

The modelling and the automation of an independent wound DC motor*

Robert Pecsi¹, Eleonora Darie²

¹Lecturer, Eng. Ph.D., the Faculty of Building Services and Equipment, Technical University of Civil Engineering of Bucharest, Lacul Tei Bvd., no. 122 – 124, RO 020396, sector 2, Bucharest, Romania

²Assoc. Prof., Eng. Ph.D., the Faculty of Building Services and Equipment, Technical University of Civil Engineering of Bucharest, Lacul Tei Bvd., no. 122 – 124, RO 020396, sector 2, Bucharest, Romania

Abstract

In this paper the authors analyse a dynamic system, namely the independent wound DC motor and a new automation mode for this. Starting from the voltage balance equation and the torque balance equation, a Matlab/Simulink model is built for the motor and the motor's answer to unit level signal and a ramp signal is analysed. For the automation of the system a PID regulator is used. By the fine tuning of the regulator's parameters, an optimal variation is obtained, which satisfies all the performances.

Key-words: *Electrical drive, speed control, automation PID*

1. Introduction

In the dc motor based systems the independent wound DC motor is the most frequently used. For this motor, the excitation current is constant for a large interval of motor speeds.

There is well-known from the literature [1-7, 9] that the operation of the independent wound DC motor is determined by a voltage balance equation for the rotor wound (electric balance) and a torque balance equation (mechanical balance), as follows:

$$u(t) = R \cdot i(t) + L \cdot \frac{di(t)}{dt} + e(t); \quad (1)$$

$$J \frac{d\omega(t)}{dt} = C_m(t) - C_r(t). \quad (2)$$

By using the basic equations from [1] and [2], we obtain:

$$\begin{aligned} e(t) &= \Phi \cdot \omega(t) \\ C_m(t) &= \Phi \cdot i(t) \\ C_r(t) &= f \cdot \omega(t) \\ \omega(t) &= \frac{d\theta(t)}{dt}, \end{aligned} \quad (3)$$

By introducing these equations (3) into the above equations (1 and 2), we obtain:

$$\begin{cases} \frac{di(t)}{dt} = -\frac{R}{L} \cdot i(t) + \frac{1}{L} \cdot u(t) - \frac{\phi}{L} \cdot \omega(t) \\ \frac{d\omega(t)}{dt} = \frac{\phi}{J} \cdot i(t) - \frac{fr}{J} \cdot \omega(t) \end{cases}; \quad (4)$$

where:

u – is the powering voltage present at the rotor's terminals;

ω – is the rotation speed of the motor axis;

i – is the rotoric current;

R – is the rotor wound's resistance;

L – is the rotor wound's inductance;

e – is the induced electromotive force;

Φ – is the excitation magnetic flux;

J – is the inertia moment of the motor axis;

θ – is the angular displacement of the motor axis;

C_m – is the active torque of the motor;

C_r – is the resistive torque of the load;

F_r – is the friction coefficient.

The two system variables, the electric one (the current intensity) and the mechanical one (the rotor axis rotational speed) can be found in each equation (4). In both (4) equations the other system variable produces an adverse reaction, being opposite to entry measure (in this case the power voltage present at the rotor circuit's terminals), realising the „coupling” between the two variables, a coupling necessary for the electromechanical conversion. The electromotive force is opposed to the power voltage present at the rotor circuit's terminals and the resistive torque is opposite to the electromagnetic torque, attenuating the mechanical speed's dynamics. For the motor mode, the difference between the electromagnetic torque and the load's resistive torque is strictly positive. If the entry value is not enough, the difference between the electromagnetic torque and the load's resistive torque becomes negative and the electromechanical conversion is not possible. In this way a skip area of the electromechanical conversion is introduced for the cases when the difference between the electromagnetic torque and the load's resistive torque is negative [9]. The numerical integration of the (4) equation system leads to the preparation of the system's model (figures 1 and 2).

2. The analysis of the independent wound DC motor's operation

By applying the Laplace transform for the (1-4) linear equations, we can obtain the following algebraic equations for zero condition ($i(0) = 0$ and $\omega(0) = 0$) [2]:

$$\begin{cases} s \cdot i(s) = -\frac{R}{L} \cdot i(s) + \frac{1}{L} \cdot u(s) - \frac{\phi}{L} \cdot \omega(s) \\ s \cdot \omega(s) = \frac{\phi}{J} \cdot i(s) - \frac{f_r}{J} \cdot \omega(s) \end{cases}; \quad (5)$$

which conduct to the followings [2]:

$$\begin{cases} i(s) = \frac{1}{L \cdot s + R} \cdot u(s) - \frac{\phi}{L \cdot s + R} \cdot \omega(s) \\ \omega(s) = \frac{\phi}{J \cdot s + f_r} \cdot i(s) \end{cases}. \quad (6)$$

3. The Matlab/Simulink model for the independent wound DC motor

By using the equations (5) and (6), the authors have built the numerical model for the said independent wound DC motor, with transfer functions, described is Simulink, as in figure 1 [2].

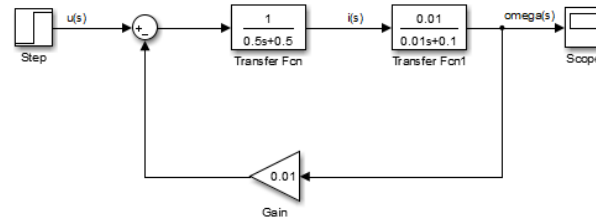


Fig. 1: The numerical model for the said independent wound DC motor for an unit level signal.

The model has been constructed with the blocks available in Matlab/Simulink.

4. The answer of the analysed system to the unit level signal

For visualizing the indicial answer of the analyses system [1, 2], after setting the values of the constants (by example $J = 0,01$; $f_r = 0,1$; $R = 1$; $L = 0,5$; $\phi = 0,01$) the simulation has been proceeded ($t=10$ s) and the oscilloscope window displayed the graphics showed in the below figure, showing the dependence of the output value ($\omega(s)$) of an unit level input signal $u(s)$) (figure 2).

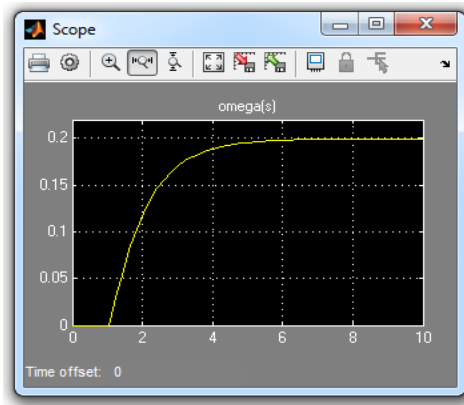


Fig. 2: The indicial answer ($\omega(s)$) of the independent wound DC motor to an unit level signal.

5. The answer of the analysed system to a ramp signal

The analysed numerical model (built with the blocks available in Matlab/Simulink) is shown in figure 3 below [1-2].

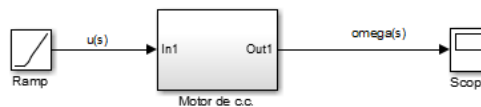


Fig. 3: The numerical model for the said independent wound DC motor for a ramp signal

The figure below (figure 4) shows the indicial answer (showing the dependence of the output value ($\omega(s)$) of an ramp input signal $u(s)$), displayed by the oscilloscope window. In this figure, the model of the DC motor is represented by a sub-system.

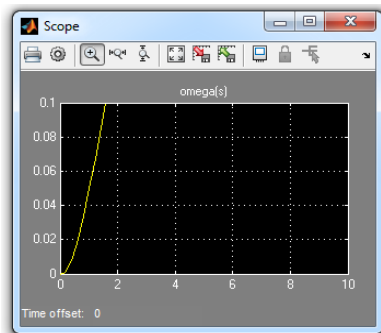


Fig. 4: The answer ($\omega(s)$) of the numerical model of the independent wound DC motor to a ramp signal.

6. The model's automation

A few performances are necessary to be ensured for the analysed system, namely:

The modelling and the automation of an independent wound DC motor

- Zero stationary error;
- The less transient time;
- Over-switch less than 20%;

The reference value is a unit level signal [1-5]. Figure 5 shows the analysed motor's automation scheme, including a PID regulator and figure 6 shows the indicial answer of the PID regulator close loop.

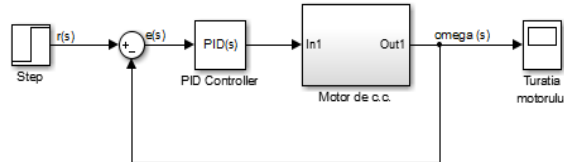


Fig. 5: The automation circuit for the independent wound DC motor.

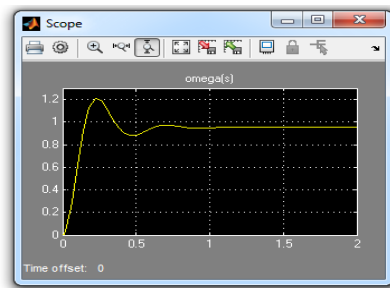


Fig. 6: The indicial answer ($\omega(s)$) of the closed loop system including a PID regulator.

From figure 6 we can deduct that there is a stationary error and it is necessary an integrative part. The over-regulation has a high value, being necessary the derivative component of the regulator, too. By refining these values we find an optimal value (figure 7), a value for which all the imposed requirements are satisfied.

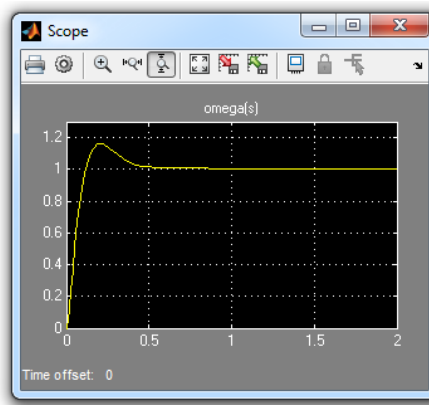


Fig. 7: The indicial answer ($\omega(s)$) of the closed loop system including a PID regulator.

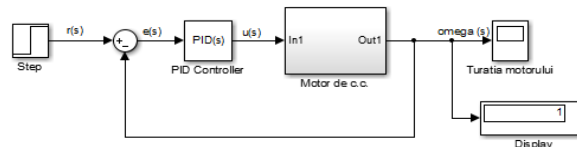


Fig. 8: The automation circuit ($P=120$; $I=320$; $D=5$) for the independent wound DC motor.

The stationary value of the system can be visualised by connecting at the output of a display block, as that one from figure 8. This block displays the last value, that of stationary mode (corresponding to $t = 2$ s).

7. Conclusions

The presented numerical models (figures 1 and 3) can be enhanced, considering the regulating possibilities by an adequate algorithm, that uses the information received from the transceivers – a current transceiver and a rotational speed transceiver. These can be engineered as a low-pass filter, their necessity being determined by the ripples of the rotor current, produced by the execution element or by the constructive structure itself.

In figure 2 there is shown the indicial answer of the system and we can notice that for $t = 1$ s, the output of the model is zero, inconvenience that can be solved by setting the *Step time* accordingly, so that the level signal will be applied at $t = 1$ s [2].

By the fine tuning of the regulator's parameters, the over-switch will be less and the stationary value will be close to zero [2].

The stationary value of the analysed system can be visualized by connecting a display block to the output, that will display the last value, meaning the stationary regime value (corresponding to $t = 2$ s).

In case of some more complicated building equipment processes, the Matlab/Simulink Model of figure 5 can become more complex.

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