Real Time Compensation of the Load Torque for DC Drive System

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The objective of this paper is to improve the control quality of the DC drive system based on Arduino platform. The nameplate DC motor data are useful to provide the DC motor parameters. The cascade control loops provides good dynamic performances for the DC drive system. By using an adequate electric generator, the DC motor is loaded appropriately. Compared to the conventional control methods, in order to improve the load torque disturbances, this paper introduces feedforward load control loop. The simulation and experimental results are shown in this paper.

Keywords*: DC motor, PI control, Simulink, Matlab, Arduino, load torque*

1. Introduction

The DC drive systems are often used in industry due to the high torque capability at zero speed, i.e in the starting conditions, attractive linear control up to rated speed. Depends on the magnetic flux conditions, there are two speed adjustment ranges:

I. between the rated speed clockwise or counterclockwise by assuring constant flux, the DC drive operates at the maximum torque, the power varies linearly with speed,

II. up to maximum speed by flux weakening conditions. The half of the rated flux is ususaly the minimum limit of flux weakening. The DC drive operates at the constant power.

The DC drive applications are in robotics, steel and paper mills, electric traction, so on. The main disadvantage of the DC drive is the maintenance costs due to the brush gear and the commutator. By using the least square identification method [1-4], the parameters of the DC motor have been delivered.

The objective of the DC drive system is to control one of the kinematic quantities: speed, acceleration, angular displacement or the jerk, the other being limited and considered as auxiliaries quantities [5].

Mainly, there are two types of control: armature and flux weakening. The DC drive system uses the armature voltage control at constant flux by means of the static power converters. By using the flux weakening control the constant power is achieved.

The speed adjustment can be in one way (unidirectional) or in both ways (bidirectional). By using the four quadrant static power bridge converter the bidirectional speed can be obtained. The four quadrant static power bridge converter can be used either on stator circuit or on rotor circuit.

2. The mathematical model of the DC drive system

The DC drive system consists of the DC machine, the AC-DC static power converter, the speed measurement through the tahogenerator, the armature current measurement through the current transformers.

The DC motor differential equations are as follows:

$$u_A = R_A\, i_A(t) + L_A \frac{di_A(t)}{dt} + k\phi\, \Omega(t)$$
$$m_e = k\phi\, i_A(t) = J \frac{d\Omega(t)}{dt} + Kf\, \Omega(t) + T_L \tag{1}$$

in which: $u_A(t)$: rotor voltage; $i_A(t)$: rotor current; $\Omega(t)$: angular velocity; R_A : rotor resistance; L_A : rotor inductance; $k\phi$: DC motor constant; Kf : viscous friction constant; J: equivalent moment of the rotor inertia; T_L : the load torque.

Taking into account the dead time into static power converter, the continuous conduction, the static power converter can be modelled as:

$$\frac{K_d}{1+sT_m} \tag{2}$$

where the gain factor is

$$K_d = \frac{U_N}{10}. \tag{3}$$

and T_m is the dead time constant.

The attenuation factor of the current transducer is as follows:

$$k_{TI} = \frac{10}{I_{A\,max}} = \frac{10}{2I_{AN}} \left[\frac{V}{A}\right].$$

In the same manner, the attenuation of the speed transducer can be provided :

$$k_{T\Omega} = \frac{10}{n_{max}} = \frac{10}{1.2n_N} \left[\frac{V}{rpm}\right]. \tag{4}$$

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3. Feedforward control of the DC drive system

The proposed method is an improvement of DC drive system based on the feedforward load torque compensation component. The method is based on the steady state mathematical model of he DC machine. By maintaining the constant flux, the operating speed is assured between the clockward and backward rated speed. Therefore, in the dynamical regime (starting, braking, reversing) the maximum torque is assured. Based on the steady state speed equation the following DC motor block diagram is deducted (Fig.1).
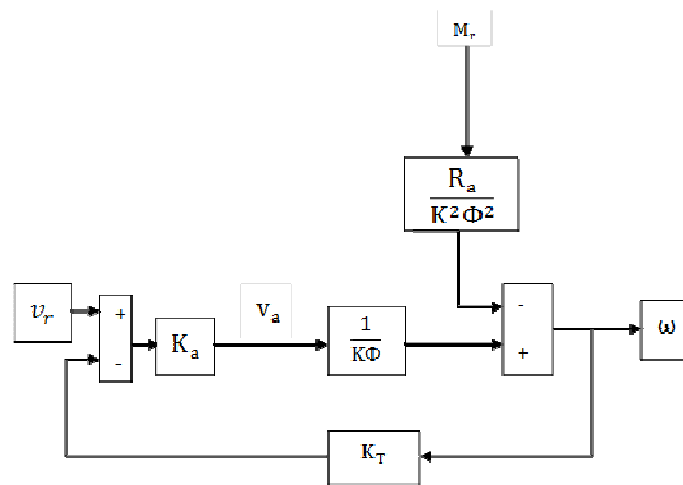
Figure 1. The armature voltage control of the DC machine

By taking into consideration the armature voltage control, the following block diagram is obtained (Figure 2).
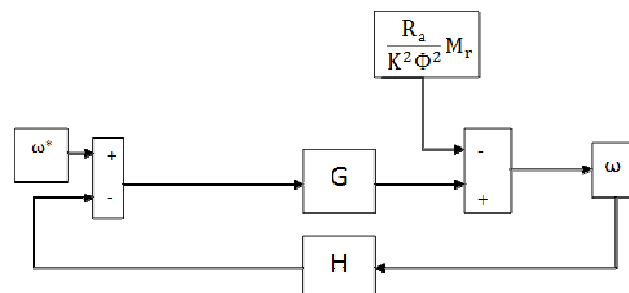

Figure 2. The equivalent speed loop control of the DC machine
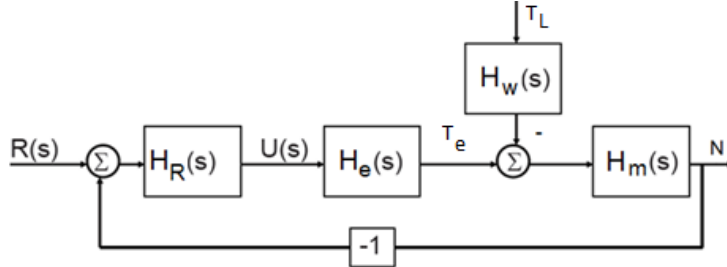The Figure 2 could be redrawn as in Figure 3.

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Figure 3. The equivalent speed control block diagram

In order to compensate the influence of the load torque, the adequate load torque compensator should be design (Fig. 4).
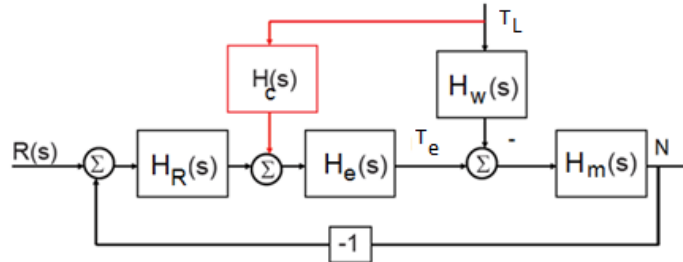

Figure 4. The speed control of the DC machine with load torque compensation

The obtained control system is linear, therefore, superimposed principle could be used:

$$N(s) = \frac{H_R H_e H_m}{1+H_R H_e H_m} R(s) + \frac{H_c H_e H_m - H_w H_m}{1+H_R H_e H_m} T_L(s).$$ (5)

In order to cancel the influence of the load torque, the following design equation is used:

$$H_c H_e H_m \quad H_w H_m = 0$$ (6)

Therefore, the transfer function of the load torque compensator is obtained, $H_c(s)$:

$$H_c = \frac{H_w}{H_e}.$$ (7)

In terms of the DC machine parameters, taking into account the design equation for the load torque compensation the following block diagram is depicted:
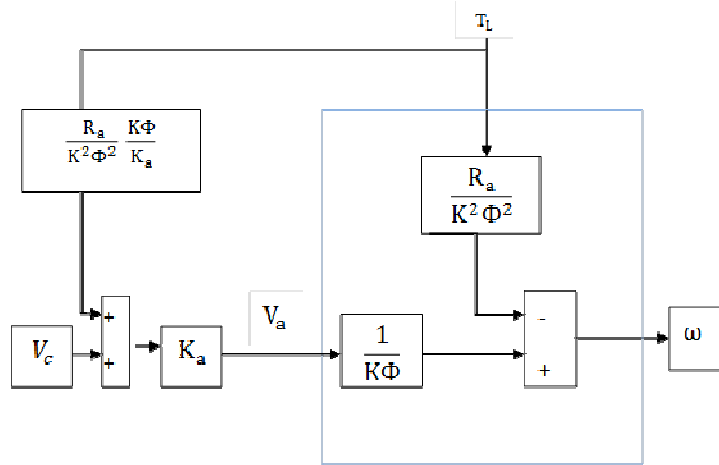
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Figure 5. The feedforward load torque component added to the control signal feedforward

4. Real time implementation

In order to show the feasebility of the proposed solution, the Arduino platform has been used. In this manner, the rapid prototyping control has been obtained. The main parameters of the DC motor are: $U_n=12V$, $P_n=400W$, $J=0.1kgm^2$, $T_N=6.4Nm$.
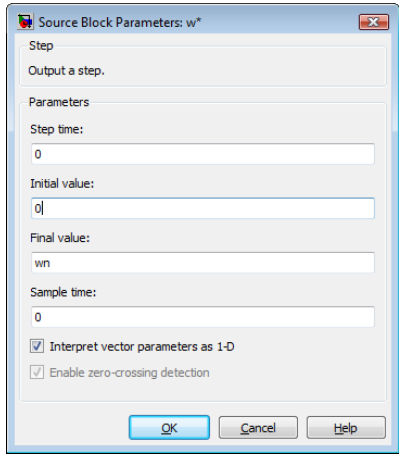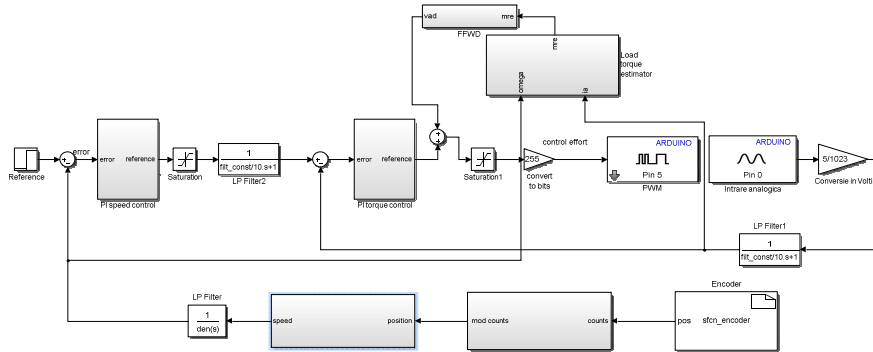

Figure 6. The speed reference

Figure 7. The Arduino based DC drive control with feedforward load torque compensation

The DC drive control has been implemented in Matlab-Simulink. By using the appropriate driver, the entire DC drive control has been downloaded into Arduino platform.
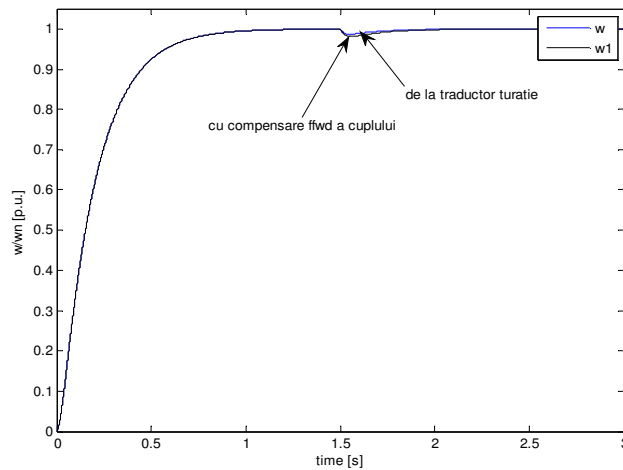

Figure 8. Comparative experimental results of the normalized speed response

In order to compare the efficacity of the proposed solution, the speed control has been used. At t=1.5s the rated load torque is initiated and the comparative results of both DC drive control (with and without load torque compensation) are shown (Fig.8). In case of using the load torque feedforward component, an improvement of the speed response has been obtained (Fig.8).

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4. Conclusion

The main perturbation of the electrical drive system is the load torque. The objective of the DC drive system, speed regulation, has been accomplished. A method of diminish the influence of the load torque over the speed has been proposed by the authors of this paper. Feedforward load torque component has been added to the voltage control of the DC machine. In order to prove the feasibility of the solution a real time implementation based on the Arduino platform has been provided.

References

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