The Adaptive Control of Drive System for HS2000 Electric Vehicle

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Abstract
The drive system of electric vehicle (EV) will suffer various disturbances inevitably during its driving process. In order to overcome the variety of the load, an adaptive control scheme for drive system is developed, and it is applied to the design of HS2000EV's controller. The satisfied result is obtained from the simulations.

Keywords
electric vehicle, drive system, adaptive control

1. INTRODUCTION
The drive system of induction motor is the heart of electric vehicle, which affects the dynamic performance directly. In order to gain the ideal dynamic behavior, we must have good control technique [Cirrincione et al., 2005; Lascu et al., 2000]. The traditional linear control (such as PID control) hasn't satisfied the high performance request for drive system. Considering of the complexity of induction motor rotating magnetic field, the torque of load, the variety of magnetic flux, and so on, the drive control system of electric vehicle with the model reference adaptive control (MRAC) technique will be designed. There are some papers about MRAC controller about resisting interference, such as [Wu, 2000] aiming to measurable interference; [Wu et al., 2005] aiming to result the unmeasurable interference. The latter adopt various forms to imitates the interference such as polynomial, sine, cosine, step, exponential functions or the integration of them. A new MRAC control scheme which regards the changing load as interference is proposed. Without any intimation, the control scheme matchs the actual circumstance well. Simulation shows the feasibility.

2. THE MATHEMATICS MODEL
Take the electric car HS2000 in [Zhai et al., 2003] as an example and establish its mathematics model as follows. The parameters of the induction motor are showed in the Table 1.

Table 1 The parameters of the induction motor

Parameter	Unit	Symbol	Value
Rated power	kw	P_n	30
Rated frequency	Hz	f_n	120
Rated voltage	V	U_n	200
Primary resistance	Ω	R_1	0.0109
Primary inductance	H	L_s	0.008
Secondary resistance	Ω	R_2	0.01436
Secondary inductance	H	L_r	0.01472
mutual inductance	H	L_m	0.0138
Total inertia	Kg. m^2	J	0.379
Number of pole pairs		n_p	2

The equivalent plant is consisted of current loop and motor. When the load is constant, the transfer function of the control plant is described by:

$$G_p(p) = \frac{Y_p(s)}{U_p(s)} = \frac{155}{0.00734s^2 + s} \quad (1)$$

The index of the drive system performance is required as: M_p=20%, t_s=2s. where, M_p is called overshoot which represents the maximum instantaneous amount by which the step response exceeds its final value; t_s is settling time that means the time elapsed until the response enters (without leaving it afterwards) a specified deviation band, $\pm\delta$, around the final value.

The reference model takes the form as below: F

$$G_m(p) = \frac{Y_m(s)}{U_r(s)} = \frac{20.89}{s^2 + 45.7s + 20.89} \quad (2)$$

where, the output of reference model $Y_m(s)$ is the rotating speed of motor, the control input $U_r(s)$ is regular speed. After calculating, the model can meet the requirement of the system performance.

3. THE DESIGN OF MRAC SYSTEM

Consider the equation of the reference model is:

$$A_m(p)Y_m(t) = B_m(p)r(t) \quad (3)$$

here, $A_m(p) = p^n + \sum_{i=0}^{n-1} a_i p^i$, $B_m(p) = \sum_{i=0}^{m_2} b_i p^i$.

$m_2 \le n-1$

a_i, b_i are chosen to be constants; r and Y_m are the input and output of the reference model, respectively. The input $r(t)$ is continuous in subsection and bounded; $p = d/dt$ is the differential operator.

The control plant is given by equation (4) :

$$A_p(p)Y_p(t) = B_p(p)u_p(t) + A_L(p)L(t) \quad (4)$$

And $L(t)$ is the measurable interference of the system.

$$A_p(p) = p^n + \sum_{i=0}^{n-1} \alpha_i p^i \quad B_p(p) = \sum_{i=0}^{m_1} \beta_i p^i \quad m_1 \le n-1$$

here, α_i, β_i, γ_i are unknown and constant or slowly time-varying. Suppose $t \in [0, \infty)$, and the variety of α_i is known.

The target to design the MRACS is: for any input $r(t)$ which is bounded consistently and continuous in subsection, we can find the reference signal with any original conditions, the output error between the model and the plant $e(t)$ goes to zero, $\lim_{t\to\infty} e(t) = 0$.

where, $e(t) = Y_m(t) - Y_p(t) \quad (5)$

The structure of the adaptive control system is constructed as Figure 1. Accoring to the text [Wu et al., 2005], we can prove the controller is rational. That is to say, there are the adaptive parameters k_i, q_i that can make the plant transfer function match to the model.

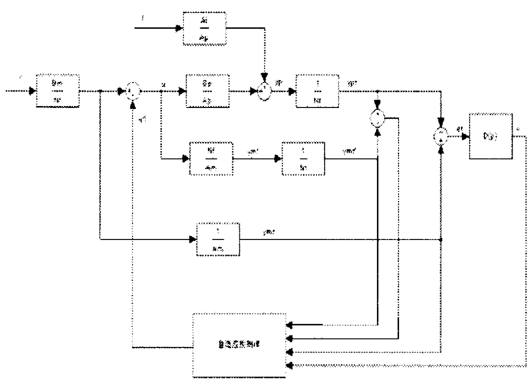

Fig. 1 Frame diagram of MRAC system

From Figure 1,we can get $\frac{B_m(p)}{N_f(p)} r(t) = u(t) + u_1(t)$, put it into function (3), and add $A_p(p)Y_m(t)$ from the two sides contemporarily, we can get

$$A_p(p)Y_m(t) + A_m(p)Y_m(t) = A_p(p)Y_m(t) + N_f(p)[u(t) + u_1(t)] \quad (6)$$

Solving function (6)-(4) and put the function (5) into it yields

$$A_p(p)e(t) = N_f(p)u(t) + N_f(p)u_1(t) + [A_p(p) - A_m(p)]Y_m(t) - [B_p(p)u_p(t) + A_L(p)L(t)] \quad (7)$$

Put $A_p(p)Y_p(t) = B_p(p)u_p(t) + A_L(p)L(t)$ and $N_f(p)u(t) = A_m(p)Y_m'(t)$ into function (7), we get

$$A_p(p)e(t) = N_f(p)u_1(t) + A_m(p)Y_m'(t) + [A_p(p) - A_m(p)]Y_m(t) - A_p(p)Y_p(t)] \quad (8)$$

Adding and subtracting $A_p(p)Y_m'(t)$ from the right-hand side of the function (8) give

$$A_p(p)e(t) = N_f(p)u_1(t) + [A_m(p) - A_p(p)]Y_m'(t) + [A_p(p) - A_m(p)]Y_m(t) - A_p(p)[Y_p(t) - Y_m'(t)]$$

Introducing $\varepsilon = Y_p(t) - Y_m'(t)$, and passing the filter $N_f(p) = \sum_{i=0}^{n} f_i p^i$ (f_i is a known constant)

$$A_p(p)e_f(t) = u_1(t) + [A_m(p) - A_p(p)]Y_{mf}'(t) + [A_p(p) - A_m(p)]Y_{mf}(t) - A_p(p)\varepsilon_f \quad (9)$$

where, $e_f = \frac{1}{N_f(p)} e$; $Y_{mf} = \frac{1}{N_f(p)} Y_m$;

$Y_{mf}' = \frac{1}{N_f(p)} Y_m'$; $\varepsilon_f = \frac{1}{N_f(p)} \varepsilon$

Link the linear compensator $D(p)$, then $v=D(p)e$, the equivalent error equation is derived from function (7):

$$v(t) = \frac{D(p)}{A_p(p)} \left\{ u_1(t) + [A_m(p) - A_p(p)]Y_{mf}'(t) + [A_p(p) - A_m(p)]Y_{mf}(t) - A_p(p)\varepsilon_f(t) \right\} \quad (10)$$

Therefore $u_1(t)$ is

$$u_1 = \hat{K}(p)Y_{mf}' + \hat{Q}(p)Y_{mf} + \hat{G}(p)\varepsilon_f \quad (11)$$

Introducing (11) into (10)

$$v(t) = \frac{D(p)}{A_p(p)} \left\{ [\hat{K}(p) + A_m(p) - A_p(p)]Y_{mf}'(t) + [\hat{Q}(p) + A_p(p) - A_m(p)]Y_{mf}(t) \right.$$

$$\left. + [\hat{G}(p) - A_p(p)]\varepsilon_f(t) \right\} \quad (12)$$

where, $\hat{K}(p) = \sum_{i=0}^{n-1} k_i p^i$; $\hat{Q}(p) = \sum_{i=0}^{n-1} q_i p^i$; $\hat{G}(p) = \sum_{i=0}^{n} g_i p^i$

According to the hyperstability theory[Wu et al., 2005; Xu et al., 2004], when the adaptive parameters satisfy the following conditions, function (12) is asymptotically hyperstable:

(1) transfer function $D(p)/A_p(p)$ must be positive real;

(2) the PI adaptation law is:

$$\frac{d}{dt} k_i = -k_{i1} v p^i Y_{mf}' - k_{i2} \frac{d}{dt}(k_{i1} v p^i Y_{mf}')$$

$i = 0, 1, ..., n-1$

$$\frac{d}{dt} q_i = -q_{i1} v p^i Y_{mf} - q_{i2} \frac{d}{dt}(q_{i1} v p^i Y_{mf})$$

$i = 0, 1, ..., n - 1$

$$\frac{d}{dt} g_i = -g_{i1} v p^i \varepsilon_f - g_{i2} \frac{d}{dt}(g_{i1} v p^i \varepsilon_f)$$

$i = 0, 1, ..., n$

The adaptive parameters k_{i1}, k_{i2}, q_{i1}, q_{i2}, g_{i1}, g_{i2} can be chosen any positive constant.

4. SIMULATIONS

The structure of the adaptive drive system is shown in Figure 2. The reference model is shown as function (2). The expression of the process is defined as function (1). The reference input is step signal with $r = 50\text{m.s}^{-1}$. The load interference is selected to be sine signal with 10N.m, other controller parameter values are shown in the block 2. The result of the simulation is described in Figure 3-7. Figure 3 is the figure of time varying magnetic flux; Figure 4 is the supposed load disturbance curve, which is 20% of control input; Figure 5 is output figure with the fixed speed is 50m/s, y_m is the output of the reference model, y_p is the output of the plant. Figure 5 demonstrates the perfect tracing performance when the changing magnetic flux and disturbance are existing; Figure 6 is the output error figure and the error satisfied the request of the system performance within the error permission; Figure 7 is the output figure of traditional PID control. Comparing Figure 6 with Figure 7, the adaptive control system has less melody, shorten adjustable time, stronger ability of resisting disturbance and more desired control effect.

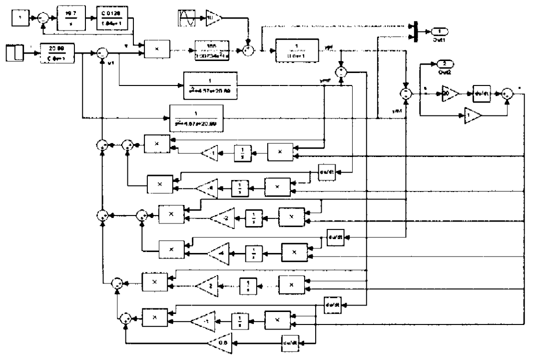

Fig. 2 The configuration of MRAC system

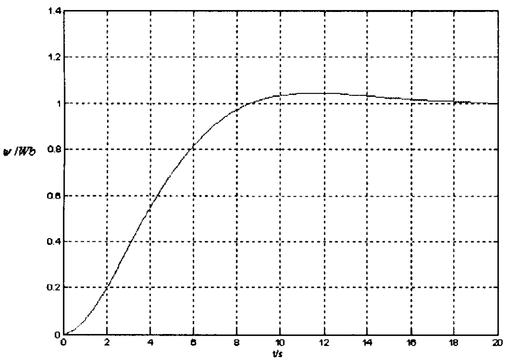

Fig. 3 The figure of magnetic flux

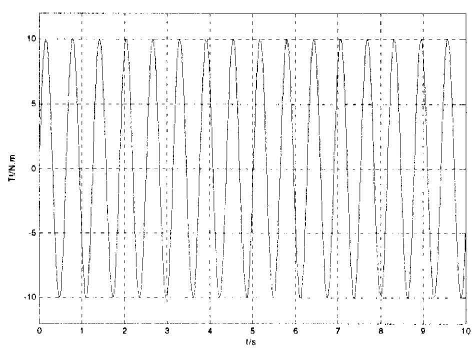

Fig. 4 The figure of load disturbance

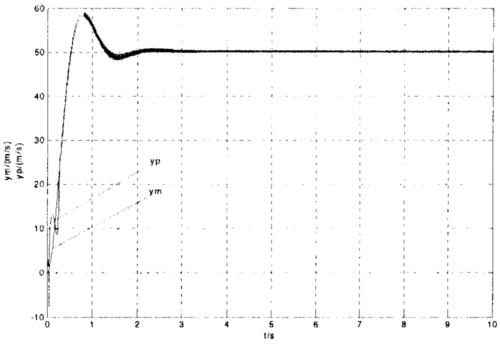

Fig. 5 The output figures of plant and model

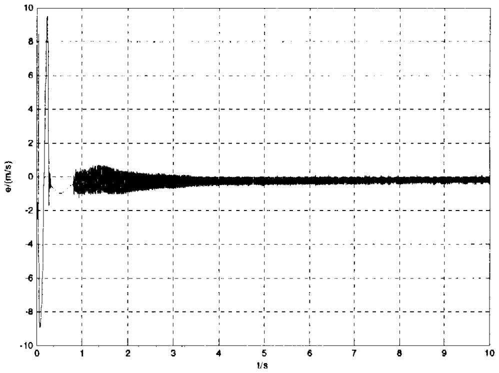

Fig. 6 The figure of output error

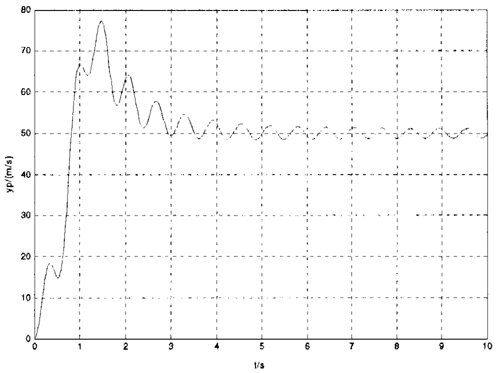

Fig. 7 The output figure of PID controller

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