Adaptive Learning Control of Chaotic Brushless DC Motors

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Abstract

In this paper, the problems of globally asymptotical stability of chaotic brushless DC motors(BLDCM) with single input is studied respectively. Then, by applying adaptive control technology and stability theory, we design three controllers to achieve the stability of the chaotic brushless DC motors. The numerical simulations show the correctness of the proposed methods.

Keywords

brushless DC motors ;single input;; adaptive control technology

1. Introduction

During recent years, there has been significant effort in improving the performance of electricmotors[4]-[8]. In electric traction and most other applications, a wide range of speed and torque control of the electric motor is required. The DC machine fulfills these requirements, but it requires constant maintenance. In the brushless permanent magnet motors, they do not have brushes and so there will be lesser maintenance, brushless DC motors are widely used in applications because of its low inertia, fast response, high reliability and less maintenance. In comparison to classical dc motors, brushless dc motors are very reliable. However, they can also fail which caused by overheating, mechanical wear or disadvantage chaotic phenomena. As we known that chaotic phenomena in numerous natural and social systems have attracted a great interest, very often, chaos in many control systems is a source of instability[1]-[5]. Especially, in the complex industries. In this paper, we will use adaptive control technology to design three single input controllers to stabilize the unstable BLDCM system, and without loss of generality.

The structure of the paper is as follows: In Section 2, the problem of state estimation and control of DC motors is analyzed. In Section 3 adaptive control of chaotic BLDCM with single input is discussed. In Section4, the numerical simulations show the correctness of the proposed methods. Finally, Section 5 is the conclusion.

2. Description of the chaotic BLDCM

In this section, the mathematical dq-model of BLDCM is given by [17]

$$\begin{cases} \frac{di_d}{dt} = u_d - \delta i_d + i_q w \\ \frac{di_q}{dt} = u_q - i_q + i_d w + \gamma w \\ \frac{dw}{dt} = \sigma(i_q - w) - T_L \end{cases} \tag{2.1}$$

where variables i_q,i_d and w denote angle speed, quadrature and direct axis current of the motor, respectively. δ and σ are positive parameters, which determine the type of the dynamical regime of the motor. If the motor is running freely under no loading conditions, it hold that $u_q = 0, u_d = 0$and $T_L = 0$.For simplification of our discussion, let$x_1 = i_d, x_2 = i_q, x_3 = w$,system (2.1) becomes:

$$\begin{cases} \dot{x_1} = -\delta x_1 + x_2 x_3, \\ \dot{x_2} = -x_2 - x_1 x_3 + \gamma x_3, \\ \dot{x_3} = \sigma(x_2 - x_3), \end{cases} \tag{2.2}$$

For the purpose to study the stability property at zero equilibrium point, add controllers *ui*(*i* =1, 2, 3) to system (2.2), one can obtain that:

$$\begin{cases} \dot{x_1} = -\delta x_1 + x_2 x_3 + u_1, \\ \dot{x_2} = -x_2 - x_1 x_3 + \gamma x_3 + u_2, \\ \dot{x_3} = \sigma(x_2 - x_3) + u_3, \end{cases} \tag{2.3}$$

3. Adaptive control of chaotic BLDCM with single input

In this section, by using the adaptive controller with single input, we will study the stability property of the chaotic BLDCM at zero equilibrium point.

If the parameter γ in system (2.3) is uncertain, let $\hat{\gamma}$be the estimate of the uncertain parameter γ,and $\tilde{\gamma} = \hat{\gamma} - \gamma$,one can construct the following controlled system:

$$\begin{cases} \dot{x_1} = -\delta x_1 + x_2 x_3 + u, \\ \dot{x_2} = -x_2 - x_1 x_3 + (\hat{\gamma} - \tilde{\gamma}) x_3 + u_2, \\ \dot{x_3} = \sigma(x_2 - x_3) + u_3, \end{cases} \tag{3.1}$$

Theorem3.1 If the following adaptive controller is added to system (3.1)

$$\begin{cases} u_1 = u_3 = 0, \\ u_2 = -(\hat{\gamma} + \sigma) x_3, \\ \dot{\hat{\gamma}} = \dot{\tilde{\gamma}} = x_2 x_3 \end{cases} \tag{3.2}$$

Then, the controlled system (3.1) is globally asymptotically stable at the zero equilibrium point.

Proof: Construct the radially unbounded and positive Lyapunov function:

$$V_1 = \frac{1}{2}(x_1^2 + x_2^2 + x_3^2 + \tilde{\gamma}^2) \tag{3.3}$$

The derivative of V_1, taking into account of the model (3.1) and controller (3.2), is found to be

$$\dot{V_1} = x_1 \dot{x_1} + x_2 \dot{x_2} + x_3 \dot{x_3} + \tilde{\gamma}\dot{\tilde{\gamma}} \quad = x_1(-\delta x_1 + x_2 x_3) + x_2(-x_2 - x_1 x_3 + \hat{\gamma} x_3 - \tilde{\gamma} x_3 - (\hat{\gamma} + \sigma) x_3 + x_3 \sigma(x_2 - x_3) + \tilde{\gamma} x_2 x_3) \quad (3.4) \ = -\delta x_1^2 - x_2^2 - \sigma x_3^2 \le 0$$

By LaSalle-Yoshizawa theorem [18], one obtains that

$$\lim_{t\to\infty}(\delta x_1^2 + x_2^2 + \sigma x_3^2) = 0$$

So, the controlled system (3.2) is globally asymptotically stable at the zero equilibrium point

If the parameter σ in system (3.1) is uncertain, one has:

$$\begin{cases} \dot{x_1} = -\delta x_1 + x_2 x_3 + u_1, \\ \dot{x_2} = -x_2 - x_1 x_3 + \gamma x_3 + u_2, \\ \dot{x_3} = (\hat{\sigma} - \tilde{\sigma})(x_2 - x_3) + u_3, \end{cases} \tag{3.5}$$

where $\hat{\sigma}$ is the estimate of the uncertain parameter σ, $\tilde{\sigma} = \hat{\sigma} - \sigma$.

Theorem 3.2 If the following adaptive controller is added to system (3.4)

$$\begin{cases} u_1 = u_3 = 0, \\ u_2 = -(\hat{\sigma} + \gamma) x_2 + (\hat{\sigma} - 1) x_3, \\ \dot{\hat{\sigma}} = \dot{\tilde{\sigma}} = x_3(x_2 - x_3) \end{cases} \tag{3.6}$$

the controlled system (3.5) is globally asymptotically stable at the zero equilibrium point.

Proof: Construct the radially unbounded positive Lyapunov function:

$$V_2 = \frac{1}{2}(x_1^2 + x_2^2 + x_3^2 + \tilde{\sigma}^2) \tag{3.7}$$

Taking the derivative of V_2 along system (3.5) with controller (3.6), it has

$$\dot{V_2} = x_1\dot{x_1} + x_2\dot{x_2} + x_3\dot{x_3} + \tilde{\sigma}\dot{\tilde{\sigma}} = x_1(-\delta x_1 + x_2x_3) + x_2(-x_2 - x_1x_3 + \gamma x_3) + x_3((\hat{\sigma} - \tilde{\sigma})(x_2 - x_3) - \hat{\sigma}(x_2 - x_3) - \gamma x_2 - x_3) + \tilde{\sigma}x_3(x_2 - x_3) \quad (3.8) = -\delta x_1^2 - x_2^2 - \sigma x_3^2 \le 0$$

Similarly, one has

$$\lim_{t\to\infty}(\delta x_1^2 + x_2^2 + x_3^2) = 0$$

Then, the controlled system (3.5) is globally asymptotically stable at the zero equilibrium point.
If the parameter δ in system (3.1) is uncertain, one can construct the following controlled system.

$$\begin{cases} \dot{x_1} = -(\hat{\delta} - \tilde{\delta})x_1 + x_2x_3 + u_1, \\ \dot{x_2} = -x_2 - x_1x_3 + \gamma x_3 + u_2, \\ \dot{x_3} = \sigma(x_2 - x_3) + u_3, \end{cases} \quad (3.9)$$

where $\hat{\delta}$ is the estimate of the uncertain parameter δ, $\tilde{\delta} = \hat{\delta} - \delta$.

Theorem 3.3 If the following adaptive controller is added to system (3.9)

$$\begin{cases} u_1 = -\frac{\gamma+\sigma}{x_1}x_2x_3 + \hat{\delta}x_1 - x_1 \\ u_2 = u_3 = 0 \\ \dot{\hat{\delta}} = \dot{\tilde{\delta}} = -x_1^2 \end{cases} \quad (3.10)$$

the controlled system (3.9) is globally asymptotically stable at the zero equilibrium point.

Proof: Construct the radially unbounded positive Lyapunov function:

$$V_3 = \frac{1}{2}(x_1^2 + x_2^2 + x_3^2 + \tilde{\delta}^2) \quad (3.11)$$

The derivative of V_3, taking into account the model (3.9) and controller (3.10), is found to be

$$\dot{V_3} = x_1\dot{x_1} + x_2\dot{x_2} + x_3\dot{x_3} + \tilde{\delta}\dot{\tilde{\delta}} = x_1\left(\hat{\delta}x_1 - \tilde{\delta}x_1 + x_2x_3\right) - \frac{\gamma+\sigma}{x_1}x_2x_3 + \hat{\delta}x_1 - x_1 + x_2\left(-x_2 - x_1x_3 + \gamma x_3\right) + x_3\left(\sigma(x_2 - x_3)\right) - \tilde{\delta}x_1^2 \quad (3.12) = -x_1^2 - x_2^2 - \sigma x_3^2 \le 0$$

Similarly, one has

$$\lim_{t\to\infty}(\delta x_1^2 + x_2^2 + x_3^2) = 0$$

Then, the controlled system (3.9) is globally asymptotically stable at the zero equilibrium point.

Remark 3.1 Since the controller (3.10) contains the term $\frac{\gamma+\sigma}{x_1}x_2x_3$, the control gain will approach 1 .if x1 approach zero. Then, controller (3.10) is not a good control input to solve the problem, and wewill use two control input to solve it in the next section.x1

4. Numerical Simulations

In this section, several examples are proposed to illustrate the theoretical results obtained in the preceding sections. A fourth order Runge-Kutta method is used to obtain the simulation results with MATLAB software.

For the BLDCM system (2.1), let $\delta = 0.875, \gamma = 55. \sigma = 4.35$ the initial state *x*(0) = 0, *y*(0) =2, *z*(0) = 1.

Single-input:

Fig.1 shows the state track of system (3.2) with controller (**??**), Fig.2 shows the convergence estimates of the parameters γ, Fig.3 shows the state track of system (3.5) with controller (3.6), Fig.4 shows the convergence estimates of the parameters σ, Fig.5 shows the state track of system (3.9) with controller (3.10), Fig.6 shows the convergence estimates of the parameters δ.

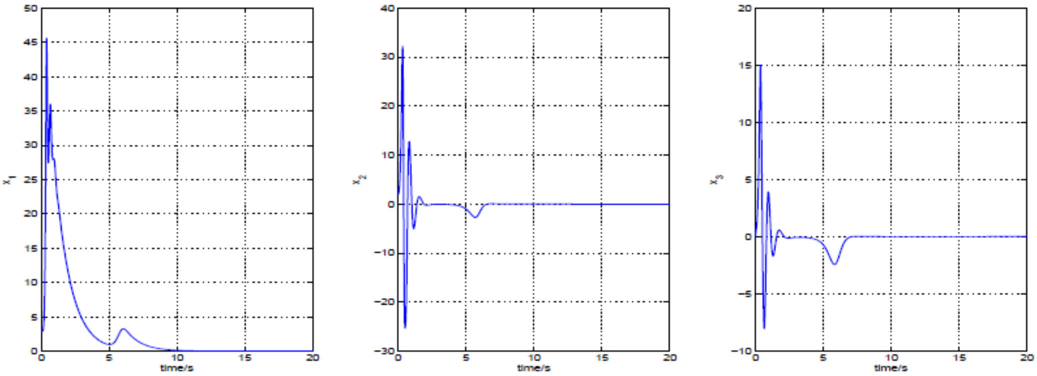

Figure1. the state track of system (3.2) with controller(??)

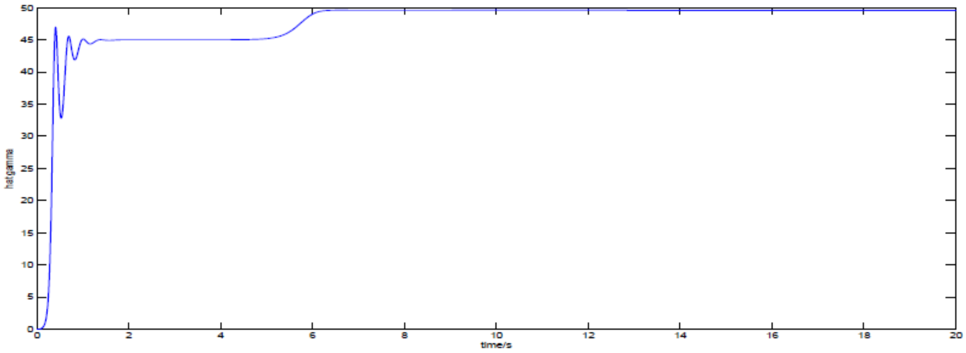

Figure 2. The convergence estimates of the parameters

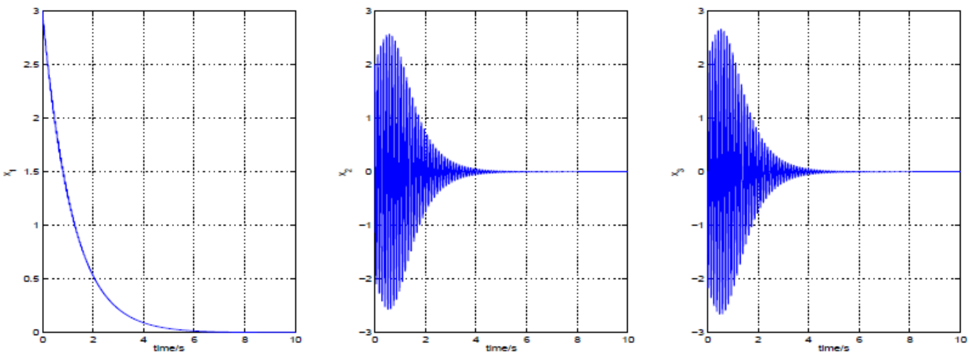

Figure 3: the state track of system (3.5) with controller (3.6)

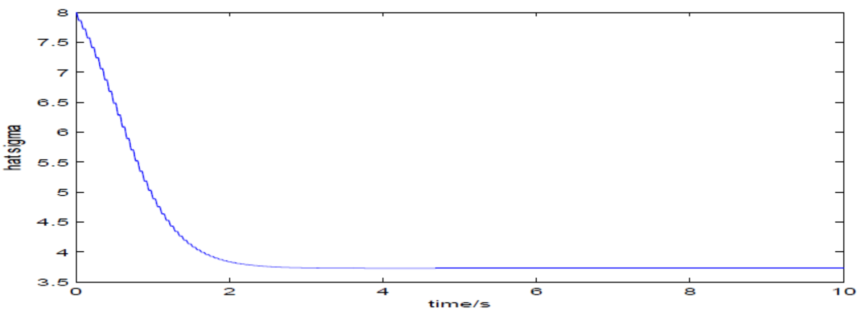

Figure 4. The convergence estimates of the parameters σ

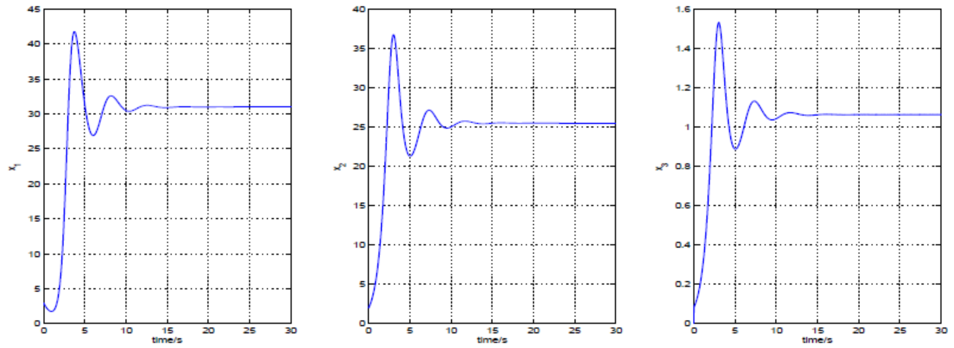

Figure 5.the state track of system (3.9) with controller (3.10)

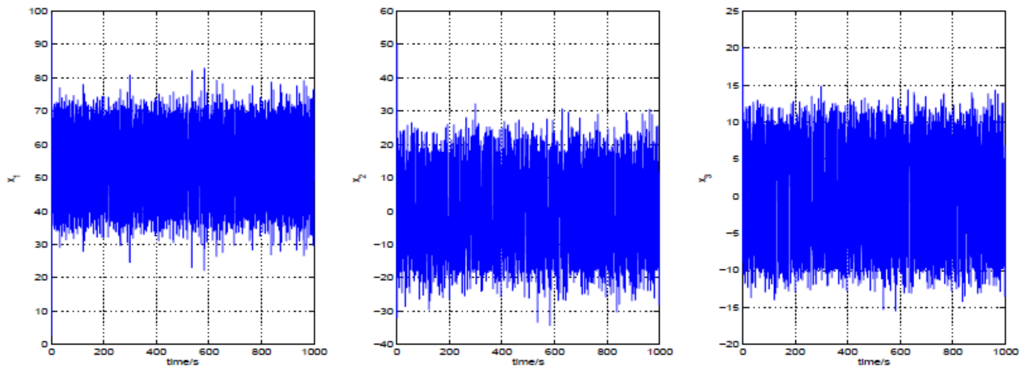

Figure 6. The convergence estimates of parameters δ

5. Conclusion

In this paper, the problems of globally asymptotical stability of chaotic brushless DC motors (BLDCM) with single input or multiple input is studied respectively. Then, by applying adaptive control technology and stability theory, we design seven controllers to achieve the stability of the chaotic brushless DC motors, from the numerical simulations we can know that no matter the single-input or multiple-input, the state trajectory convergence time is very fast, however, the cost of multiple-input is higher than the single-input and the difficulty of the controller is greatly reduced.

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