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Determination of the Sampling Period Required for a Fast Dynamic Response of DC-Motors

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Abstract: DC motors provide a high starting torque and play a significant role in modern industrial drives. The speed of a dc-motor is responding to the change in load torque, armature voltage and field flux. For a sudden change in applied torque, there is a change in the motor speed. This speed change goes in transient period for some time before settling to the new value.

To keep a constant motor speed for a sudden change in applied torque, a proportional control of armature voltage can be used. In this work, to have an optimum and faster speed response for the torque change a sampled- data controller is applied. The continuous response of the motor speed is sampled and the action for proportional control of armature voltage is taken at discrete manner. A proper value of sampling frequency is determined for a satisfactory speed response of the dc- motor. The paper discussed the results of dynamic response for off- time and real time controls.

Keywords: DC-machines, Dynamic Response, Digital Control, Transient Response, Real- time Control, Sampled- data Control, Optimum Control, Proportional Control.

1 Introduction

Both series and separately excited dc motors are normally used in variable- speed drives [1]. With the help of their variable characteristics, it is possible to obtain speed control over a wide range. The most flexible control is obtained by means of a separately excited dc motor in which the armature and field circuits are provided with separate sources. This arrangement produces speed- torque characteristics approximately close to the ideal characteristics. For armature voltage, a controlled rectifier or a chopper is required [2]. The field current can be also controlled by the same provisions. Controlled rectifiers provide a variable dc output voltage form a fixed ac voltage, whereas choppers can provide a variable dc output voltage from a dc voltage.

In this work, the continuous dynamic response of the dc motor for a sudden change in load torque is sampled. The speed is measured at each sampling instant and the action for proportional control of armature voltage is taken at discrete manner. The method that was suggested in this work for determining the sampling period gives a faster and optimum speed response for the dc motor.

2 DC Motor-speed control

The steady- state speed of a dc- motor reacts to the change in load torque, armature voltage and field flux. A separately excited motor with constant values of armature voltage and field current develops a speed that is decreased as the load torque is increased.

During the transient period for a sudden change in load torque, the addition load torque demand is met initially by a sudden retardation of the rotating masses which contribute to the moment of inertia of the motor shaft. Some studies ignore the mechanical system transient by considering rotor speed to be constant over the short time , or ignoring machine field and armature winding inductance [3].

The dc/dc converter or chopper and phase controlled ac/dc converter are using exclusively on the control of the armature voltage supply [4]. The chopper is involving semiconductor switches to chop the constant supply voltage at a fairly high repetition rate, enabling the average value of armature voltage to be variable between zero and the supply voltage. In the essential circuits of the chopper, the constant voltage source is feeding to the thyristor switch. This thyristor switch chops the voltage source before applied to the armature circuit. As the conducting period of the thyristor

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switch is changed, the average value of armature voltage is varied which result in speed control.

3 DC Motor- Model for Transient Operation

The equivalent circuit of a separately excited dc-motor is shown in Fig.1. The field current is assumed constant. The control is applied on terminal voltage (V_a) which equals:

$$V_a = R_a\, i_a + L_a\, di_a / dt + e_a \text{ volt} \quad (1)$$

$$\text{and: } e_a = K\Phi\omega \quad \text{volt} \quad (2)$$

where:

e_a : armature e.m.f (volt).
Φ : flux per pole (web).
ω : motor speed (r/s).

The air-gap or electromechanical torque (T_e) equals:

$$T_e = J\, d\omega /dt + B\omega + T_w \quad \text{N.m} \quad (3)$$

$$\text{Also; } T_e = K\Phi i_a \quad \text{N.m} \quad (4)$$

Where:
J: Inertia of both motor and driven mechanism (kg.m^2).
B: Viscous friction of both motor and driven mechanism (N.m.s/r).
T_w: loading torque (N.m).

Transient behavior of dc motor can be analyzed by transforming the above equations to s-domain. By taking the Laplace transform of (1) and after some arrangements becomes :

$$I_{a(S)} = \frac{V_{a(S)} - K\Phi\Omega_{(S)}}{R_a\,(1 + \tau_a\,.S)} \quad (5)$$

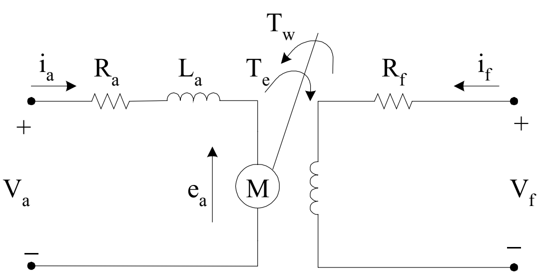


Fig.1 A separately excited dc- motor.

$\tau_a = L_a / R_a$ (sec) , is the armature- circuit time constant.
Also by taking the Laplace transform of (3) and (4) we get :

$$\Omega_{(S)} = \frac{T_{e(S)} - T_{w(S)}}{B\,(1 + \tau_m\,.S)} \quad (6)$$

And:

$$T_{e(S)} = K\Phi I_{a(S)} \quad (7)$$

$\tau_m = J / B$ (sec), is the mechanical time constant.

4 Transient Response With Discrete Control

The motor- mechanism model is determined from (5), (6) and (7) and given in Fig.2. For a sudden change in applied torque (T_w), there is a change in the motor speed. This speed takes some time before settling to new value. To keep a constant motor speed for a sudden change in applied torque, a proportional voltage control is added. In this work, the response time is sampled with sampling period of (T-sec), and the action of proportional control is taken at each instant of the discrete period. This discrete manipulation will show a fast speed response with less oscillation.

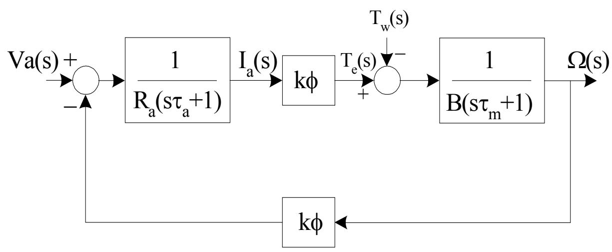


Fig.2 DC- motor block diagram.

4.1 Off- time Control

The transient response of motor speed to an unit-step change in load torque with no control of armature voltage is determined and given in Fig.3. The final value of speed is changed and settled on new low value because there is no action of armature control.
The control of armature voltage can be activated using discrete manner. This is done by sampling the time response of the speed at a sampling time

of T- sec and the speed change is manipulated at each sampling instant. The manipulation is done at off-time, i.e. the calculations for new action of armature control is taken at each sample.

It is important to select a proper value for the sampling frequency to have a satisfactory transient response. In this paper, the transient response of the continuous- data control system is investigated and a proper equation is developed for the determination of sampling period (T_P).

This equation is:

$$T_P = \frac{t_s}{(Mv - F_v) * 800} \text{ sec} \qquad (8)$$

Where:

T_s: Settling time of the continuous response.

M_v: Maximum value of the response.

F_v : Final value of the response.

From the continuous unit- step response of motor speed shown in Fig.3, the optimum sampling period is determined and given below:

$$T_P = \frac{0.2}{(0.02666 - 0.0225) * 800} = 0.06 \text{ sec.}$$

Speed response to an unit- step change of load torque using discrete control for the armature voltage with different values of sampling period

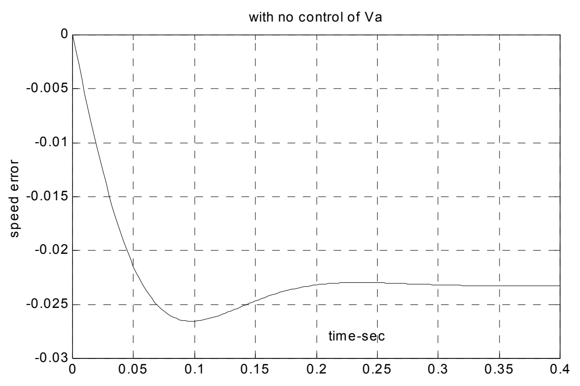


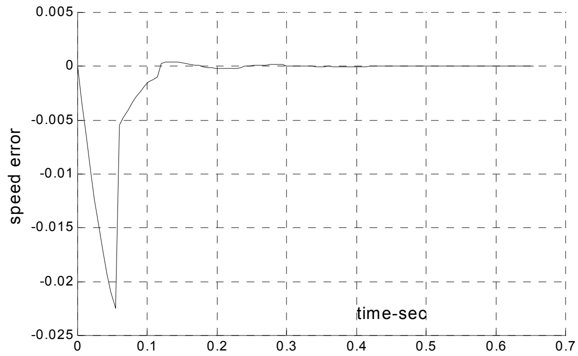
Fig.3 Speed response to an unit- step change in T_W

is given in Fig.4. The sampling period is calculated from (8) which equals 0.06 sec and its response shown in fig.4-a. For a larger sampling period of 0.1 sec, the motor-speed response has a large overshoot as shown in Fig.4-b. The response in Fig.4-c is for a smaller sampling period of 0.006 sec which has more oscillation and caused speed perturbation. Fast and optimum speed response is obtained at the determined sampling period T_P.

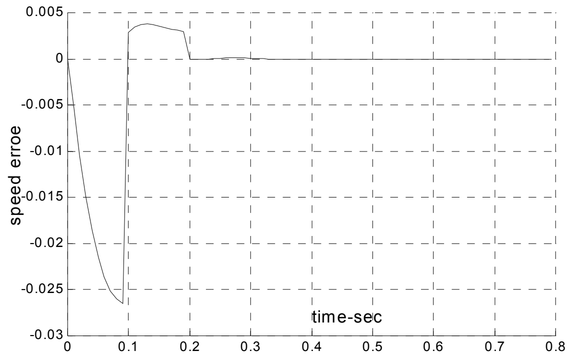
4.2 Real-time Control

In the previous results, the calculations and action for new speed were done simultaneously. But practically, the controller needs some time for calculations before taking the new action for the armature voltage. Therefore, the first sample after the change is left for calculations, and the action of controller is taken in the second sample. The speed response to an unit- step change of load torque and for sampling period equals to that one calculated by (8) but with off- on controller is shown in Fig.5. The response for a half value of the calculated sampling period is shown in Fig.6. Results show that the first overshoot with T= 0.03 sec is less than that with T = 0.06 sec but with more speed perturbation.

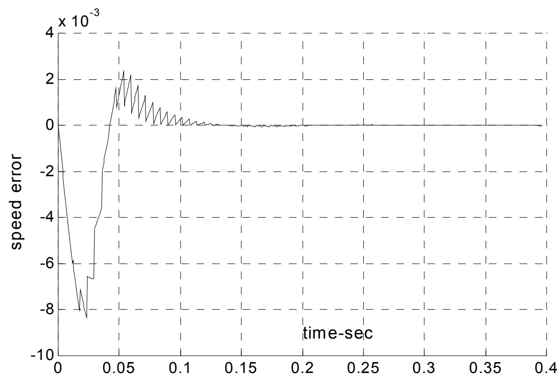
Practically, real- time discrete control of the dc-motor speed is proposed in Fig.7, using a dc-chopper of a constant frequency. Using the pulse-width- modulation method, the chopping period of the chopper can be defined, which is the same sampling period (T) of the digital controller. Figure.7-b explains the way of generating switching signals for the chopper. The triangular carrier signal (c) has a frequency of (1/T Hz). The amplitude (p_r) of the rectangular reference signal (r) depends on the speed error signal of the dc-motor caused by the change of the loading torque. Different load torques give different amplitudes of (p_r). The conduction angle (σ) of the chopper is then determined by comparing the carrier signal amplitude (p_c) with the reference signal amplitude (p_r). If the difference between the carrier signal (c) and reference signal (r) becomes zero, the chopper will stop conducting and the reference signal sets to zero. Figure.8 shows the way of generating different conduction angles at different speed error signals.



a-With discrete control of T= 0.06 sec



b-With discrete control of T= 0.1 sec



c- With discrete control of T= 0.006 sec

Fig.4 Motor-speed response to an unit- step change of Load torque.

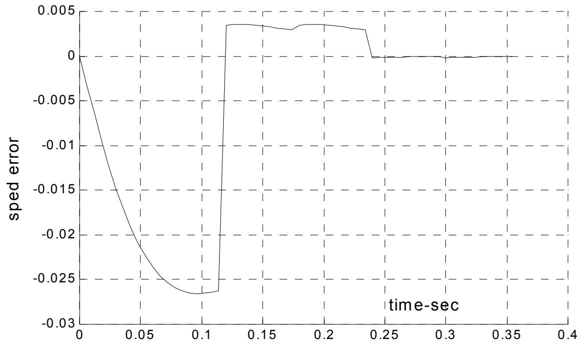


Fig.5 Real- time speed response with discrete control of V_a at T= 0.06 sec.

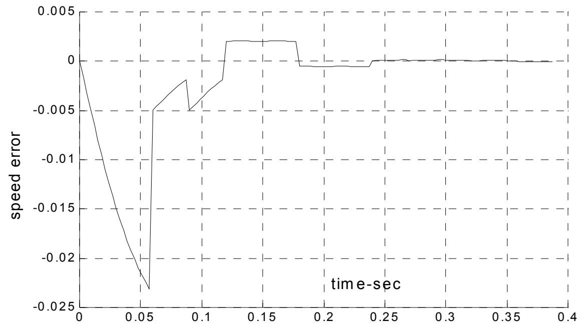
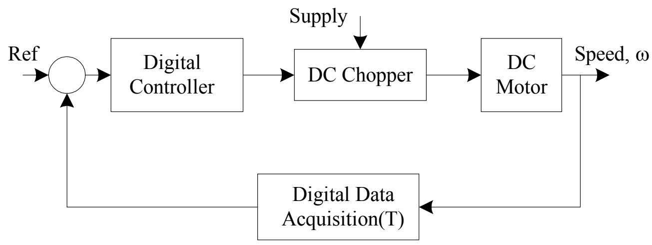
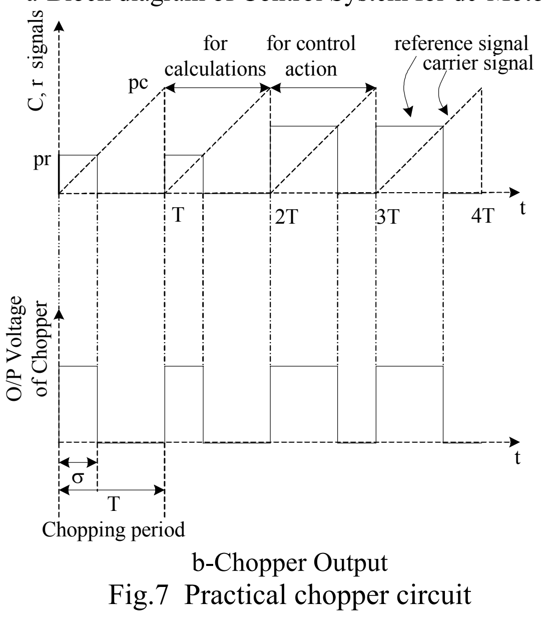


Fig.6 Real- time speed response with discrete control of V_a at T= 0.03 sec.



a-Block diagram of Control System for dc-Motor



b-Chopper Output

Fig.7 Practical chopper circuit

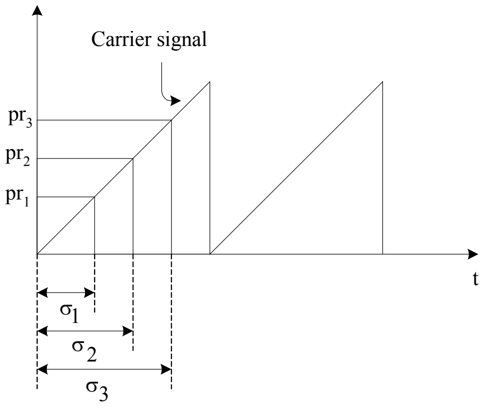


Fig.8 Different conduction angles for chopper

5 Conclusions

A sampled- data control system is developed for a dc- motor to improve the dynamic response of motor speed for load torque changes. An optimum value of sampling period for a best behavior of the motor speed through transient response is determined. The transient response of motor speed to an unit- step change in load torque is investigated for both off- time and real- time control, and a practical model for real- time control is included.

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