The Hybrid Stepper Motor Modeling in Simulink

Dmitry Samokhvalov PhD, IEEE Member, Sergei Stoliarov IEEE Student Member,
Andrey Kekkonen
Saint-Petersburg Electrotechnical university "LETI" Department of Robotics and Industrial Automation
dmitry.samokvalov@gmail.com
serj.stolyarov@gmail.com
mias812@yandex.ru

***Abstract* – the article is devoted to creation of clarified mathematical model of stepper motor in Simulink. The main advantage of this model is opportunity for further development to taking into account the steps missing and torque drops which could not be accounted for the hybrid stepper motor library block.**

Keywords – stepper motor; mathematical model; Simulink;

1. INTRODUCTION

Simulink as the environment for visual modeling of a technical systems is the necessary product for observing an electrical drives systems. This necessity is caused by the positive perception of visual modeling by students, prevalence of Simulink in the scientific community and by ability to create user's blocks that are programmable on the high level language similar to the C.

Stepper motor block from SimPowerSystems library is in the form of the masked subsystem.

After decomposition of the library block, the following drawbacks were revealed:

1. It is impossible to trace the influence of input parameter "step angle" on system behavior.
2. There are three subsystem levels in the model structure. This makes Simulink model hard to be compared with fundamental equations.
3. The powersysdomain sub-block has a locked logic, which can't be analyzed. This impedes to find out how phase voltages (supplied pulses) are processed in the further model blocks .

The main goal of this work is to design a new Simulink model of hybrid stepper motor that allows to get rid of the drawbacks of the library model.

2. FUNDAMENTAL EQUATIONS

In the case of two-phase motor the back EMF induced in the coil A is given by [1]:

$$E_A = \omega p \psi_m sin(p\theta) \quad (1)$$

Similary, the back EMF induced in the coil B is given by:

$$E_B = \omega p \psi_m sin(p\theta - \lambda) \quad (2)$$

where p – the rotor teeth number;
ψ_m –the maximum flux linkage;
Θ – the angular position of the rotor;
λ – the phase angle.

In this case of two stator phases $\lambda = \frac{\pi}{2}$ and the E_B equation can be modified as follows:

$$E_B = \omega p \psi_m cos(p\theta) \quad (3)$$

In according to the equations 1-3 the phase currents equations are in form of [2]:

$$L\frac{di_A(t)}{dt} = V_A(t) - Ri_A(t) + \omega(t)p\psi_m sin(p\theta)$$

$$L\frac{di_B(t)}{dt} = V_B(t) - Ri_B(t) - \omega(t)p\psi_m cos(p\theta) \quad (4)$$

where V_A, V_B - the phase voltages;
R – the resistance of the phase winding;
i_A, i_B – the phase currents.

The equations of the components of electromagnetic torque generated by the separate phases are as follows [3]:

$$T_A = i_A p\psi_m sin(p\theta)$$

$$T_B = i_B p\psi_m cos(p\theta) \quad (5)$$

If the stator and rotor have teeth the total torque is complemented by reluctance torque component called the detent torque or cogging torque Td which formula is [2]:

$$T_d = T_{dm} sin(2p\theta) \quad (6)$$

where T_{dm}– the maximum detent torque.

The instantaneous value of electromagnetic torque of the stepper motor is the sum of phase torques and detent torque [4]:

$$T_e = -i_A\, p\psi_m sin(p\theta) - i_B\, p\psi_m cos(p\theta) - T_{dm} \quad (7)$$

The rotor motion is described by equation of rotating motion, which takes into account the sum of rotor inertia, load torque, electromagnetic torque and the viscous friction torque [3]:

$$J\frac{d\omega(t)}{dt} = T_e(t) - T_L - B\omega(t) \qquad (8)$$

By substitution the equation (7) into (8), the following can be obtained:

$$J\frac{d\omega}{dt} = -i_A p\psi_m \sin(p\theta) - i_B p\psi_m \cos(p\theta) - \\ - T_{dm}\sin(2p\theta) - T_L B\omega; \qquad (9)$$

The detent torque value is negligible compared with phases torques and as usual not even counted [2].

3. THE LIBRARY MODEL STRUCTURE

The structure of library block has three levels of subsystems (fig.1, fig.2, fig.3) and uses the powersysdomain block. This one makes the model merely looking but this structure is hides most of processes and makes the model difficult to observe.

The system which is under library model mask is represented in fig.1. Here are two subsystems – Model and powersysdomain. The second one is closed for browsing.

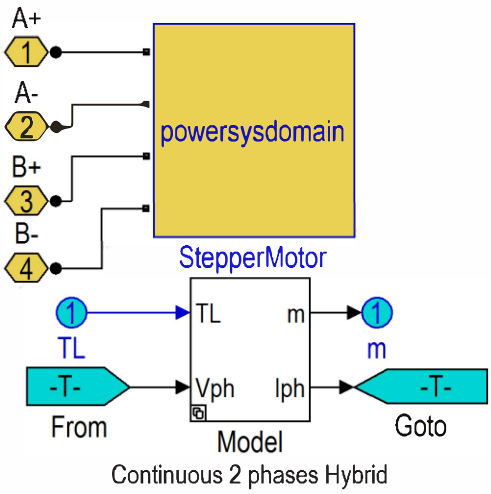


Fig.1. Looking under library's model mask

When opening the subsystem named Model, the system represented in fig.2 can be seen. Here are three connected subsystems – windings, FEM and Mechanical. This subsystems shows separately each of three parts of the machine – electrical, electromagnetical and mechanical.

If one of these three subsystems being opened, the detailed model will be available for editing and analysis. For example the fig. 3 shows a FEM subsystem.

This structure is difficult to perceive. For example there is not named output1 in the FEM subsystem that becomes input3 in the winding subsystem, or output 2 that becomes input4 and so on.

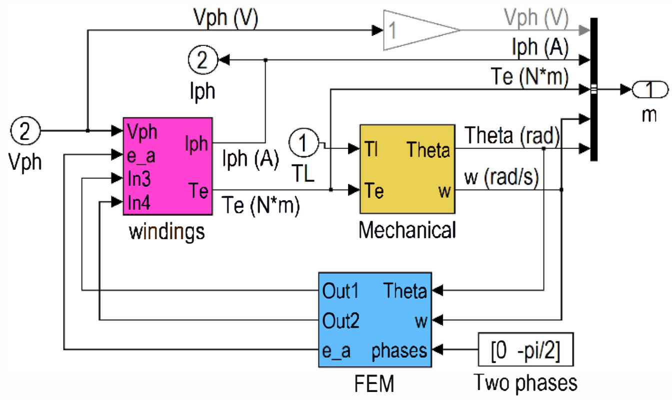


Fig.2. The content of the Model block

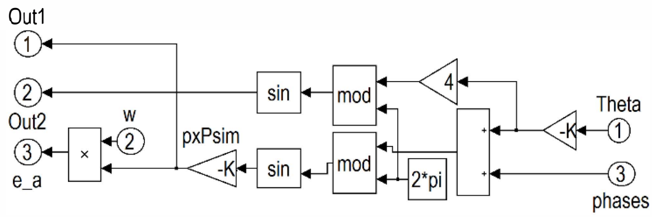


Fig.3. The content of the FEM subsystem

From the comparing fundamental equations with the model of Simulink library block Stepper Motor it was found that the step angle α that is specified in the model parameters window is invisibly transforms to the rotor teeth number p.

4. THE DESIGNED MODEL

To set the dependence between angle α as input parameter of the model and rotor teeth number p as design parameter let's consider the equation [2]:

$$\alpha = \frac{360}{p * N} \qquad (10)$$

where p – rotor teeth number;

N – stator phases number;

In according to this equation the rotor teeth number calculates as follows:

$$p = \frac{360}{\alpha * N} \qquad (11)$$

Eq. (11) can be realized by the scheme shown in the Fig.4.

In accordance with (11) for a two-phase stepper motor the step angle α=1,8° corresponds to the rotor teeth number p=100.

The new Simulink model, created by the equations (1), (3) – (7), (9), (11), is shown in fig.5. As well as the library model the new model is based on the masked subsystem but contain only one sub-block.

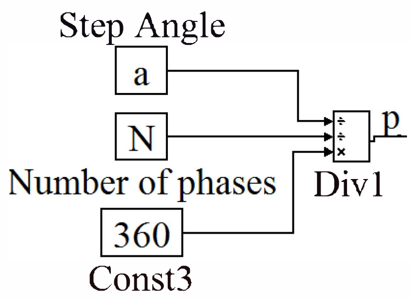


Fig4 The transformation of the step angle α to the rotor teeth number p.

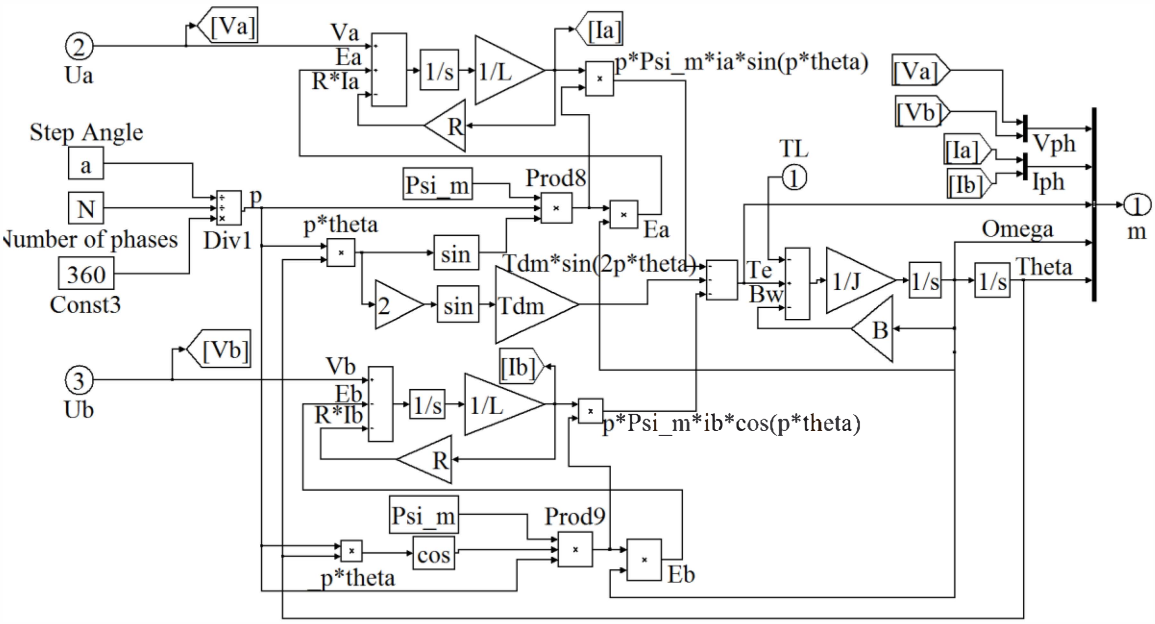


Fig.5. The structure of the designed model

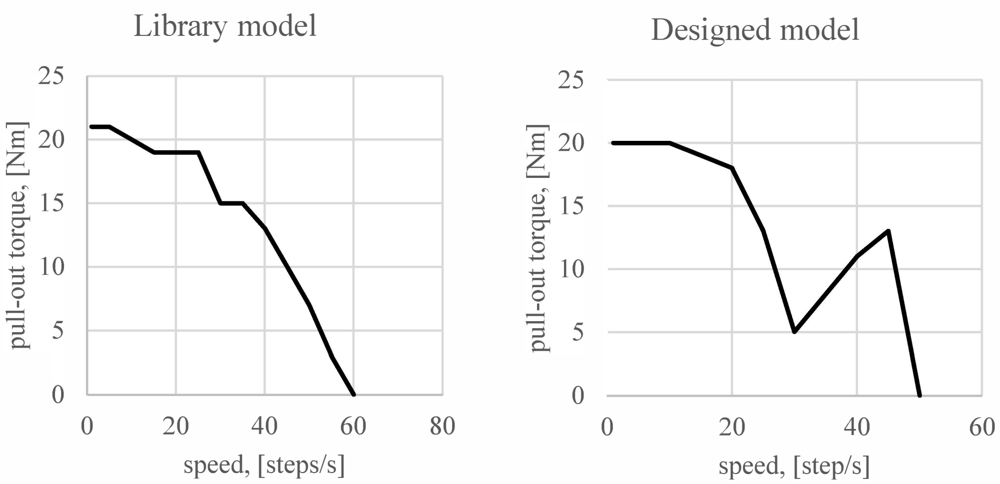
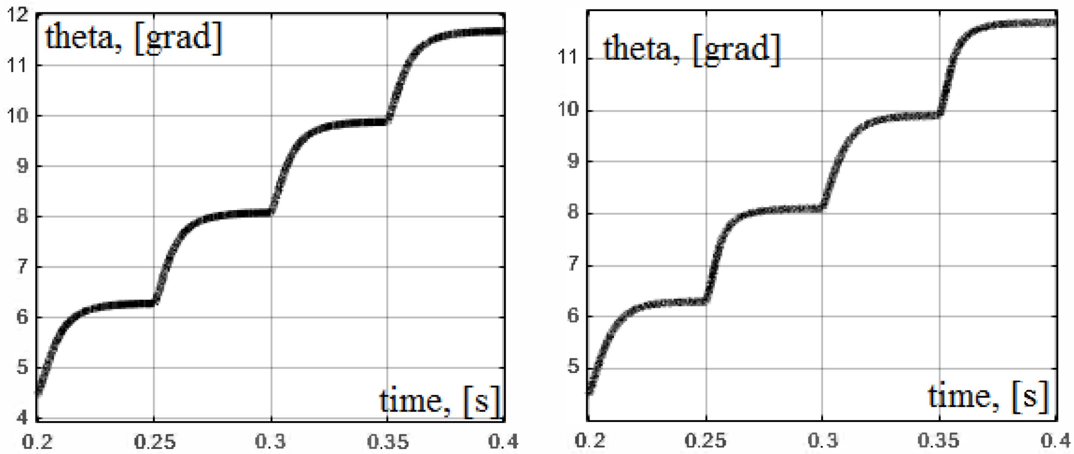


Fig.6 Simulated pull-out torque vs. speed characteristics.



a) b)

Fig.7. Simulated rotor motion characteristics for the library model (a) and the proposed model (b

In the designed model unlike to library model the phases are represented separately. This allows to watch clearly the forming of the back-EMF and the torques of the each phase and to perceive the model easier because the process of comparing the Simulink model with the fundamental equations became lightly.

By Simulink models pull-out torque vs. speed dependence and step response curve were received. Pull out torque characteristics (fig.6) shoes significant differences between two models. The designed model has torque drop at speed equal to 30 step/s, while the library model hasn't.

Angle response curves are similar for both models (fig.7).

5. CONCLUSIONS

The designed Simulink model explicitly reflects the influence of the step angle. It reflects the formation of back-EMF and phases torques in a clear manner. The structure of model was simplified and there is no longer need to use block «powersysdomain». This makes it possible to abandon the binding blocks like controlled voltage sources. New model allow to establish easily an original equations by the new model.

The pull-out torque curve of the proposed model has the region where values of the pull-out torque decrease rapidly and then rise back. Such behavior of the curve is similar to theoretical curve (fig.8).

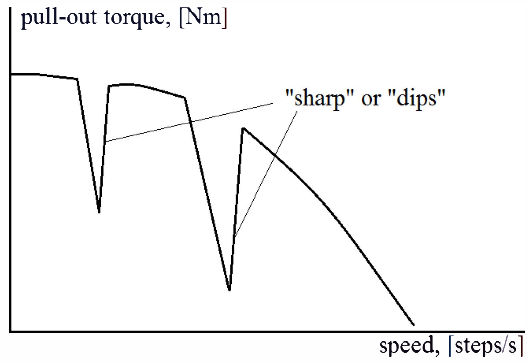


Fig.8.Theoretical curve of pull-out torque characteristic

Thereby the new model in contrast to library model reflects the mechanical resonance, which occurs in the system at the natural frequencies of the machine.

REFERENCES

[1] Acarnley. «Stepping Motors: A Guide to theory and practice 4th edition» Milton Keynes U.K.: Lightning Source UK ltd 2007.pp.1-89

[2] T. Kenjo and A. Sugawar, «Stepping Motors and Their Microprocessor Control». New York: Oxford Science, 1994.pp.69-100

[3] J.Chiasson «Modeling and high performance control of electric machines» IEEE Press series on power engineering., 2005, pp.591-651

[4] Stepper Motor. Available at: http://www.mathworks.com/ help/physmod/sps/powersys/ref/steppermotor.html