Andrzej ANDRZEJEWSKI
Bialystok Technical University, Bialystok

THE TIME-MINIMAL SPEED CONTROL ON THE BASIS OF NOISY FEEDBACK SIGNAL

Key words

Variable speed drive, DC motor, speed control.

Summary

This paper concerns the speed controller modification for the time-minimal speed control of DC motor without overshoot. The speed control system consists of nonlinear speed controller and the adaptive electromechanical subsystem estimator. The adaptive estimator of the electromechanical subsystem is used in order to compensate the motor load torque. The basic nonlinear shape of speed controller characteristic was obtained based on Bellman dynamic programming method based on the motor speed and motor current step responses. The modification of speed controller characteristic was done to deal with the noise of feedback signal of speed controller. The paper contains the experimental results. The influence of the speed noise on speed controller response and speed control process is shown. The paper contains a time–minimal speed control process without overshoot. The two speed control processes (with and without nonlinear speed controller modification) are compared as well. In addition, the experimental results show the speed control process, which is done with use of one switching process of a transistor converter supplying DC motor.

Introduction

In time-optimal position control systems, the speed control subsystems are used [1–3]. The most popular are the sliding mode speed controllers [1–5]. The sliding mode speed controllers use the infinite gain, in order to obtain the speed control accuracy. The mentioned position control systems are called time--optimal. The high gain of sliding mode speed controllers caused speed waving (chattering), because it is not possible to change motor current immediately. Motor current can not be changed immediately, because windings have inductance. Next, the approximate time-optimal position control system was proposed [2]. In an approximate time-optimal position control system, the signum function of the speed controller was replaced by a saturation function. The speed controller was linear with saturation. As the result, the reference motor current was changed fluidly according to the *acceleration discount factor* [2]. The chattering effect was cancelled. However, the speed control subsystem of loaded motor is inaccurate. The speed control error depends on the speed controller gain and the motor load torque [1].

This paper concerns the speed control system for time-minimal speed control without overshoot [6]. The time-minimal speed controller has a nonlinear characteristic. As the result, the speed control time can be shorter. The speed controller characteristic is derived in paper [6]. All parameters of the DC motor model and the nonlinear model of the voltage converter and current control process were taken into account. The speed control system is accurate, because motor load torque is compensated by electromechanical subsystem estimator [6].

The aim of this paper is to obtain time-minimal speed control process based on the noisy feedback signal of the speed controller. The problem of control is that the speed controller gains speed noise. As the result, the reference motor current changes like the speed noise. It is an undesired phenomenon, because the motor current changes cause the motor torque ripples and additional energy loses in the motor windings and in the transistor converter.

The basic way for dealing with the noise of feedback signal (speed) is to use dynamic filters [1]. However, application of dynamic filters causes a slower reaction of the feedback signal. As the result, the speed control time is longer. However, it is expected to have as short speed control time as possible.

In order to obtain time-minimal speed control process based on a noisy signal, the modification of the speed controller characteristic is proposed. The speed controller characteristic is divided into two areas, depending on the value of the speed control error. If the speed control error is high, the speed controller has high gain, because the result the speed control system reaction is very fast. Therefore, if the speed control error is low and comparable with the speed noise, the speed controller has very low gain. As a result, the oscillation amplitude of reference motor current is very small. The advantage of this solution is that, in the area of high-speed error, the speed control time is very short. Additionally, there is no delay between real speed and the signal of the measured speed as it occurs in the solution with filters. The disadvantage of this solution is that, in the area of the low speed, error the speed control time is long. However, it is important to emphasise that the speed error is so small that it is comparable with the feedback signal noise (motor speed).

1. Speed control system with time-minimal speed controller

The proposed speed control system consists of the DC motor, the DC/DC converter, the current controller, the electromechanical subsystem estimator, and the time-minimal speed controller (Fig.1). The DC motor is supplied by a DC/DC transistor converter. The converter is controlled by output (two-state) signal of the motor current controller u_{ctrl}. If the converter control signal u_{ctrl} is “0,” the converter output voltage is negative. If signal u_{ctrl} is “1,” the motor supply voltage is positive. The DC motor current i_{rot} is controlled by the current controller with delta-modulation. The current controller operates so that the DC motor supply voltage is positive for positive current control error Δi_r and vice versa. If the current control error Δi_r is negative, the motor supply voltage is negative. The converter switching frequency is limited by a sample and hold device. The sample and hold operation is triggered every 12 μs.

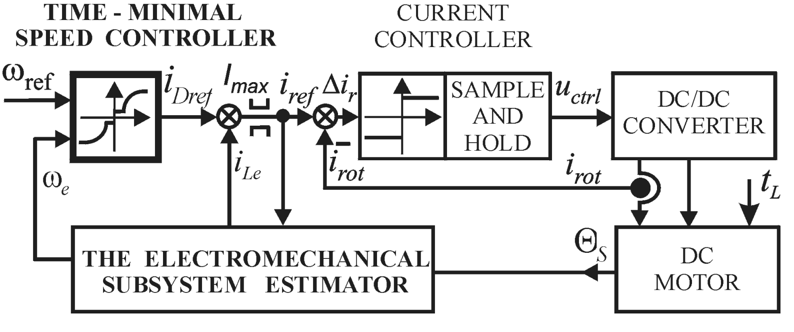

Fig. 1. The scheme of speed control system

For the speed control, the time-minimal speed controller and the electromechanical subsystem estimator are used. The tasks of the speed controller and estimator are different. The electromechanical subsystem estimator works, in the speed control system, as a precise load torque compensator. In addition, the electromechanical subsystem estimator provides the speed controller with the actual speed of motor. The operation of the electromechanical subsystem estimator is described in paper [6]. Generally, the electromechanical subsystem estimator replaces the integral element inside speed controller. As the result, the speed controller does not contain the integral element. Therefore, the time-minimal speed controller influences only the dynamic features of the drive. In the case of the strict load torque compensation, the output signal of the speed controller influences only the acceleration torque of the DC motor. This fact was utilised for the evaluation of the speed controller characteristic for fast-speed control [6].

2. The time-minimal speed controller characteristic

The speed controller characteristic was found as the result of the use of the dynamic programming method [6]. The original speed controller characteristic is nonlinear (dashed line in Fig. 2). The characteristic was found based on the speed control error step response and the dynamic current (acceleration torque) step response. The derivation procedure of speed controller characteristic is given in paper [6]. The speed controller characteristic shows the relationship between the input and the output signals of speed controller (Fig. 2).

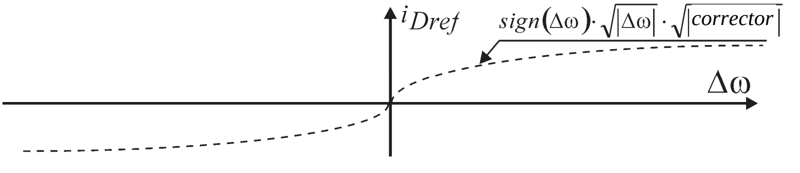

Fig. 2. The nonlinear shape of speed controller characteristic

The input signal of the speed controller is the speed control error $\Delta\omega$, whilst the output signal of speed controller is the reference dynamic current i_{Dref}. The speed controller characteristic is described by the following equation:

$$i_{Dref}(t) = sign(\Delta\omega)\cdot\sqrt{|\Delta\omega|}\cdot\sqrt{|\,corrector\,|} \qquad (1)$$

The speed control error is the difference between the reference speed ω_{ref} and the estimated speed ω_e (the controller feedback signal). The output signal of speed controller is the square root function of speed error and the sign function. The function sign returns plus one for positive speed control error and returns minus one for the negative speed control error. The output signal of speed controller i_{Dref}. depends also on the signal *corrector*. The signal *corrector* influence is essential to obtain the time-minimal speed response. The signal *corrector* assures that the time-minimal speed control process does not depend on the motor electromotive force and the motor load torque. The signal corrector is calculated from the following formula:

$$corrector = \frac{1}{c_{Je} \cdot Lr} \cdot \left| \left(U_{DC} + I_{MAX} \cdot Rr\right) \cdot sign(\Delta\omega) + k_M \cdot \omega_{ref} + L_r \cdot \left(di_{Le}/dt\right) \right| \cdot$$
$$\cdot \left(1 + \sqrt{1 - 2c_{Je} \cdot L_r \cdot k_M \frac{\left[I_{MAX} \cdot sign(\Delta\omega) - i_{Le}\right]^2}{\left[\left(U_{DC} + I_{MAX} \cdot R_r\right) \cdot sign(\Delta\omega) + k_M \cdot \omega_{ref} + L_r \left(di_{Le}/dt\right)\right]^2}} \right) \tag{2}$$

where:

k_M – the motor torque constant [Nm/A],
L_r – the inductance of motor armature windings [H],
R_r – the resistance of motor armature windings [Ω],
U_{DC} – the voltage of DC link of DC/DC converter [V],
I_{MAX} – the value of motor current limiter [A],
c_{Je} – estimated inertia coefficient.

The estimated inertia coefficient is calculated as the ratio of motor torque constant k_M [Nm/A] to moment of inertia J [kgm^2]. Signal i_{Le} is the estimated load current. Estimated load current is the output signal of the electromechanical subsystem estimator. In the case of the strict load torque compensation, the estimated load current is equal to the ratio of the load torque in [Nm] to the motor torque constant in [Nm/A]. Symbol di_{Le}/dt means the derivative of estimated load current in [A/s].

3. The modified characteristic of time-minimal speed controller

The modification of time-minimal speed controller characteristic is proposed in Fig. 3. The modification is made for the attenuation of the chattering effect caused by the noise of the estimated speed (speed controller

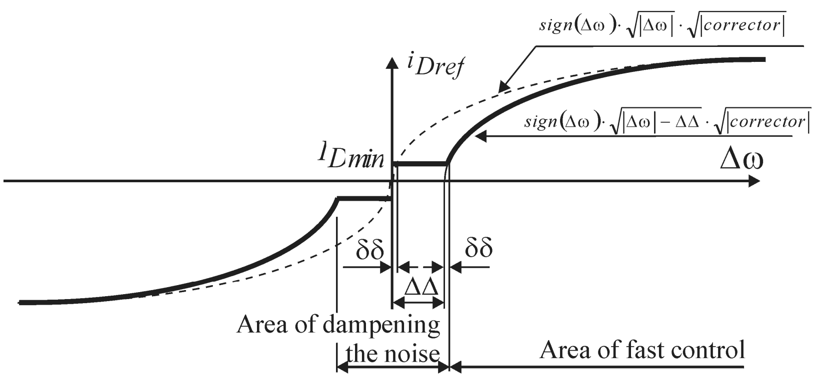

Fig. 3. The modified characteristic of the time-minimal speed controller

feedback signal). The modified speed controller characteristic is divided into two areas. The area of the noise attenuation is for the speed error $\Delta\omega$ less than the sum (ΔΔ+δδ). The area of the fast speed control is for the speed error $\Delta\omega$ greater than the value of the sum (ΔΔ+δδ).

In the area of the noise attenuation, the output signal speed controller i_{Dref} takes very low value I_{Dmin}. The value of I_{Dmin} should be set as the result of the experiment. However, the value I_{Dmin} is usually set to 2% of the I_{MAX}. In this area of the noise attenuation, the output signal of the speed controller is calculated from equation:

$$i_{Dref} = I_{D\min} \cdot sign(\Delta\omega) \tag{3}$$

whereas, in the area of the fast speed control, the output signal of the speed controller is calculated from equation:

$$i_{Dref}(t) = sign(\Delta\omega) \cdot \sqrt{|\Delta\omega| - \Delta\Delta} \cdot \sqrt{|\ corrector\ |} \tag{4}$$

The unknown value $\delta\delta$ could be derived from the condition (from Fig. 3):

$$I_{D\min} = \sqrt{|\delta\delta|} \cdot \sqrt{|\ corrector\ |} \tag{5}$$

The equation:

$$\delta\delta = \frac{I_{D\min}{}^2}{|corrector|} \tag{6}$$

for calculation of $\delta\delta$ was derived from (5). The value of ΔΔ should be set experimentally.

4. The experimental results

The experimental investigations were done on the test stand consisting of the electronic part and mechanical part. The electronic part components are the computer PC, the microprocessor system with DSP96002 (40MIPS), and the DC/DC converter. The mechanical part consists of the two DC motors, the rotational encoder, and the electromechanical clutch between DC motors. The nominal parameters of the DC motors are P_N = 1.2 kW, U_N = 230 V, I_N = 5.2 A, and n_n = 1450 rpm. The encoder resolution is 2048 marks per rotation. The experimental results in Fig. 4 and Fig. 5 show the motor current i_{rot}, the motor estimated speed ω_e and the converter control signal u_{ctrl} responses on reference speed step.

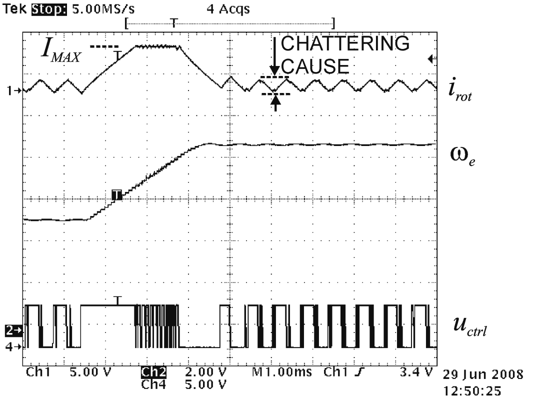

Fig. 4. The speed control process without modification of speed controller

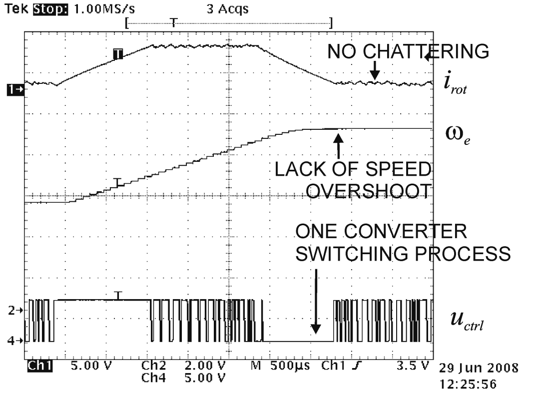

Fig. 5. The speed control process after the speed controller modification

Firstly, the influence of the speed noise on speed controller response is examined in Fig. 4. During the first test, the time-minimal speed controller had a characteristic like that in Fig. 2, without modification. At the end of the speed control process, the chattering effect in motor current response is observed.

In order to show the contrast, the results with the modified speed controller are shown in Fig. 5. As the result of the time-minimal speed controller characteristic modification, the chattering phenomenon is not observed.

Conclusions

The experimental results show the time–minimal and without overshoot speed control process. Therefore, in the active state of the speed controller, the speed is controlled with use of one DC/DC converter switching process. This is the time-minimal speed control process, because it is not possible to obtain the lower number of the switching processes than one. The speed control process is extremely fast, even though it was based on the noisy feedback signal speed controller.

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Reviewer:
Krzysztof KLUSZCZYŃSKI

Minimalno-czasowe sterowanie prędkością na podstawie sygnału sprzężenia zwrotnego zawierającego szum

Słowa kluczowe

Napęd o zmiennej prędkości, regulacja prędkości, silnik prądu stałego.

Streszczenie

Praca dotyczy modyfikacji regulatora prędkości na potrzeby minimalno-czasowej i pozbawionej przeregulowania regulacji prędkości silnika prądu stałego. Regulator prędkości zmodyfikowano celem uodpornienia go na szum w sygnale sprzężenia zwrotnego prędkości. Praca zawiera wyniki badań laboratoryjnych systemu regulacji prędkości. Przedstawiono wpływ szumu prędkości na jakość regulacji prędkości silnika prądu stałego. Zarejestrowane procesy regulacji prędkości, z regulatorem prędkości bez modyfikacji i regulatorem prędkości z modyfikacją zostały ze sobą porównane. Przedstawiono minimalno-czasowy i pozbawiony przeregulowania proces regulacji prędkości, który został zrealizowany za pomocą jednego przełączenia przekształtnika tranzystorowego DC/DC zasilającego silnik prądu stałego.