Indonesian Journal of Electrical Engineering and Computer Science
Vol. 19, No. 2, August 2020, pp. 723~728
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v19.i2.pp723-728

The MRAC based - adaptive control system for controlling the speed of direct current motor

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Article Info

Article history:

Received Jan 1, 2020
Revised Mar 2, 2020
Accepted Mar 16, 2020

Keywords:

DC motor
MARC
PID control
Speed control

ABSTRACT

This research aims to propose an adaptive control system for controlling the speed of the Direct Current (DC) motor. The system consists of two control loops: the first control loop is a traditional PID controller and the second control loop is an adaptive controller. The role of the adaptive controller is adjusting the output of the control object follows with the output of the reference model. The adjustment mechanism is very simple, but the quality of the whole system is very high: the conversion time is short and there isn't overshoot. The quality of the proposed adaptive control system is also compared to the traditional PID control system to show the advantages of the new system.

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1. INTRODUCTION

The Direct Current (DC) motor is a traditional electric motor. In comparison to the other electric motor such as brushless DC motors [1-3], induction motor [4-6], the intrinsic structure of the DC motor [7] has advantages such as the ease of maintenance, the simple control structure, the large electromagnetic torque, and the wide range of speed control. Therefore, DC motors are increasingly widely used in areas that require high-quality control, such as crane, elevator, conveyor, steel rolling, transportation, mining, etc [8], [9-13]. There is some research for controlling the DC motor such as [14-18]. Most of these researchers use a simple controller such as Proportional–Integral–Derivative (PID) controllers [19-20]. The advantage of the PID control is a simple structure, but the drawback is that the quality of the control system is not high. In the research [21], the author has proposed a method for controlling the DC motor that has achieved high-quality, that is the control method based on the flatness principle, but the limitation of this method is that the control algorithm is complex. In the other research [22], the author has proposed a solution to build a control system based on the linear quadratic regulator controller. This control algorithm is simple, but for the system to achieve good quality, it is necessary to know the exact parameters of the control object.

From the above overview, we see that if the structure of control system is simple, the quality of control system is low. In order for the system to achieve high-quality control, the control structure must be complex and at the same time know exactly the parameters of the control object. Therefore, to overcome the above limitations, in this article, the author will propose a new control system for DC motors with simple structure but high quality. That is the model reference adaptive control (MRAC) system. Moreover, the proposed control system can adapt to the transformation of the object. This control system is suitable for the object in the case of unknown exactly the parameters of the control object or the parameters are changed.

The remnant of this research is structured as follows. The sate separately excited DC motor is presented in Section 2. The design of the control system is presented in Section 3. The results and analysis are presented in Section 4, and lastly, in Section 5, some conclusions are presented.

2. THE SEPARATELY EXCITED DC MOTOR

The diagram of a separately excited DC Motor is presented as Figure 1 [22-23], it includes:

a) The field windings are in the stator, they are used to excite the field flux.
b) The armature coils are on the rotor, they are supplied current via brush and the commutator.

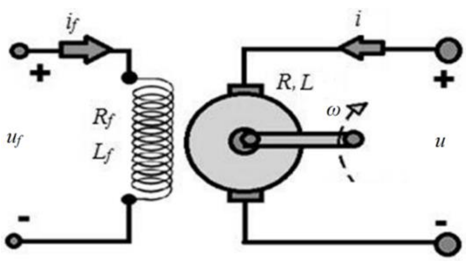


Figure 1. The diagram of a separately excited DC Motor

The mathematical equations of the DC Motor include:
The voltage equation:

$$u = Ri + L\frac{di}{dt} + E \text{ (V)} \tag{1}$$

Where u is the armature voltage, which is fed into the armature coil; i is the armature current; R, L is the armature resistance and inductance; E is the electromotive.

The electromotive equation:

$$E = K_b\omega = (L_{af}.i_f).\omega \text{ (V)} \tag{2}$$

Where ω is the speed of the rotor, K_b is the coefficient of voltage, i_f is the winding field current, L_{af} is the field armature mutual inductance.

The motion equation:

$$J\frac{d\omega}{dt} = T_m - T_d - T_f \text{ (N.m)} \tag{3}$$

Where J is the inertia, T_m is the electromechanical torque, T_d is the torque which impact to the shaft, K_f is the coefficient of the viscous friction, $T_f = K_f.\omega$ is the coulomb friction torque.

The electromechanical torque equation:

$$T_m = K_m i = (L_{af}.i_f).i \text{ (N.m)} \tag{4}$$

Where K_m is the torque coefficient.

3. BUILDING THE CONTROL SYSTEM

3.1. The structure of the control system in the case of non-adaptation

The traditional control system structure is a feedback control system with a PID controller. It has the diagram as shown in Figure 2.

PID controller is a common controller, it is applied in automatic control systems of production processes such as rolling steel, paper production, cement furnaces, and in the electrical control system, steam control system, diesel motor, etc. The structure of a PID controller consists of three components:

a) The proportion component (P)
b) The integral component (I)
c) The derivative component (D)

The block diagram of the PID controller is shown in Figure 3.

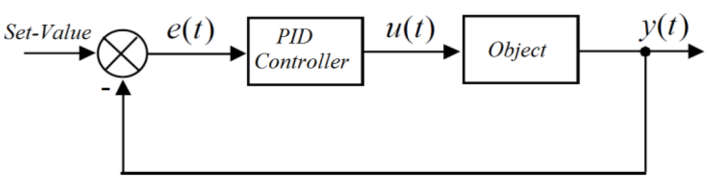


Figure 2. The diagram of control system with PID controller

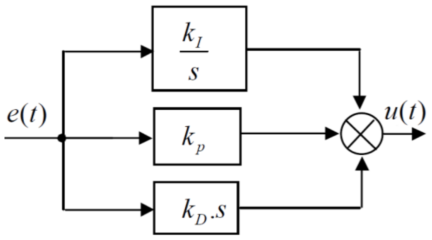


Figure 3. The PID controller

The relationship of input and output of the PID controller is as follows:

$$u(t) = k_p.e(t) + k_I.\int e(t)dt + k_D \frac{de(t)}{dt} \quad (5)$$

The function of each component is as follows:

a) The proportion component performs the main role of the controller. If there is an output deviation, this deviation will be amplified through the proportion component to affect the object and reduce the deviation.
b) The integral component is a supporting component to the role is increasing the accuracy of the system. If the static deviation is not equal to zero, then through the integral component, there is a signal fed into the input of the object to reduce the static error.
c) The derivative component also is a supporting component to the role is increasing the sensitivity of the system. Just a small change of external factors that affect the system will create a big change and impact on the object, so the object will react quickly to changes in the environment.

The control system built in Matlab is shown in Figure 4.

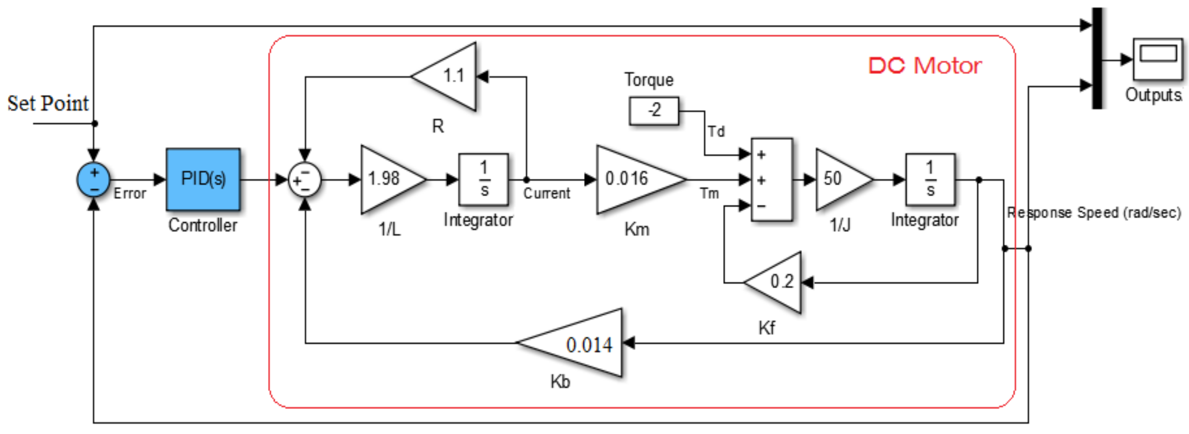


Figure 4. The control system with PID controller

3.2. The MRAC based - control system

The traditional PID controllers are only suitable for systems with unchanged or known parameters. The parameters of the controller are determined experimentally by the Ziegler-Nichols [24-25] method or optimizing module. After defining the parameters k_P, k_I, k_D, these parameters will be stable during control processes.

To control the systems that are continually changing or unknown parameters, the parameters k_P, k_I, k_D must be continuously adjusted during control processes. The author proposes a simple self-tuning algorithm based on the adaptive control method according to the reference model MARC. The purpose of the control system is that the output response of the control object (the speed of the DC motor) must follow the output of the reference model even if the parameters or the state of the DC motor change. The diagram of the adaptive control system according to the reference model is shown in Figure 5.

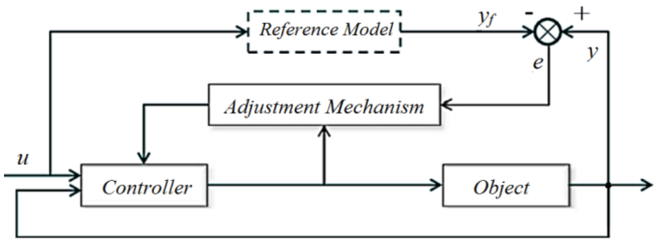


Figure 5. The diagram of the model reference adaptive control (MRAC) system

The control object is a DC motor, with the input is the armature voltage, the output response is the speed of the motor. The reference model is a first-order inertia component with a time constant $T = 0.1$ so that the output of The Reference Model adheres to the set signal quickly. The adjustment mechanism is a gamma multiplier. The MARC control system built in Matlab is shown in Figure 6.

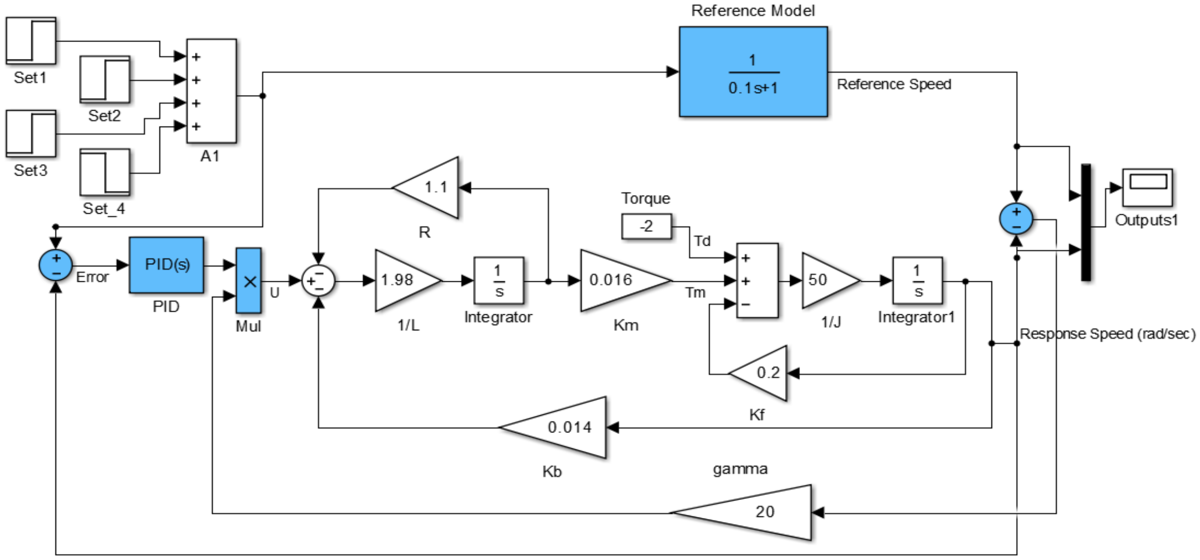


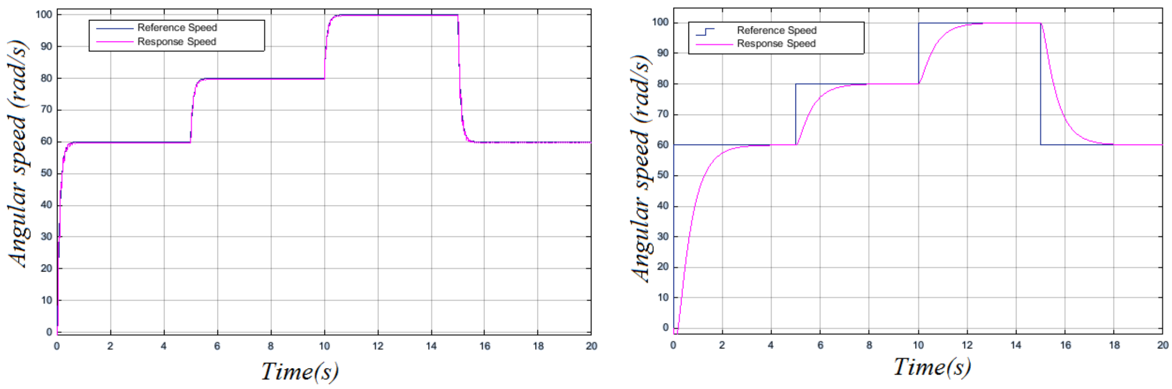
Figure 6. The MRAC control system

4. THE RESULTS AND ANALYSIS

Before running the system simulation, we set the motor parameters as shown in Table 1. To demonstrate the superiority of the proposed system, the author simulates two systems: the MARC adaptive control system and the traditional PID control system. The simulation results are shown in Figure 7. Figure 7(a) shows the response of the adaptive control system and Figure 7(b) shows the response of the PID control system.

Table 1. The parameters of the DC Motor

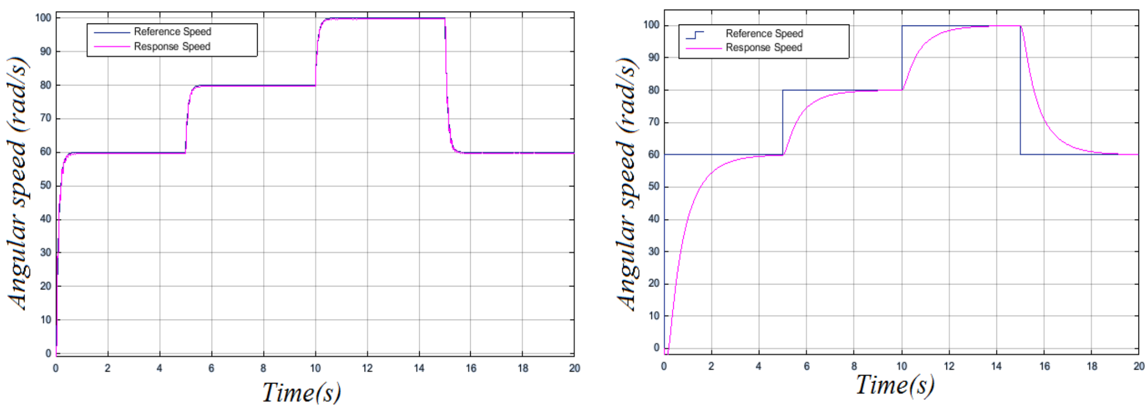
R(Ω)	L(H)	Km	Kb	J(kg.m^2)	T_d+T_m(N.m)
1.1	0.505	0.016	0.014	0.02	Var



(a) (b)

Figure 7. The response of the control system: a) MARC control system; b) PID control system

The simulation results show that the quality of the adaptive control system is much better than the PID control system. In PID control system, the conversion time is about 2-3s. In the adaptive control system, the conversion time is very small, about 0.05s, the response speed almost always adheres to the reference speed immediately. To show more clearly the advantages of the adaptive control system, the author runs two systems in case of changing in motor parameters: *R=0.12; Kb=0.016*. The results are shown in Figure 8.



(a) (b)

Figure 8. The response of the control system in case of changing in motor parameters: a) MARC control system; b) PID control system

The results in Figure 8 show that when the parameters of the control object change, the quality of the PID control system is significant decline, but the adaptive control system is still as good as the original. Therefore, it can be affirmed that the adaptive control system can apply to the DC motor control with good quality in the condition of unknown exactly the DC motor parameters or the DC motor parameters are changed.

5. CONCLUSION

The author successfully proposed the MARC adaptive control system for controlling the DC motor. This control system is simple but highly effective. The structure of the calibration system is very simple, just a multiplier, so the cost of the control system is low. The quality of the proposed control system is superior to that of a traditional PID system: The conversion time is very small and there is no static deviation during the control. The success of this study is a good basis for the author to apply it to practice in further studies.

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