ELECTROMAGNETIC GEARS IN ELECTROMECHANICAL SYSTEMS

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Currently, due to the rise in electricity prices, wind generators of small power (1-5 kW) are often used to supply consumers with electricity. In this case, wind generators with both horizontal and vertical rotation axes are used, the rotation frequency of which at an average wind speed V = 5 ÷ 10 m / s is sufficiently low and is approximately n = 100 ÷ 300 rpm. The low-speed electric generator for a wind generator with such speed of rotation with direct connection of a shaft of a wind rotor and the electric generator has a large number of poles and rather big sizes. Therefore, step-up gearboxes (multiplexers) are often used, which allow increasing the rotational speed of the electric generator several times and, thereby, reducing the mass of its active part, since the electromagnetic torque is proportional to the volume of the electrical machine. However, mechanical gearboxes are a source of additional noise, require fairly frequent maintenance, and reduce the durability of the wind turbine.

The research proposal will to use gears on permanent magnets for wind turbines, which, unlike mechanical gearboxes, do not create additional noise, do not require lubrication, their durability is higher, operating costs are also significantly reduced, while the magnetic gearbox can be integrated with an electric generator or structurally disconnected.

For example, with a wind rotor power of P = 4 kW and a rotation frequency of n = 100-300 rpm, a high-speed electric generator and a magnetic gear have approximately 2 times less total mass of magnets and 1.7 times less total mass of active materials (magnetic gear + electric generator), than a low speed multi-pole external rotor generator.

The purpose of the dissertation research is to develop and implement an electromagnetic gearing in electromechanical systems. The basis of such systems are high-coercive magnets.

To achieve this goal, the following tasks are set:

- literary-patent search on the topic of dissertation research;
- selection of a prototype of a magnetic gearing and calculation of its main parameters;
- development of graphical and numerical models to evaluate the effectiveness of the developed prototype;
- optimization of the design of the magnetic gearing;
- development of a system for converting low-potential mechanical energy into electrical energy;
- prototyping and experimental studies of the system of conversion of low-potential mechanical energy into electrical energy.

Magnetic gears have been of interest since the early 20th century with the earliest designs being very ordinary to conventional mechanical gears with the gear teeth replaced with magnetic analogues [1, 2]. However, these designs received little attention, most likely due to the low torque densities achieved as a result of the permanent magnet (PM) materials available at the time (namely SmCo5). A new interest came in the 1980s with the development of neodymium iron boron (NdFeB) magnetic material though the designs still depend on direct mechanical substitution, thus resulting in poor PM utilization and never achieved torque densities high enough to rival with traditional mechanical alternatives [3, 4].

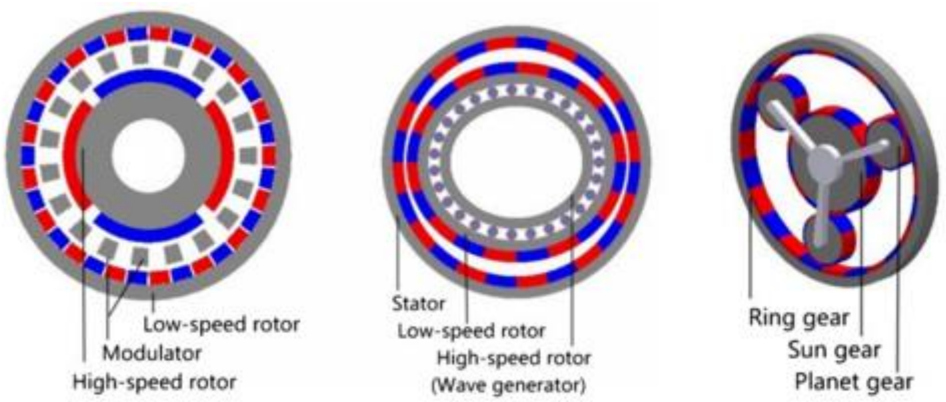

Figure 1 – Concentric, harmonic and MGs [5]

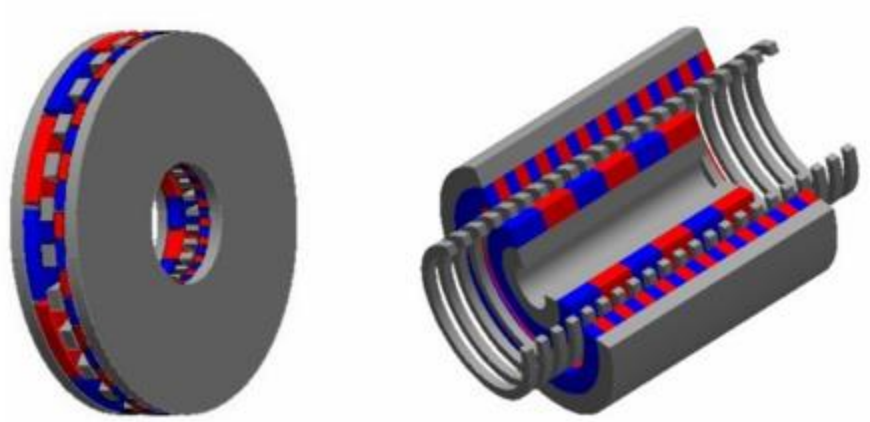

Figure 2 – Disc – type and linear type MG topologies [5]

As of the moment turn of the century MG are divided into three types, which are considered modern because they have a comparable torque density with that of conventional mechanisms (50–150 kNm/m3 for a helical gear and 100–200 kNm/m3 for a spur type gear). These are flow-modulated fields MG (FFM-MG), harmonic transmissions and magnetic planetary transmissions (MPG), as shown in Fig. 1.

Although they are considered the leading models, other designs are under development, as well as a special room made for the recent development of Dave Rodgers et al. [6], which as of 2015. Developed version of the usual worm and wheel transmission with a helical magnetic arrangement. Experiments have shown that the potential gear ratio exceeds 100: 1 and the air gap voltage is in the range of 485 kNm / m2. Successfully successful in both computer simulation and demonstration protocol, a very new technology for further verification and demonstration of the work is required.

In addition, as a worm gearbox, the high shear stress will be localized in a small part of the machine, and the use of total TV material will be low. The harmonic gear [7] showed very promising torque densities in the range of 150 kNm / m3. Despite its attractiveness with its torque density, high gear ratios and smooth torque transmission, it is difficult to design and relies on a flexible low-speed rotor to create time-varying sinusoidal changes in the magnetic field in the air gap between the rotors. The gear ratio of a harmonic gear is given as

$$G_r = \frac{(-1)^{(k+1)} p_w}{p_l}$$

with pl and pw the number of poles on the low-speed rotor and the number of sinusoidal cycles between low-speed rotor and stator, respectively, and k represents the various asynchronous space harmonics which are associated with each harmonic of the magnetic field produced by the PMs.

In 2001, Atalla and Howe [8] proposed, as a rule, a leading design for MG - concentric MG (CMG). Although a similar design can be seen in TB Martin's 1968 patent "Magnetic Transmission" [9], it was in the work of Atalla and Howe that the high torsional capabilities of the design were demonstrated. CMGs fall into the FFM-MG category because they use ferromagnetic pole segments in the air gap between the rotors to modulate the magnetic flux active between the rotors. This design allowed the full use of all PM material and led to a high torque density in the range of 70–150 kNm / m3 with a relatively simple design. In addition, proposing CMG, Atallah et al. demonstrated two other forms of this MG, linear and axial field models [10, 11], as shown in Fig. 2. This adaptability makes the FMMG design particularly useful in marine energy, where there are a number of PTOs depending on how the device interacts with tidal waves or tidal currents. There are two modes of operation with this type of MG. Either the ferromagnetic poles are held stationary and the outer and inner magnetic rotors are allowed to rotate, or the ferromagnetic poles are allowed to rotate by one of the other rotating rotors. Modes affect the possible gear ratio and direction of rotation.

Also, the scope of MG includes relatively new concepts of MG with a rotary type, which work similarly to the concept of mechanical lead screws in the conversion of linear motion into rotational with the replacement of the thread on the magnetic material (Fig. 3). This form of MG is very applicable to wave energy because the typically low-speed linear motion of, say, a wave-like buoy energy converter (WEC) will not only increase the speed, but may also allow a more traditional electric machine to be applied.

Although a patent for a magnetic screw device was registered in 1997 [12], it was presented by Wang et al. in 2011 [13] the possibilities of high force density of magnetic lead screw (MLS) were analyzed in detail. Using this analysis, it was found that the thrust force density exceeding 10 MN / m3 is possible in models with air gaps ranging from 0.4 to 0.8 mm with a lead (λ)> 7 mm. Thanks to this feature, created in 2012, Pakdelyan et al. [14] developed this concept by developing a speed-torque ratio,

and the design and scaling of such a device now lubricate the loading MG or TROMAG for its transmissions. Here, the gear ratio is set as the ratio of the angular velocity of the rotor to the linear velocity of the converter ω (rad / s) and V (m / s), respectively.
Although TROMAG has great potential in WEC, the need for a large amount of magnetic material on a linear translator makes devices expensive. In a recent work [15], a new lead screw transmission with magnetic transmission (MGLS) was developed and analyzed, which combines the principles of linear MG (LMG) and TROMAG. The structure consists of three main sections: an inner rotor with spirally skewed, radially magnetized pole pairs (pi), an outer cylindrical structure consisting of magnetic elements arranged with steel segments focusing the flow, and a transducer made of ferromagnetic annular bevels (ni) (Fig. 4).

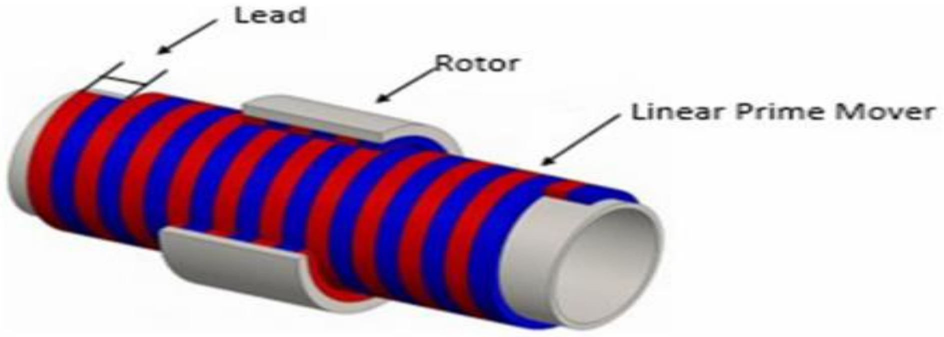

Figure 3 – Magnetic lead screw

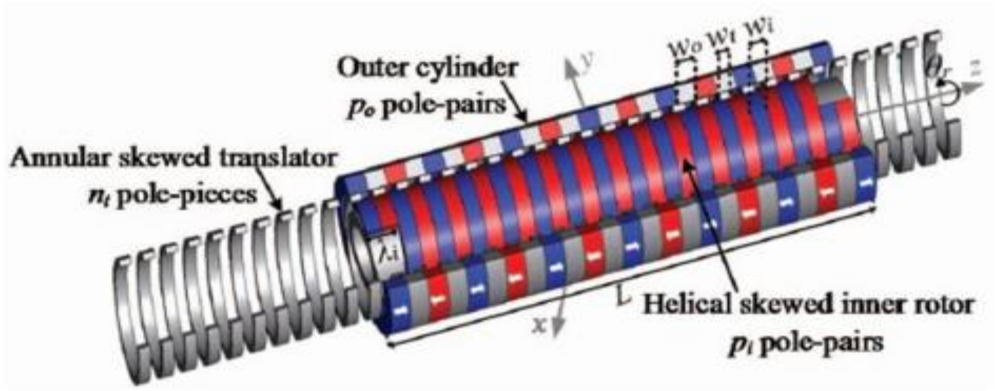

Figure 4 – MG lead screw

Based on the basic concepts, further work was carried out to improve the functionality of the MG, the main achievement of which is the development of designs of variable gear ratios. This is a potentially important development in the application of marine energy technology, as marine states can often vary widely, and the ability to change gear ratios gives designers more control, such as maintaining optimal generator speeds from different inputs. As already mentioned, the planetary type MG is able to perform three modes of transition [16], but further work has been done to allow a similar adaptation of the concentric type MG. Wang et al. [17], the principle of operation is that in a typical CMG design, instead of a fixed rotor, it is allowed to rotate so that the rate of change of the magnetic field seen by the other two rotors is adjusted to a given range ratio. This concept is further studied in terms of topology and application, as well as the use of non-rare earth magnets with the possibility of changing poles [18].

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