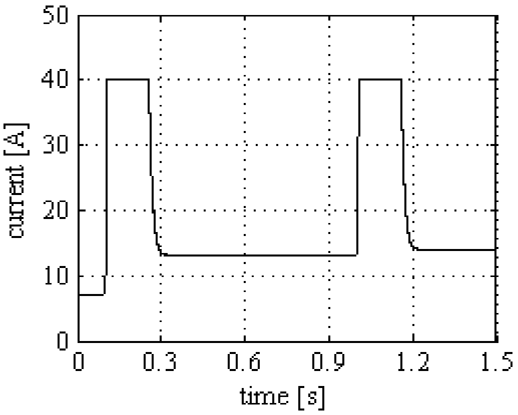
(a) speed response of DC motor by PI controller



(b) speed response of DC motor by ADRC controller

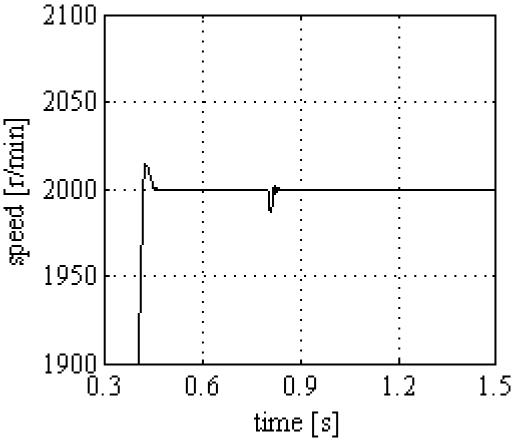


(c) current curve of DC motor by PI controller

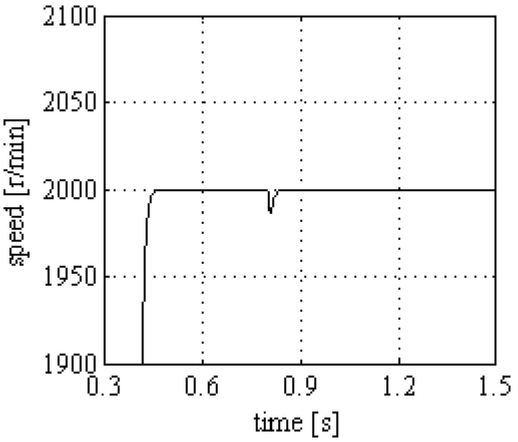


(d) current curve of DC motor by ADRC controller

Fig. 2 step response of series excited DC motor



(a) speed response of DC motor under load disturbance by PI controller



(b) speed response of DC motor under load disturbance by ADRC controller

Fig. 3 speed response of series excited DC motor with load disturbance

V. Conclusion

This paper proposes a new speed control algorithm for series excited DC motor drives. Active rejection disturbance control technique is applied to the outer speed loop control. Using the extended state variable, the disturbance of the speed control system is observed, which is compensated in the output signal of nonlinear state feedback controller. The model of speed and armature current is modeled. Simulation model is established. Simulation experiment results show the effectiveness of the proposed algorithm.

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