Model of Magnetic Precession Gear Dynamics Based on 3D Finite Element Analysis and Prototype Investigation

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Łukasz Macyszyn,[1] Cezary Jędryczka,[2]
Michał Mysiński[2]

[1] Poznan University of Technology, Faculty of Mechanical Engineering, Poznan, Poland
lukasz.macyszyn@put.poznan.pl
[2] Poznan University of Technology, Faculty of Control, Robotics and Electrical Engineering, Poznan, Poland
cezary.jedryczka@put.poznan.pl, michal.mysinski@put.poznan.pl

The presented research is focussed on analysis of dynamics of a two-stage magnetic precession gear system. In the proposed mathematical model of studied gear dynamics two approaches have been considered. Firstly, the model has been defined using the torque versus angle characteristics determined by means of detailed 3D FEM model of the magnetic field. In the second approach the model is based on torque vs. angle characteristics determined by measurements of the prototype step response. The results obtained by the two methods are compared and discussed.

Keywords:
magnetic gear,
Finite Element Method,
analysis of dynamics,
precession gear,
MATLAB Simulink

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I Introduction

Magnetic gears have garnered significant attention owing to the development of high-energy-density magnets utilizing rare-earth components and the refinement of precise modelling techniques for electromagnetic phenomena through Finite Element Method (FEM) analysis. In comparison to conventional mechanical gears, magnetic gears offer contactless transmission of torque, thereby mitigating wear, minimizing vibrations and noise, and providing inherent overload protection [1].

For the successful implementation of a new magnetic gear design, the development of a comprehensive model of the dynamic behaviour of the gear is necessary as the occurrence of magneto-mechanical resonances of a gear can be the cause of powertrain system failure.

The paper deals with a model of a two-stage magnetic precession gear dynamics. The construction and design of the discussed gear was introduced by the authors in [2]. Magnetic precession gear provides the possibility of obtaining a notably higher ratios compared to the currently known magnetic gears solutions.

II Design of a two-stage magnetic precession gear and model of dynamics

The two-stage magnetic precession gear (MPG) is build of four key components: the input shaft (a), the immovable ring (b), the intermediate ring (c) and the output ring with the output shaft (d). Permanent magnets are fixed to the circumferences of each ring. The kinematic scheme of discussed MPG is illustrated in Figure 1. A detailed description of the gear design and its kinematic analysis were presented in [2]

Two-stage magnetic precession gear is very complex system, because intermediate ring moves with a precession motion (which is a combination of rotations about two inclined axes). To simplify the model, only the dynamics about main axis of the gear was analysed. For better understanding the mathematical model of the gear dynamics, in Figure 2 the MPG operation was presented as a two-stage gear with 'magnetic springs' representing the analogies to torque vs. internal load angle characteristics known from synchronous machines.

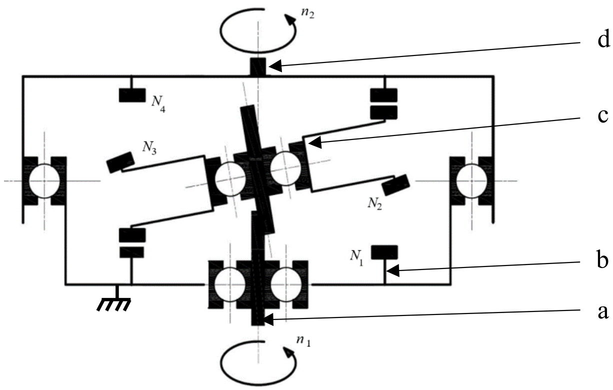

Figure 1: Kinematic scheme of the MPG [14]:
n_1 - input rotational speed, n_2 - output rotational speed
N_i - the number of neodymium magnets on the i-th ring

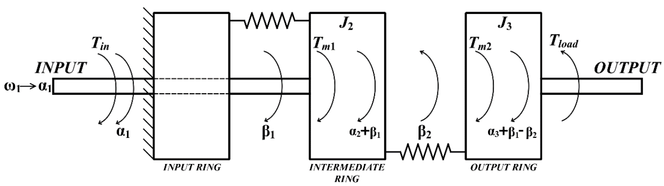

Figure 2: Graphical interpretation of a MPG dynamic model

In order to formulate the mathematical model, it is required to determine two equations of dynamics of the movable elements of the described MPG. The dynamic of the intermediate ring describes equation (1) and the dynamic of the output ring describes equation (2). Both equations contain the mechanical quantities, i.e. the load torque (T_{load}), the moments of inertia of the intermediate ring J_2 and the output ring J_3, as well as coefficients k_{f2} and k_{f3} representing mechanical friction and losses in the magnetic circuit caused by eddy currents and magnetic hysteresis phenomena. It was assumed that these 'magnetic' losses depend directly on the velocity in changes of the magnetic field.

$$J_2 \frac{d^2\alpha_2}{dt^2} = T_{m1} - T_{m2} - k_{f2}\omega_2 \tag{1}$$

$$J_3 \frac{d^2\alpha_3}{dt^2} = T_{m2} - T_{load} - k_{f3}\omega_3 \tag{2}$$

Detailed mathematical model was derived in [3].

In order to study the performance of the proposed MPG the mathematical model was implemented the MATLAB Simulink environment. Figure 3 presents model of the whole gear, while Figure 4 presents a detailed model for the second gear stage.

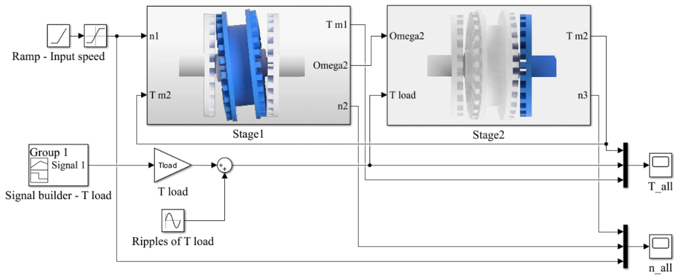

Figure 3: Model of MPG developed in MATLAB Simulink environment

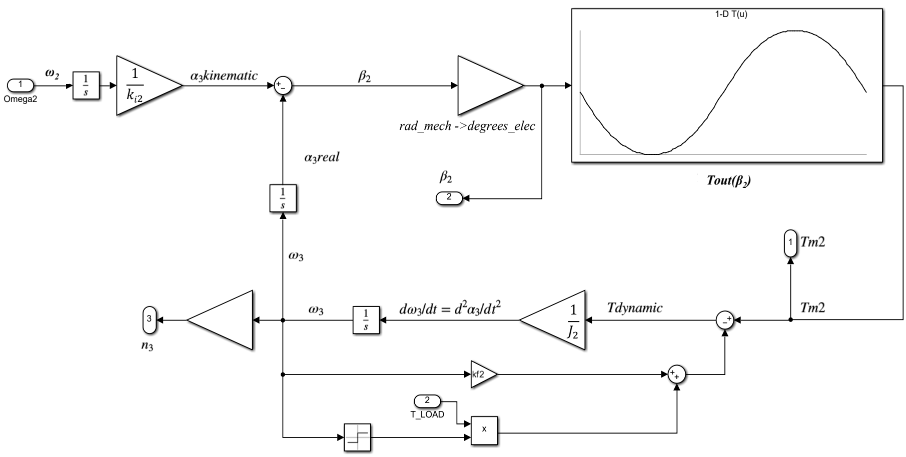

Figure 4: Model developed in MATLAB Simulink environment- second stage of MPG

In preliminary model, the magnetic torques characteristics were determined by means of the 3D FEM model of the magnetic field and implemented in Simulink as lookup table.

Then the MPG prototype was investigated on a test stand, shown in Figure 5. The dynamic response of the MPG output ring is presented in Figure 6.

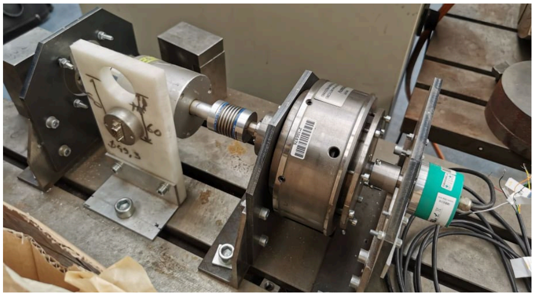

Figure 5: MPG test stand

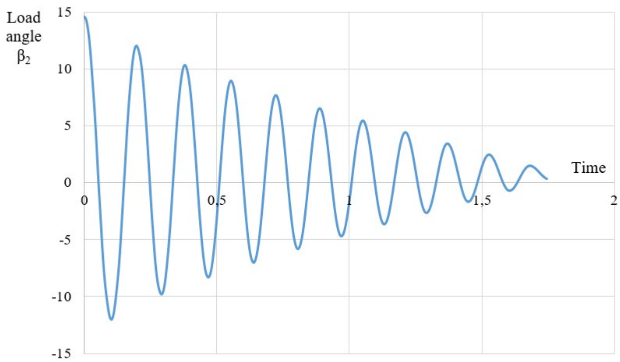

Figure 6: Dynamic response of the output ring

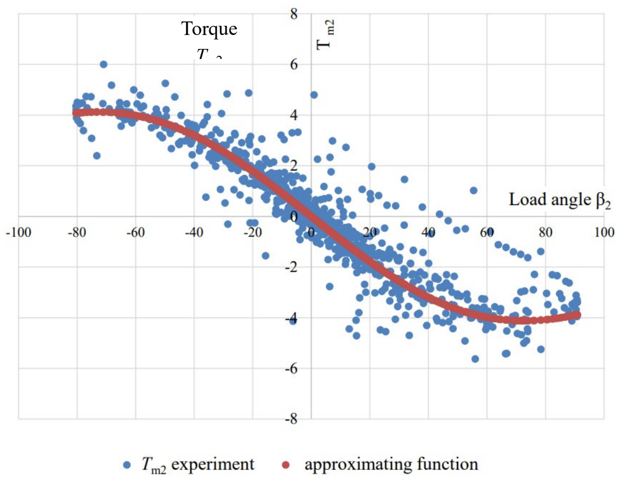

Figure 7: Approximation of magnetic torque function based on MPG prototype examnination

Based on experimental research, the magnetic torque function was approximated (Figure 7) and implemented in Simulink instead of 3D FEM characteristic.

The results of simulations carried out with both variants of model was compared and discussed.

Summary

The research described in the paper demonstrates how to carry out an analysis of the dynamics of a magnetic gear.

Detailed results of the conducted research will be presented during EPNC 2024 conference in Portorož and published in the full version of the paper.

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