Power Engineering, Control and Information Technologies in Geotechnical Systems – Pivnyak, Beshta & Alekseyev (eds)
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Compensation of the cogging torque by means of control system for transverse flux motor

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ABSTRACT: The problem of the cogging torque influence of gearless drives with transverse flux motor is described. The way of the cogging torque compensation for transverse flux motor has been proposed. The task of the delay between current reference and the reproduced electromagnetic torque and a ratio correction factor, which depend on the frequency, has been solved. Recommendations are given on using the methods of control law synthesis.

1 INTRODUCTION

Gearless drives with synchronous motors with permanent magnets (PMSM) are used in more and more mechanical applications that require high torque, because of the importance of technology improvement by means of electric drives (O. Beshta 2012). One of the alternatives to replace the standard PMSM in gearless drives is a transverse flux motor (TFM) with permanent magnets. The magnetic flux of TFM runs transversely to the plane of rotation of the rotor. The magnetic field still rotates because of the geometry of the motor. There are geometrical shifts between phases by 120° electrical degrees. TFM has advantages such as high torque at low speed because it can have a big number of poles, small loss compared to the same conventional PMSM because the TFM has no front part in its winding.

2 RESEARCH

Along with the advantages TFM has some of disadvantages: high leakage inductance and torque ripples. These ripples have a negative influence on the accuracy of regulation and bring acoustic noise and vibration, which often is not acceptable in gearless drive applications. Much of the ripple of the torque happen because of cogging torque. Particularly significant influence has cogging torque in low speed gearless drives, because of large magnetic induction of permanent magnets in air gap. There are many ways to reduce the cogging torque for classical PMSM by constructional changes, such as bevel of stator teeth or permanent magnets on the rotor, choosing the optimal combination of number of teeth of the stator and rotor poles, improving the system of the excitation on the rotor and stator design improvements. These methods are also suitable for TFM (Wan-Tsun Tseng 2008), but they lead to increased cost and complexity of electric motor production. Another way is creating such a harmonic component of stator current that would compensate cogging torque.

Cogging torque is a function of rotor position. It is difficult to calculate the value of cogging torque analytically, because it is a function of the angle of the rotor position and the result will not be too exact. It is possible to remove the torque function of the angle of the rotor position using special equipment at low speed and without load, but this method requires substantial financial costs. An alternative is to calculate the cogging torque with a specialized program for the calculation of electromagnetic fields. One of these specialized programs is Maxwell (ANSYS), which is a finite element design package.

Maxwell calculates a cogging torque for TFM in idling mode of a generator. The rotational speed is set at 1°rad/sec, the required simulation time is calculated very easy. The TFM with external rotor and the following parameters was taken for example:

$T_n = 100Nm$, $n_n = 187{,}5\ {}^{1}\!/_{\min}$, $f_n = 50Hz$,

$I_n = 4{,}5A$.

In Fig. 1 the cogging torque function of the angle of rotation of the rotor, which is obtained in the program Maxwell, is shown.

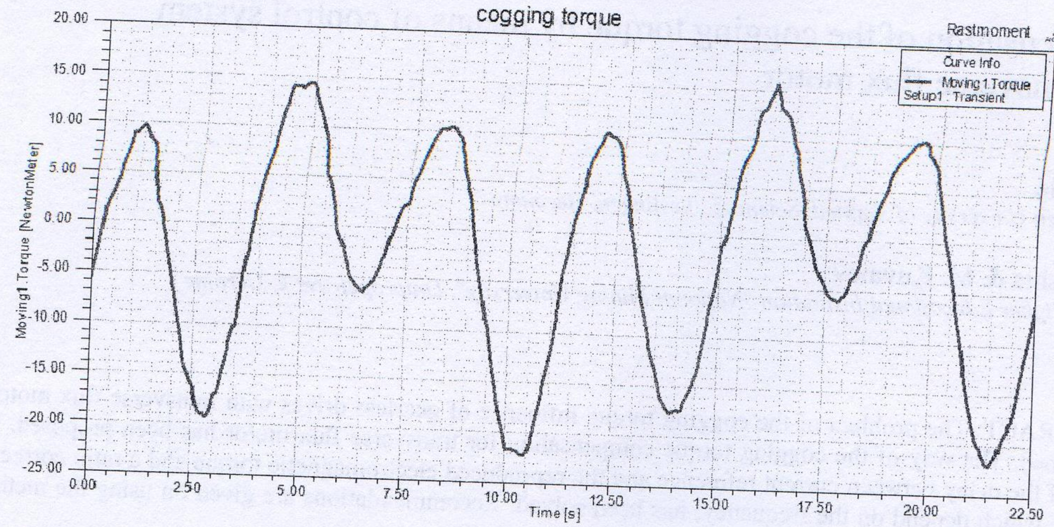


Figure 1. Cogging torque of TFM simulated in Maxwell

The equation for cogging torque function of the rotor was received with the help of Maxwell special tools. The harmonic analysis of cogging torque was done for this purpose.

As a result of this analysis we've got amplitude (Fig. 2) and phase shifts (Fig. 3) of harmonics for the cogging torque.

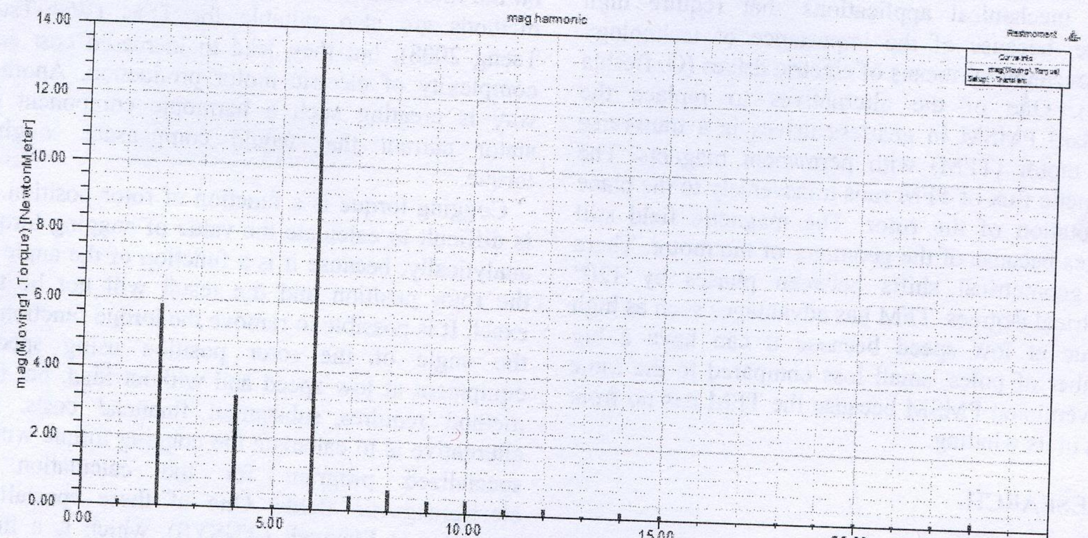


Figure 2. Amplitude of harmonics of the cogging torque calculated in Maxwell

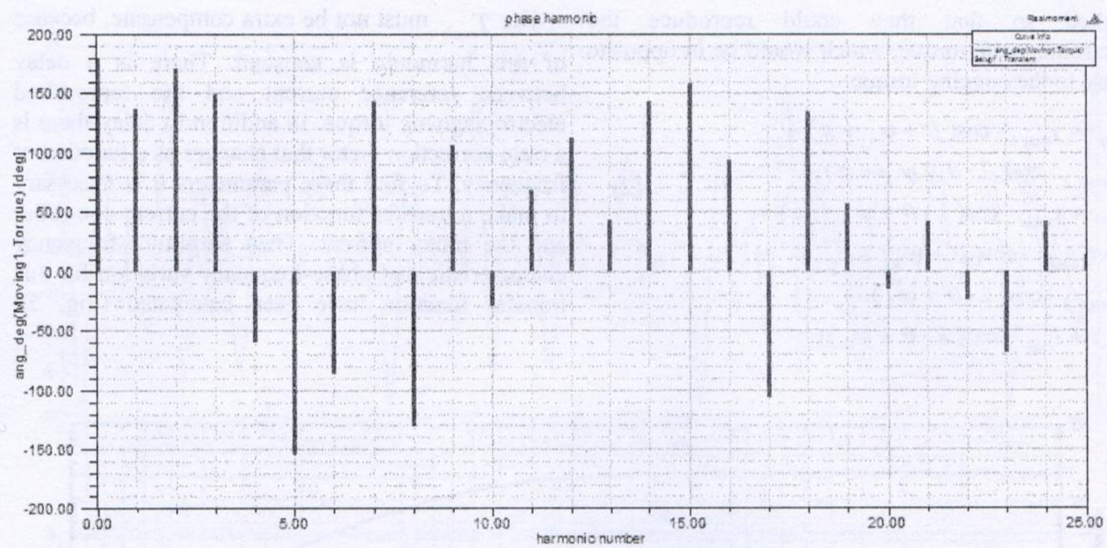


Figure 3. Phase shifts of harmonics of the cogging torque calculated in Maxwell

Using the results of harmonic analysis we've got the equation for cogging torque as a function of the rotor angle in the form of a Fourier series:

$$T_{cog} = T_{cog\ 0} + T_{cog\ 1} \times \times \cos(\theta + \psi_1) + T_{cog\ 2} \times \times \cos(2 \cdot \theta + \psi_2) + \ldots + + T_{cogk} \cdot \cos(k \cdot \theta + \psi_k) \quad (1)$$

According to equation the function $T_{cog} = f(\theta)$ was generated in Simulink application (Fig.4).

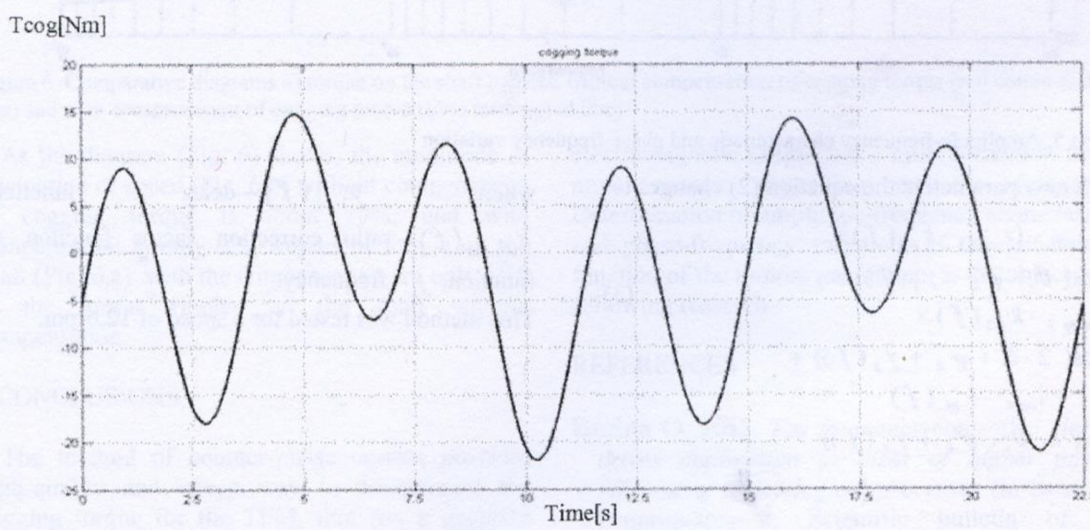


Figure 4. Cogging torque of TFM in Simulink

To compensate the cogging torque, the classical vector control system with the rotor position sensor (digital position encoder) was taken because the value of the cogging torque depends on the rotor angle.

In the classical vector control system for PMSM the component of current i_d is always zero. At the input of the i_q current regulator the appropriate reference for harmonic components should be applied so that they could reproduce the electromagnetic torque, which would be in opposite phase to the cogging torque:

$$
\begin{aligned}
i_{cogq} &= i_{cogq\,1} \cdot \cos(\theta + \psi_1 + \pi) + \\
&+ i_{cogq\,2} \cdot \cos(2 \cdot \theta + \psi_2 + \pi) + \\
&+ \ldots + i_{cogk} \cdot \cos(k \cdot \theta + \psi_k + \pi) = \\
&= -(i_{cogq\,1} \cdot \cos(\theta + \psi_1) + \\
&+ i_{cogq\,2} \cdot \cos(2 \cdot \theta + \psi_2) + \\
&+ \ldots + i_{cogk} \cdot \cos(k \cdot \theta + \psi_k))
\end{aligned} \qquad (2)
$$

The T_{cog0} must not be extra compensate, because of this harmonic is constant. There is a delay between reference current and the reproduced electromagnetic torque. In addition to delay there is a ratio correction factor that changes as a function of frequency. To find these parameters it is necessary to make a transfer function of the current controller and the motor current. Than amplitude-frequency characteristic and phase-frequency variation for this transfer function have been calculated (Fig. 5):

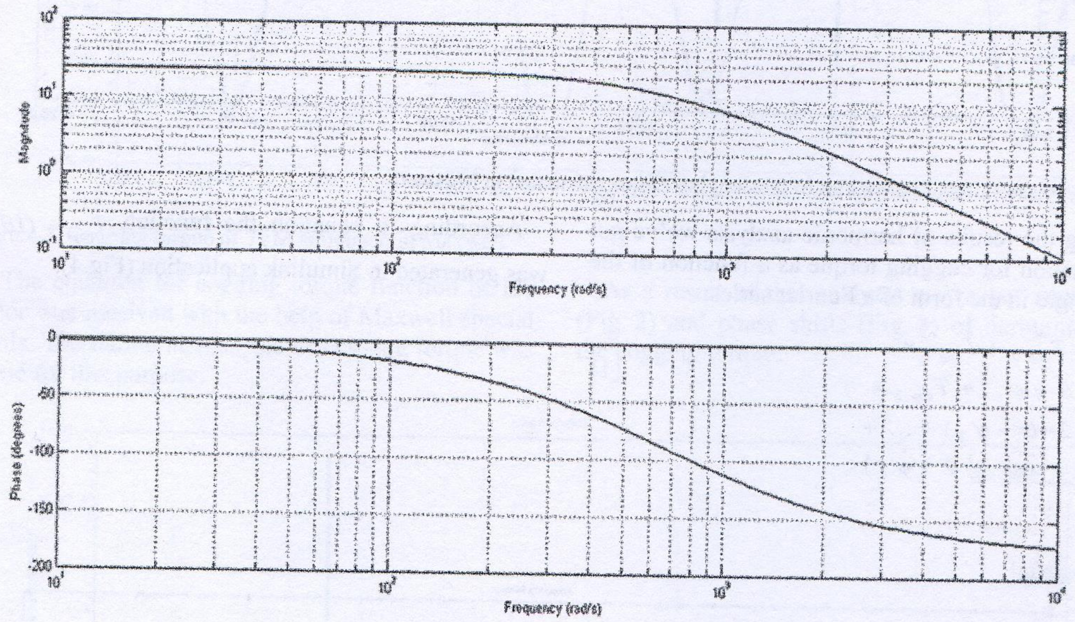


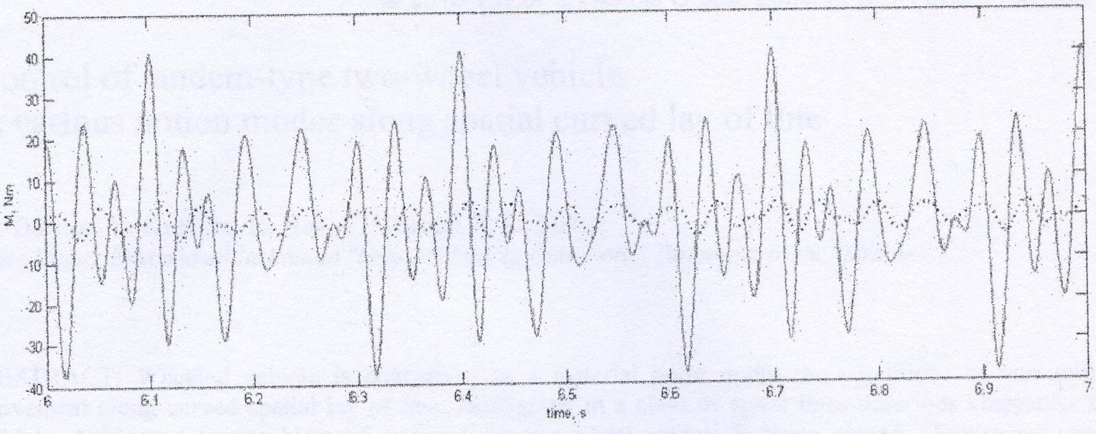
Figure 5. Amplitude-frequency characteristic and phase-frequency variation

With new parameters the equation (2) changes to:

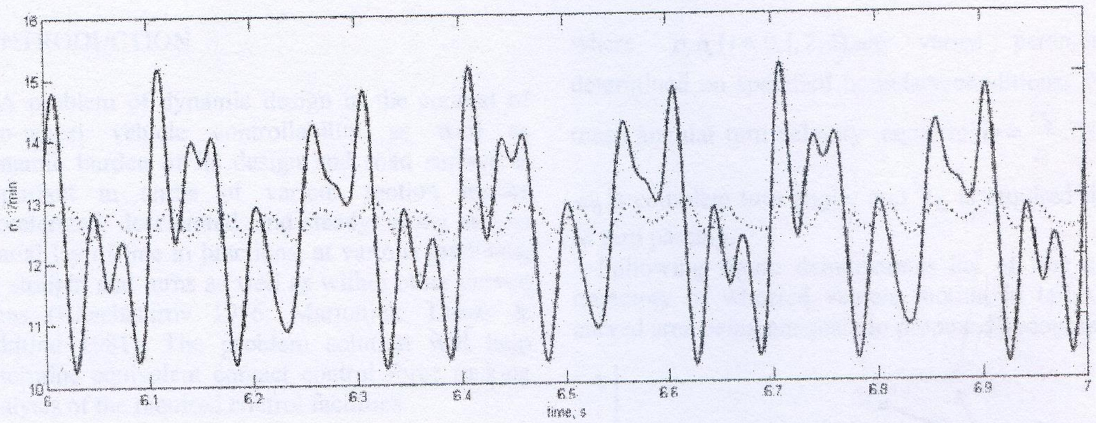
$$
\begin{aligned}
i_{cogq} &= -(i_{cogq\,1} \cdot k_{a1}(f) \times \\
&\times \cos(\theta + \psi_1 + \gamma_1(f)) + \\
&+ i_{cogq\,2} \cdot k_{a2}(f) \times \\
&\times \cos(2 \cdot \theta + \psi_2 + \gamma_2(f)) + \\
&+ \ldots + i_{cogk} \cdot k_{ak}(f) \cdot \\
&\cdot \cos(k \cdot \theta + \psi_k + \gamma_k(f))
\end{aligned} \qquad (3)
$$

where $\gamma_{1\ldots k}(f)$ – delay function, $k_{a1\ldots ak}(f)$ – ratio correction factor function of function, f – frequency.

This method was tested for a speed of 12,6rpm.



a



b

Figure 6. Comparative diagrams a) torque on the shaft b)speed without compensation of cogging torque (red continuous line) and with compensation of cogging torque (blue interrupted line)

As the diagram (Fig. 6) shows, the amplitude of fluctuation of speed (Fig. 6,b) without compensation of cogging torque is about 19%, and with compensation is only 2%, ripples of torque on the shaft (Fig. 6,a) with the compensation are only 1/10 of the torque ripples on the shaft without compensation.

3 CONCLUSIONS

The method of counter-phase current provides high-quality and cheap way to compensate the cogging torque for the TFM, that has a negative influence on the quality of the production process, especially in gearless drives at low speed. Compensation of torque ripples can be done by the vector control system with the rotor position sensor (digital position encoder) because the cogging torque is the function of the rotor angle. The delay between current reference and the reproduced electromagnetic torque and a ratio correction factor must change depending on the frequency. Determination of amplitude-frequency characteristic and phase-frequency variation, as the generalized function of the motors parameters is the object for a following research.

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