DESIGN AND ANALYSIS OF THE LOW COST INDUCTION GEAR FOR VERTICAL AXIS WIND TURBINES

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

Poznan University of Technology, Institute of Industrial Electrical Engineering[1], Faculty of Mechanical Engineering[2]
Piotrowo 3a, 61-138 Poznan, Poland, e-mail: michal.mysinski@put.poznan.pl

***Abstract* - This paper investigates the concept of induction gear based on eddy current phenomena. In the research, impact of the selected dimensions of the magnetic circuit on the electromagnetic torque and gear estimated efficiency has been examined. Numerical models that employ the finite element method have been developed to determine the electromagnetic performance of variants studied. On this basis, the best design solutions were identified for future studies.**

I. INTRODUCTION

Due to lack of mechanical contact leading to practically lack of wear, the magnetic gears have gained increased attention over the world in the past years [1, 2]. Magnetic gears can change speed and transmit torque without any mechanical contact. Therefore, they provide low vibration, low noise, and do not require maintenance. Despite the advantages discussed as a result of the use of permanent magnets and the high mechanical complexity, the magnetic gears are relatively expensive [3]. In this paper, we propose and study the concept of a low-cost and mechanically simple induction gearbox dedicated to work as a multiplier gear for small wind turbines with a vertical axis of rotation (VAWT [4]). The gear ratio (k_m) in the presented concept results from the mechanical difference between the diameter of the drive rotor (with permanent magnets) and the eddy current ring. The models in study assume an analysis of the variation of the eddy current ring width and also a variation of the ring material ratio in Al-Fe and Cu-Fe combinations. In addition, systems with the number of pole pairs *p* equal to 1 and 2 were considered.

II. CONCEPT OF INDUCTION GEAR

As is well known from Maxwell's fundamental equations according to Faraday's Law, an alternating magnetic field *B* induces an electric field *E* in a conductor causing currents *I* to flow. These currents are known as eddy currents. The current thus induced produces a magnetic field *B′* counteracting the external field *B*. This phenomenon is widely used in various fields of engineering, among others, for induction heating or induction braking. Figure 1 shows the operational principle of the prototype.

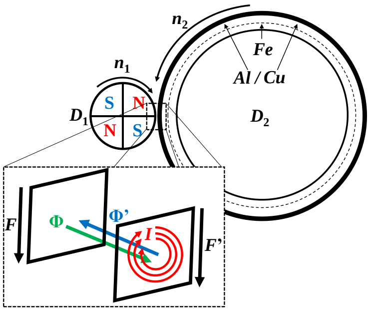

Fig. 1. Operational principle of the induction gear

As illustrated in Figure 1 when the rotor D_1 rotates at speed *n1,* it produces from the perspective of a conducting ring an alternating magnetic field Φ excited by the arrangement of neodymium magnets of *p* pairs of poles. Under the influence of the field Φ, eddy currents *I* are induced in the ring made of aluminium and copper/iron, which in turn produce a magnetic flux Φ' coupling the two rotating systems (rotor and ring) together. This causes the ring D_2 to rotate at constant load with a speed n_2. The mechanical ratio of diameters can be determined for the system:

$$k_m = \frac{D_2}{D_1} \tag{1}$$

where: D_1 - diameter of the rotor, D_2 - diameter of the ring.

Assuming a rigid transmission as in the mechanical gear, the gear ratio would be equal to k_m. Of course it should be highlight here that due to asynchronous operation resulted from the fundamentals of electrodynamic forces caused by eddy currents the real gear ratio k_{mr} will depend on the load torque of the gear. Another important aspect regarding the proposed concept is that the driving torque can be applied to the ring and, in effect, the rotor with magnets will be driven.

III. NUMERICAL MODELS

To study the performance of the proposed induction gear concept, numerical models exploiting the finite element method (FEM) have been developed in the commercially available Ansys Maxwell FEM package. The six variants of the gear have been studied: a) with the aluminium ring (*Al*), b) with the steel ring covered by the aluminium layer (Al-Fe), and c) with the steel ring covered by the copper layer (*Cu-Fe*). For all three models the rotors of *p*=1 and *p*=2 have been studied, giving in total six variants of the design. All models have been developed incorporating parameterization of the selected design variables, among others, the rotor and ring diameter ratio k_m, the speed ratio ($k_e=n_1/n_2$) as well as the ring materials described by the parameters w_{Al} and w_{Cu}. In the analysis the planar symmetry of the magnetic field has been assumed and thus the field problem hasbeen reduced to 2D. The diameter D_2 and ring thickness *g* were also parameterized. Figure 2 illustrates the selected parameters incorporated into the models.

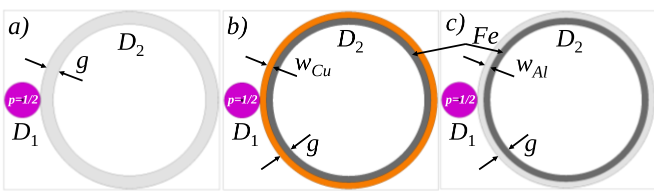

Fig. 2. Induction gear models: a) thickness of the ring *g*, b) filling of *Cu-Fe* ring w_{Cu}, c) filling of *Al-Fe* ring w_{Al}

IV. RESULTS

Analyses of the performance of the proposed gear have been carried out for the following parameters: Variant a) the (*Al*) ring thickness w_{Al} in the range of 10 to 100 mm and diameter ratio *km* = 5 to 15; Variants b) and c) (*Al-Fe*) and (*Cu-Fe*) the thickness of the aluminium and copper layer w_{Cu} and w_{Al} in the range of 2 to 48 mm (keeping the total thickness of the ring g = 50 mm). The diameter D_2 was equal to 350 mm and the k_e was in the range of 5 to 15.

In a first step, the efficiency of the gear with aluminium ring has been evaluated in different gear and speed ratios. Efficiency has been evaluated as the ratio of torques (which act on the ring and rotor, respectively) related to the mechanical ratio k_m of the PM rotor and the diameters of the rings. Figure 3 shows the evaluated efficiency of the gearbox as a function of the ratio k_m and the relative speed k_e.

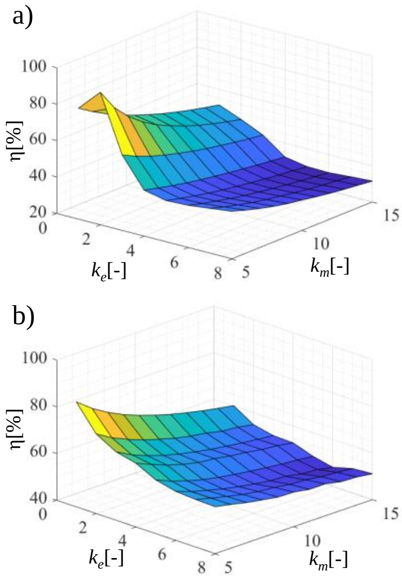

Fig. 3. Efficiency of the gearbox as a function of the k_m ratio and the relative speed k_e: a) p=1, b) p=2

Of course, the efficiency of the system increases with higher the speeds and the lower gear ratios. For further studies, the parameters k_m and k_e have been assumed to be 10 and 1, respectively.

In the next step, the impact of the filling ratios of copper and aluminium for the steel ring has been investigated. The *Al-Fe* and *Cu-Fe* models shown in Figures 2(b) and 2(c) have been examined. Figure 4 shows the efficiencies as a function of the change in ring fill for p=1 and p=2, respectively.

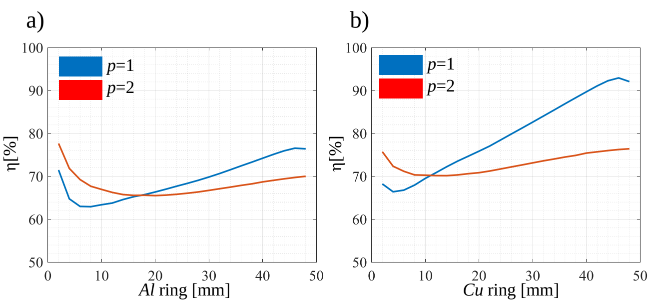

Fig. 4. Efficiency of the gearbox as a function of: a) thickness of *Al* ring, b) thickness of *Cu* ring

As a result of its higher conductivity of copper, the *Cu-Fe* design shows higher efficiency values compared to design with aluminium layer over the steel ring. Furthermore, above thickens of 20 mm of conductive material, the gear with single pair of poles in PM rotor performs better than design of 2 pairs of poles. This is due to the grater area of influence of the magnetic flux on the rim for single pair of poles PM rotor.

In the next step, the torques acting on the rotor and on the gear rim were examined. The results of the calculations are summarised in Figure 5, taking into account the number of rotor poles and the material of the ring.

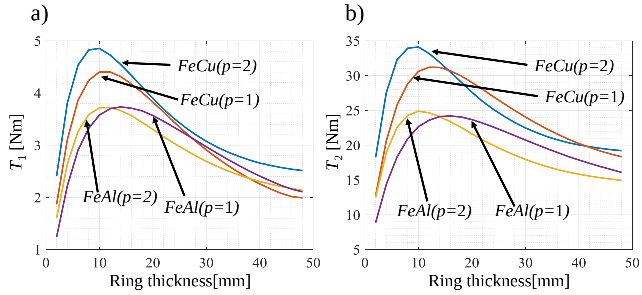

Fig. 5. The torque obtained for a) rotor and b) ring

V. CONCLUSIONS

In the paper the concept of a low-cost induction gear dedicated to work as a multiplier gear for small wind turbines with a vertical axis of rotation has been proposed. The numerical analysis exploiting 2D FEM have been carried out to examine proposed gear performance. The results of the analyses show that the proposed gear can successfully support the operation of the VAWT.

The efficiency, ratio, and price of the gear can be listed as most crucial parameters taken into account during the selection process. It has been demonstrated that incorporating layer of the copper on the steel ring, due to its higher than aluminium conductivity, allows one to achieve higher efficiency of the gear for the same ratio. However, the price and weight of the gear will also increase. Aluminium, on the other hand, is a cheaper and lighter solution despite its lower conductivity.

Further work on the concept of the induction gear for VAWT is related to integrating the PM rotor of the gear as a rotary part of the electric energy generator. The detailed results of the conducted research will be discussed during the conference and included in the extended version of the paper.

REFERENCES

[1] Rasmussen P. O., Andersen T. O., Jorgensen F. T. and Nielsen O., "Development of a high-performance magnetic gear," in IEEE Transactions on Industry Applications, vol. 41, no. 3, pp. 764-770, May-June 2005, DOI: 10.1109/TIA.2005.847319.

[2] Kowol M., Kołodziej J., Jagieła M. and Łukaniszyn M., "Impact of Modulator Designs and Materials on Efficiency and Losses in Radial Passive Magnetic Gear," in IEEE Transactions on Energy Conversion, vol. 34, no. 1, pp. 147-154, March 2019, DOI: 10.1109/TEC.2018.2862462.

[3] Macyszyn, L.; Jedryczka, C.; Mysinski, M. Analysis of a Two-Stage Magnetic Precession Gear Dynamics. Energies 2023, 16, 4484. https://doi.org/10.3390/en16114484

[4] Shahariar G. M. H., and Hasan M. R., "Design & construction of a Vertical Axis Wind Turbine," 2014 9th International Forum on Strategic Technology (IFOST), Cox's Bazar, Bangladesh, 2014, pp. 326-329, DOI: 10.1109/IFOST.2014.6991132.