MODELLING OF A SERIAL WOUND DC MOTOR SUPPLIED BY A SEMI-CONTROLLED RECTIFIER

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Summary: A serial wound DC motor is one of most used electrical machines in a small electrical instruments and home equipments by reason, that its speed is easily controlled by a supply voltage. Suppose that the motor is supplied by a semi-controlled rectifier and operate in open circuit loop. After representing of the mathematical model, a simulation model based on the Matlab-Simulink is derived; this allows for the determination of the waveforms of the speed current and torque of the machine for different state operation. Induced voltage of the rotor is determined as a function of the magnetic core saturation and of the armature reaction.

1. INTRODUCTION

Despite its disadvantages, serial DC motor belongs to the most used electric machines in home equipment as well as workshop hand tools. Thanks of its excellent regulation properties it is employed as drive motor of washing machines as well as professional mixers or mills.

Small wound DC motors are produced without compensating and commutation winding. Stator contains mostly two salient poles of exciting winding. Slotted exciting winding is used only for large outputs, where using salient poles motor diameter would enormously increase. Rotor is wound and lead out to commutator.
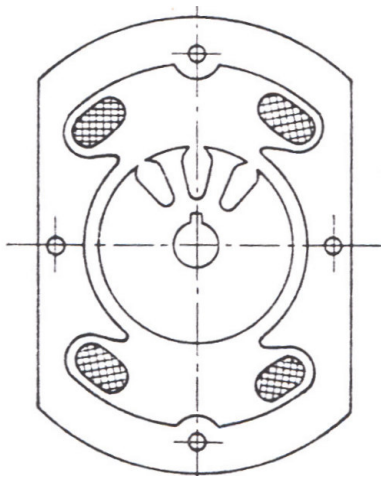

Fig. 1. Section of a two-pole serial wound motor

The number of commutator brushes is equal to the number of exciting winding poles. Since magnetic field of the machine is direct but variable, magnetic circuit is made from sheets. Stator and rotor are connected in series.
Fig. 1. shows the cross section of a two-pole DC serial wound motor.

2. MATHEMATICAL MODEL OF THE MOTOR

Mathematical analysis of serial motor is based on voltage equations, with certain simplifying assumptions:

- Mechanical losses of machine as well as losses in iron are neglected;
- Commutation influence is neglected. Perfectly commutating armature is assumed;

Figure 2 shows the equivalent circuit of a serial two-pole machine. Stator exciting winding with N_1 turns generates stator magnetic flux ϕ_1. Armature has two brushes on the diameter of commutator and it is displaced by α angle towards the axis of exciting magnetic flux. Rotor rotates with mechanical angle velocity ω.
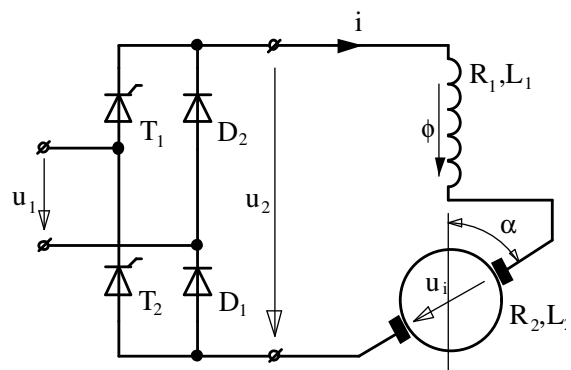

Fig. 2. Equivalent circuit of the universal motor

Suppose motor is supplied with variable voltage u, the following voltage equation can be written for the motor circuit:

$$u_2 = (R_1 + R_2) i + (L_1 + L_2) \frac{di}{dt} + u_i \qquad (1)$$

Where: R_1, R_2 is the resistance of stator or rotor of the machine; L_1, L_2 are the proper inductance of stator or rotor of the machine; u_i is internal induced armature voltage;

Following equation can be written for induced voltage:

$$u_i = M \cdot \frac{\partial i}{\partial t} \cdot \cos\alpha - M.i.\omega_m.\sin\alpha \qquad (2)$$

Instantaneous value of electromagnetic torque:

$$m = i^2.M.\sin\alpha \qquad (3)$$

Stator excitation magnetic field is deformed as a result of transversal magnetic field of armature. This phenomenon is called armature reaction. As a result of the armature reaction the neutral axis of excitation magnetic field is deflected from neutral position. Deformation value was investigated by calculating magnetic conditions of the machine by the method of finite elements. The results of magnetic field simulations were published in [1]. The calculated course of the displacement of machine neutral axis caused by current can be replaced with exponential mathematical function:

$$\alpha = a_1 + a_2 . e^{-\frac{abs(i)}{a_3}} \qquad (4)$$

Where: a_1, a_2, a_3 are coefficients of the function gained on the basis of values from [1].

Mutual and proper inductances of the machine are significant for electromechanical transformation in universal motor. Proper inductances affect the value of current as well as the power factor of machine. However, their change resulting from saturating does not significantly affect the machine properties. Proper inductances of machine are considered constants hereinafter.

On the contrary, the change of mutual inductance is not negligible. Its course depending on machine current can be found out from no-load measurement. For calculation needs, this functionality has been replaced with the analytic expression:

$$M = a_1 + a_2 . e^{-a_3 i^2} \qquad (5)$$

Function coefficients a_1, a_2, a_3 are calculated on the basis of measured values by simplex method, using Nelder-Mead algorithm.

3. DYNAMIC MODEL OF THE MOTOR

In order to compare the results offered by the mathematical model of the machine described above, with measured values, a simulation model was build.

To build model of the motor, the following parameters was used:

Power:	$800W / 230V - 50Hz$
Stator resistance:	$1,277\,\Omega$
Stator inductance:	$36,2\,mH$
Rotor resistance:	$1,564\,\Omega$
Rotor inductance:	$19,4\,mH$
Inertial moment:	$7,061.10^{-4}\,kgm^2$
Moment of friction:	$0,1\,Nm$

The behaviour of the machine was study and analysis of the overall dynamic and static steady state applying Matlab-Simulink software.

Suppose motor is supply for one phase harmonic main. Motor is running in open circuit loop. The block diagram shown in Fig.3 represent model used for this kind of study.

Fig. 3. Dynamic model of the motor.

4. DYNAMIC MODEL OF THE RECTFIER

Speed of universal motor is controlled through change of the supply voltage. To change the voltage a bridge semi-controlled rectifier is used. The thyristors of the rectifier are controlled by a gate pulses generator. The generator is synchronized to the mains voltage.

The thyristor T_1 turning-on occurs at the positive supply voltage by introducing the current gate pulse. The thyristor T_2 turning-on occurs at the negative supply voltage. The thyristors turning-off occurs after the voltage drops to zero value. It means that the output voltage of the rectifier is controlled by change in the phase shift of the turning-on pulses α (phase control angle), thus changing thyristors conduction angle in each half-cycle of the mains voltage. When the thyristor turning-off angle is 180°, then conduction angle γ is given by difference:

$$\gamma = 180 - \alpha \qquad (6)$$

On the figure 4 there is a dynamic model of the semi-controlled rectifier.

To determine the curve of the rectifier output voltage it is necessary to specify the unit pulse of the angle width of the thyristor conduction γ. In order to specify that, it is necessary to determine the phase control angle α.
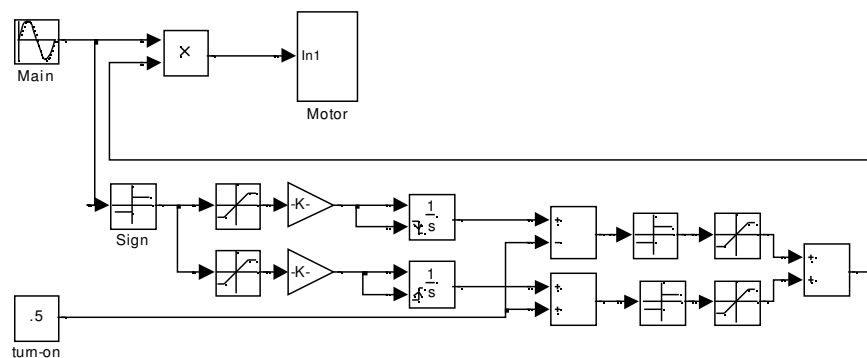
Fig. 4. Dynamic model of the rectifier.

Phase control angle is set by the pulse generator within the range of $\langle 0;1 \rangle$ by signal u_r, which corresponds to the phase control angle within interval of $\langle 0;\pi \rangle$. This is subsequently compared to saw-tooth voltage u_p that is derived from the supply voltage sinusoidal curve, for positive and negative half-period separately.
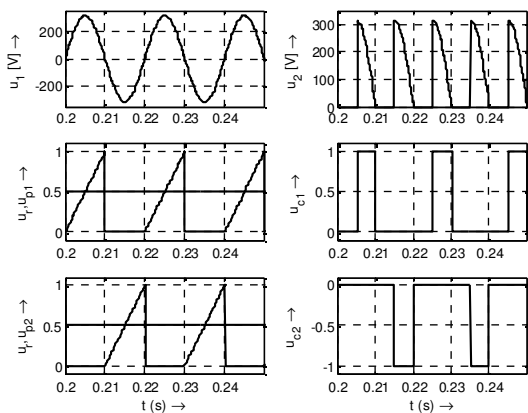

Fig. 5. Derivation of unit control pulse.

The comparator output are a unit pulses u_{1c}, u_{2c}, the width of which equals to $\langle \alpha;\pi \rangle$. The rectifier output voltage is derived by a multiplication of the main voltage and unit pulse.

Figure 5 shows the derivation of the control unit pulse.

5. SIMULATION RESULTS

To demonstrate the operation of the motor a simple simulation results are presents next.
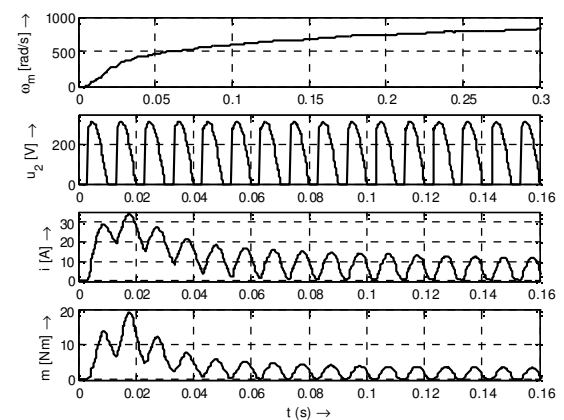

Fig. 6. Results of the simulations.

The Fig. 6 shows the simulation wave of the speed, voltage, current and torque of the machine

which is started by simply connecting to the converter working with turn-on angle of 60°. Motor is loaded by a constant torque load $0,5\,Nm$.

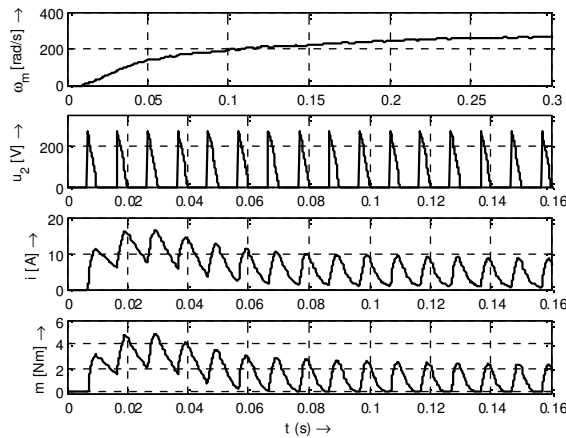*Fig. 7. Results of the simulations.*

The Fig. 7 shows the simulation waves of the start of the machine. Converter works with turn-on angle of 120°. Motor is loaded by a constant torque load $0,5\,Nm$.
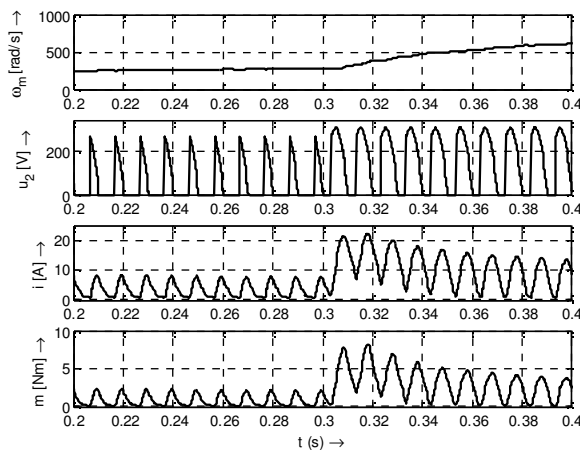

Fig. 8. Results of the simulations

The Fig. 7 shows the simulation waves of motor quantities by dynamic change of the turn on angle of the converter. Machine is started with turn on angle of 120°. In time of $t = 0,3\,s$ the turn on angle is steeply changed on the angle of 60°.

6. CONCLUSION

In a present paper a dynamic model of the serial DC wound motor and semi-controlled thyristors rectifier for computer simulation is presented. The model of the was build using the circuit parameters determined by measurements. The result of the simulation for dynamic state are showed.

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