BALKAN JOURNAL OF ELECTRICAL & COMPUTER ENGINEERING, Vol. 11, No. 4, October 2023
Research Article

Finite Element Analysis of SMC Core Magnetic Gear for Vehicle Powertrain Systems

Kadir Yilmaz , Taner Dindar, Murat Ayaz, Serkan Aktas and Serkan Sezen

***Abstract*— The utilization of gears as intermediary components for power transmission in electric drive systems addresses the insufficiency of electric machines in handling torque loads effectively. Gears, commonly employed in the industry, can be either mechanical or magnetic, allowing for the balanced transfer of torque and speed at specified ratios. The mechanical and electrical actuation of in-vehicle accessories persists both in traditional and next-generation vehicles. Particularly concerning safety and the sustainability of spare part production and supply, various electrical accessories continue to operate at the 12 V. level in modern vehicles. In this context, the use of the Lundell alternator (claw pole) also continues in next-generation vehicles. While the mechanical accessories are driven by a belt-pulley system connected to an internal combustion engine in conventional vehicles, in next- generation vehicles, both belt-pulley systems and x-drive by wire are present. The low efficiency and operational costs of belt- pulley power transmission systems necessitate the adoption of more efficient transmission systems. This study focuses on the development of a soft magnetic composite (SMC) core magnetic gear power transmission system that can serve as an alternative to belt-pulley systems in both traditional and next-generation vehicles. In the proposed system, mechanical power transfer to the Lundell alternator is realized through the intended magnetic gear. The gear ratio is determined to ensure a speed of 1800 rpm at the input of the Lundell alternator while the drive system operates at 6000 rpm. To achieve low volume and high efficiency for the proposed magnetic gear, the SMC material is considered, and a comprehensive analysis using the Ansys Maxwell finite element software is conducted. As a result of the analyses, in the magnetic gear designed with a transmission ratio of 3:1, when a torque of 11.7547 Nm is applied to the input shaft, a torque transmission of 35.9806 Nm has been achieved with an efficiency of 84.73% through the output shaft.**

Index Terms— **Magnetic gear, soft magnetic composite (SMC), power transmission systems, vehicle powertrain systems.**

KADIR YILMAZ, is with Department of Energy Systems Engineering, Kocaeli University, Kocaeli, Turkey, (e-mail: kayel@kocaeli.edu.tr).
https://orcid.org/ 0000-0002-0819-3420
TANER DİNDAR, is with Department of Electronic and Automation, Ankara University, Ankara, Turkey, (e-mail: tdindar@ankara.edu.tr).
https://orcid.org/0000-0002-4112-2114
MURAT AYAZ, is with Department of Electric and Energy, Kocaeli University, Kocaeli, Turkey, (e-mail: murat.ayaz@kocaeli.edu.tr)
https://orcid.org/0000-0001-9839-3970
SERKAN AKTAŞ, is with Department of Machinery and Metal Technologies, Kocaeli University, Kocaeli, Turkey,(e-mail: serkan.aktas@kocaeli.edu.tr)
https://orcid.org/0000-0001-6135-7597
SERKAN SEZEN, is with *Department of Electric and Energy, Kocaeli University, Kocaeli, Turkey,(e-mail: serkan.sezen@kocaeli.edu.tr)*
https://orcid.org/0000-0001-7273-7376
Manuscript received August 28, 2023; accepted Sep 19, 2023.
DOI: 10.17694/bajece.1352245

I. Introduction

Magnetic gear systems have emerged as a groundbreaking technological solution, harnessing the power of permanent magnets and magnetic forces to offer a distinct departure from conventional gear systems. These systems excel in transmitting torque between input and output shafts without the need for physical contact, thereby eliminating energy losses caused by friction and enabling high-efficiency operations. Unlike traditional gearboxes that are susceptible to friction-related heating issues due to gear contact, magnetic gear systems operate without encountering such challenges. This is due to their inherent ability to facilitate motion and torque transmission through magnetic fields, thus reducing maintenance costs and ensuring dependable power transmission [1].

In contemporary industrial applications, the demand for power transmission systems with high torque density has prompted extensive research. The conventional approach involves using mechanical gearboxes to enhance torque output from electric motors, obviating the need for larger motors and achieving high torque density [2-4]. The literature reflects a burgeoning interest in various aspects of magnetic gear technology [4,5-10]. Research endeavors span a spectrum of objectives, encompassing the reduction of magnetic gear costs, enhancement of torque density and efficiency, and exploration of diverse application domains including wind energy and automotive systems. One avenue of exploration delves into the distinctive structures of magnetic gears, such as radial-axial combinations and dual-stator designs [7]. Additionally, efforts are concentrated on increasing torque density and optimizing efficiency [2-3,11-13]. Magnetic gears are proposed as alternatives to mechanical gears in marine propulsion systems, addressing the need for compact, efficient torque solutions [14]. In the burgeoning wind turbine sector, magnetic gears are positioned to tackle challenges posed by mechanical gearboxes in direct drive systems, thereby contributing to enhanced efficiency and durability [15]. Specific studies target the fundamental elements of magnetic gear design. Analytical methods are devised to characterize the magnetic field distribution in axial magnetic gears, allowing for accurate predictions [5]. Novel topologies that incorporate modulation rings are explored to tailor torque characteristics for varying speed ranges, exemplifying the versatility of magnetic gear technology [7]. Linear magnetic gears, driven by rare-earth magnets, emerge as a potential solution for converting rotary motion into linear motion with high force density [3].

The optimization of magnetic gear designs is another active research strand. Studies delve into diverse aspects, from losses due to eddy currents and iron, to the selection of magnet materials for optimal performance [16]. Efforts are also directed towards improving efficiency and minimizing losses, with an emphasis on analyzing rotor losses and exploring innovative rotor designs [17,18]. These research directions collectively contribute to the holistic understanding and advancement of magnetic gear systems.

In view of this dynamic landscape, this study aims to contribute to the field by proposing a novel magnetic gear system design that incorporates a soft magnetic composite (SMC) core. This system integrates a permanent magnet outer rotor, an inner rotor, and a modulating carrier to achieve efficient and compact torque transmission for vehicle propulsion systems. The absence of comprehensive studies on SMC core magnetic gear systems in vehicle propulsion applications underscores the novelty and significance of this research, addressing a critical research gap. The paper is structured as follows: Section 2 details the vehicle propulsion and accessory drive system. Section 3 presents the fundamental dimension configuration and the proposed magnetic gear design. Finally, Section 4 presents the analysis results of the created models.

II. Vehicle Accessory Drive Systems

The power requirement for mechanical loads within a vehicle (such as power steering pumps, air conditioning compressors, water pumps, air compressors, Lundell alternators) is approximately 6 kW, while electrical loads (such as heated steering systems, power windows, headlights, interior lighting, battery, etc.) require around 2-3 kW of power [19]. The drive block diagram of vehicle interior mechanical and electrical accessories, as depicted in Figure 1, remains applicable to both traditional and new-generation vehicles. Particularly for safety and sustainability in terms of spare part production and supply, various electrical accessories at the 12 V level continue to be used in new-generation vehicles. In this context, Low voltage battery and Lundell alternators (claw pole) are still employed in new-generation vehicles. The drive of mechanical accessories is achieved through a belt-pulley system via an internal combustion engine (ICE) in traditional vehicles, while new-generation vehicles may feature both belt- pulley systems and x-drive by wire systems. The low efficiency and operating costs of belt-pulley power transmission systems necessitate the use of more efficient transmission systems.

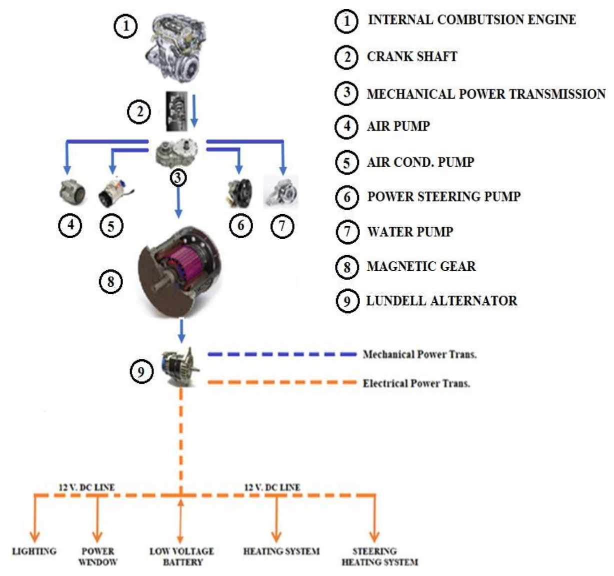

Fig.1. Vehicle accessory drive block diagram

In this study, the development of a low-volume, high-efficiency magnetic gear power transmission system is addressed as an alternative to belt-pulley power transmission systems, applicable to both traditional and new-generation vehicles. In the proposed system, mechanical power transfer to the Lundell alternator is achieved through a magnetic gear. The gear ratio is determined such that the drive system speed is 6000 rpm, while the input speed of the Lundell alternator is 1800 rpm. To achieve a low-volume, lightweight, and high-efficiency magnetic gear, SMC materials are considered, and a detailed analysis is conducted.

III. MAGNETIC GEAR DESIGN

Magnetic power transmission devices have made significant progress with the advancement of technology. Magnetic gears have a similar structure to traditional mechanical gearboxes, but the transmission process occurs through magnetic forces instead of mechanical contact. Figure 2 illustrates the representation of a magnetic gear and its mechanical counterpart, the straight-tooth gear.

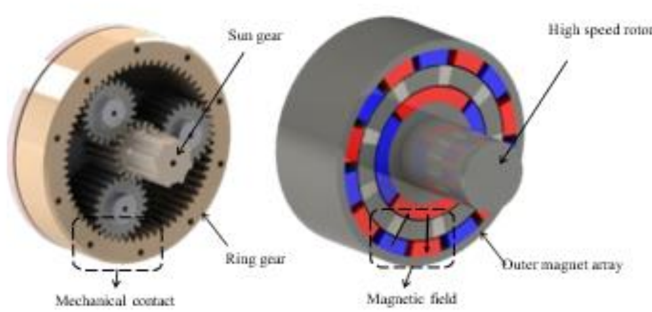

Fig.2. Mechanical gear and magnetic gear structures

Axial magnetic gears are the most common type of magnetic gear, enabling power transmission at a specific gear ratio. An axial magnetic gear consists of three main parts: the outer rotor, inner rotor, and carrier. The inner and outer rotors feature magnet pairs based on specific calculations, while the carrier is a specially designed component made from ferromagnetic and non-magnetic materials. This design allows the outer rotor to remain fixed while permitting the rotational motion of the carrier and inner rotor. The power transmission can be configured as inner rotor input and carrier output, and in some cases, the carrier can be fixed to allow rotation of both the inner and outer rotors, facilitating power transmission.

Additionally, the carrier can be made from SMC material to ensure magnetic flux transmission and high magnetic permeability. A special Hallbach array arrangement is utilized in the magnets to prevent magnetic flux leakage. In the design of magnetic gear systems, the gear ratio is determined by the number of fixed magnets. In traditional gear systems, the number of teeth and the gear ratio are interdependent, making modifications or adaptations challenging. However, in magnetic gear systems, the gear ratio can be easily adjusted. Thus, if a different gear ratio is needed, changing the number of fixed magnets is sufficient. The main components of an axial magnetic gear are shown in Figure 3, and its geometric model is presented in Figure 4.

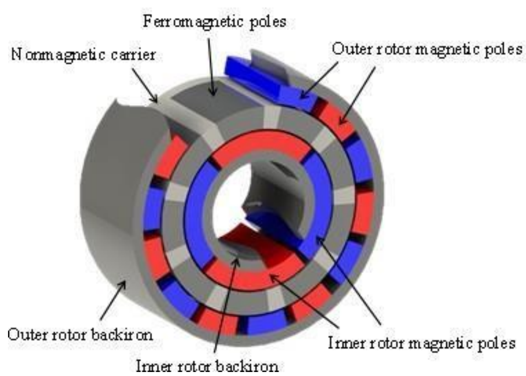

Fig.3. Axial magnetic gear model

The axial magnetic gear shown in Figure 3 is created by combining a movable inner rotor with a low number of magnets, a fixed outer rotor with a high number of magnets, and a movable carrier made from non-ferromagnetic material. In the magnetic gear, the outer rotor remains stationary, the inner rotor serves as the high-speed input shaft with low torque, and the carrier acts as the low-speed output shaft with high torque. The number of fixed magnets on the inner rotor of the axial magnetic gear is defined by using equation 1 as $n(PM{-}\text{in})$, while the number of magnets on the outer rotor is defined as $n(PM{-}\text{out})$.

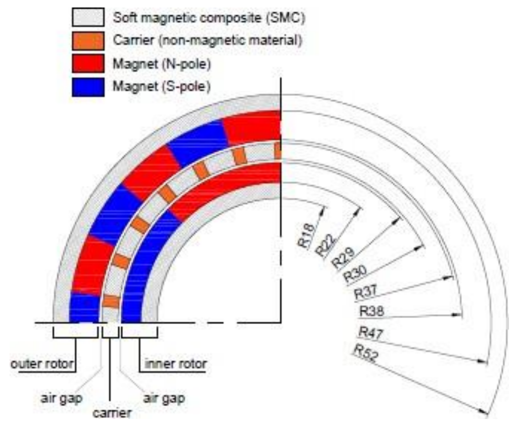

Fig.4. Geometric dimensions of the axial magnetic gear

In the designed magnetic gear, 6 fixed magnets are used on the inner rotor and 14 fixed magnets are used on the outer rotor. The Halbach array structure is preferred for magnet arrangement. The sum of the pole pairs in the inner and outer rotors determines the number of carriers. With the developments in magnet technology, studies on magnetic gear and their use have increased [22].

$$n_{sp} = \frac{n_{PM-in}}{2} + \frac{n_{PM-out}}{2} \quad (1)$$

The selection of the number of fixed magnets in magnetic gear design is also a significant aspect. In magnetic gears, the rotational ratio can be determined similarly to mechanical gear systems. In other words, gear ratios in this context are replaced by the ratio of magnet counts. In the magnetic gear depicted in Figure 3, the number of magnets on the outer rotor defines the stationary condition of the outer rotor, with the output shaft being driven by the poles in the carrier and the input shaft being driven by the poles in the inner rotor. For a magnetic gear where the outer rotor remains fixed, the gear ratio is provided by Equation 2.

$$g_r = \frac{\frac{n_{PM-in}}{2} + \frac{n_{PM-out}}{2}}{\frac{n_{PM-in}}{2}} \quad (2)$$

Here, gr represents the gear ratio of the magnetic gear. When magnet counts are substituted into Equation 2, the gear ratio of the magnetic gear is obtained as 3.33:1. The nominal angular velocity relationship between the input shaft and the output shaft can be expressed using Equation 3.

$$w_{in} = \frac{1}{g_r} w_{out} \tag{3}$$

For this configuration, the nominal torque relationship can be calculated considering constant power with the assumption that the magnetic gear configuration operates at a constant angular velocity and there are no losses. The total mechanical power of the system should be equal to zero. This design presents a structure where there are no losses when the magnetic gear system operates, ensuring high energy efficiency. In the utilized topology, the outer rotor is fixed, resulting in zero angular velocity. With the angular velocities provided in Equation (3), the torque relationship can be formulated as follows:

$$\tau_{in} w_{in} + \tau_{out} w_{out} = 0 \tag{4}$$
$$\tau_{in} = -g_r \tau_{out} \tag{5}$$

The dimensions of the used magnets and the geometric information of the magnetic gear are presented in Figure 4, while the dimensional parameters of the magnetic gear are summarized in Table 1.

TABLE I
BASIC MODEL PARAMETERS

Components	Parameters	Values	Unit
Inner Rotor	Inner radius	22	mm
	Outer radius	29	mm
	Pole pairs	6	-
	Angle, θ1, 180/(2p1)	15	degree
Carrier	Inner radius	30	mm
	Outer radius	37	mm
	Number of poles, n2	10	
	Angle, θ2, 180/(n2)	18	degree
Outer Rotor	Inner radius	38	mm
	Outer radius	47	mm
	Pole pairs	14	
	Angle	12.85	degree
Overall	Inner radius	18	mm
	Outer radius	52	mm
	Air gap	1	mm
	Axial length	40	mm

III. Proposed Magnetic Gear Analysis and Simulation Results

In this study, a magnetic gear system with a coaxial configuration was designed, and electromagnetic analysis was conducted. Electromagnetic analysis is crucial for determining factors that influence the performance and torque transmission of the magnetic gear system. Axial torque values at specific speeds were obtained for the input and output shafts, showing variations over time. These values are essential for understanding how the magnetic gear system would perform under different load and speed conditions. The obtained data indicates the potential wide-ranging applications of magnetic gear systems.

For the analysis of a coaxial magnetic gear with SMC core, a 2-dimensional model was created using the Ansys Maxwell software. The magnetic gear was defined with the outer rotor fixed, and the carrier and inner rotor movable. SMC material, specifically SMC 130 1P, was chosen as the material for these three fundamental parts. Neodymium magnets with a Halbach arrangement were selected for the inner and outer rotors. Figure 5 illustrates the B-H characteristic of the SMC material used in the core of the magnetic gear.

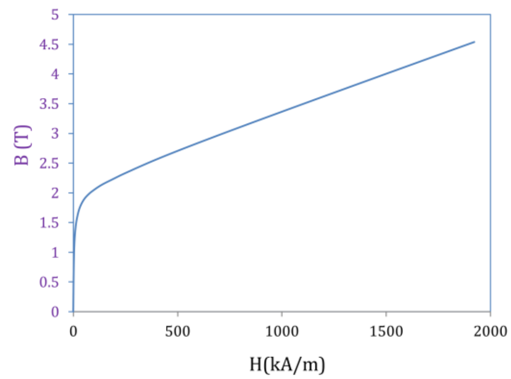

Fig.5. B-H characteristic of the SMC material.

As shown in Figure 5, the saturation point of the Somaloy series SMC material is higher compared to that of hardened steel materials. The physical, electrical, and thermal properties of SMC and hardened steel (Steel 1010) materials are provided in Table 2.

When comparing the densities of SMC material and hardened steel, it can be observed that the lower density of SMC material will lead to lower volume and weight gains compared to a core made of hardened steel of the same dimensions. In an SMC core magnetic gear, due to the material's higher resistivity, lower eddy current losses will occur compared to silicon steel. SMC materials can provide low volume-high efficiency, especially at high speeds [20]. The preference for SMC-type materials has two main purposes. The first is the ability to achieve complex geometries due to production methods, and the second is enabling three-dimensional flux flow [21].

For the parts defining the moving input and output shafts of the magnetic gear, time-dependent analyses were conducted using a moving mesh structure. The meshing process involves dividing the model into element networks to achieve realistic results. During the meshing process, it is necessary to predefine how each edge or region can be subdivided. If the mesh is too dense, it can lead to excessive computational time for solving the model.

TABLE II
PARAMETERS OF SMC AND HARDENED STEEL MATERIALS

Materials	**Density (kg/m^3)**	**Resistivity (μΩcm)**	**Loss Power (50 Hz-1 T.) W/kg**	**Thermal Resistance (W/(m-K)**
Somoloy 130 1P	7350	8000	6	22
Steel 1010	7872	5	0,5	49,8

Conversely, if the mesh is too sparse, it can deviate from accurate results. Figure 6 illustrates the distribution of magnetic flux density for the magnetic gear. It is deemed more suitable to perform the analysis with meshes of 3 degrees angle and a spacing of 0.01 mm. Within the gap between the inner rotor and the carrier, 242 elements are created, while 377 elements constitute the mesh between the inner rotor and the iron, and 40 elements form the mesh within the inner rotor's magnets.

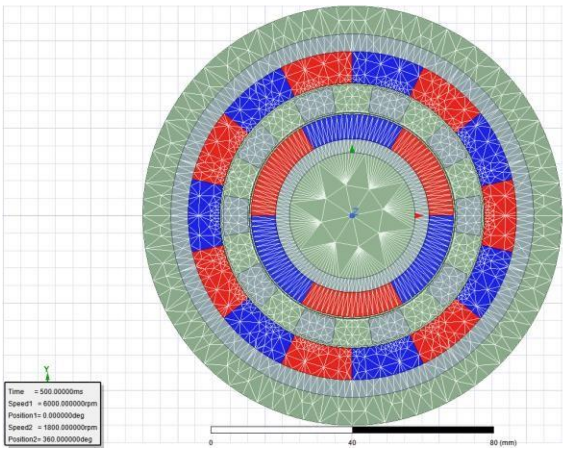

Fig.6. Mesh structure for the magnetic gear

An important aspect here is to generate denser meshes in critical areas, especially within the air gap. To enable rotational movement of the magnetic gear's moving sections, a rotating rotor model was established. To create a sliding surface for the air gap, the air gap needs to be divided into at least two parts. In Maxwell software, a band was formed to define the rotating motion, with the parts inside the band considered as moving and the parts outside as stationary. It is the division of the model into the element mesh in order to obtain a true-to-life mesh operation. When meshing, it is necessary to determine in advance which edge or how much the region can be divided. If the pattern network is large, more time can be spent in analyzing the model. If it is less, it may be possible to get away from realistic results. Figure 7 shows the magnetic flux density distribution for the magnetic gear. It is considered more appropriate to process with meshes at an angle of 3 degrees and in the range of 0.01 mm. A network of elements 242 is made in the space between the inner rotor and the carrier, 377 between the inner rotor and the iron, and 40 in the magnets in the inner rotor.

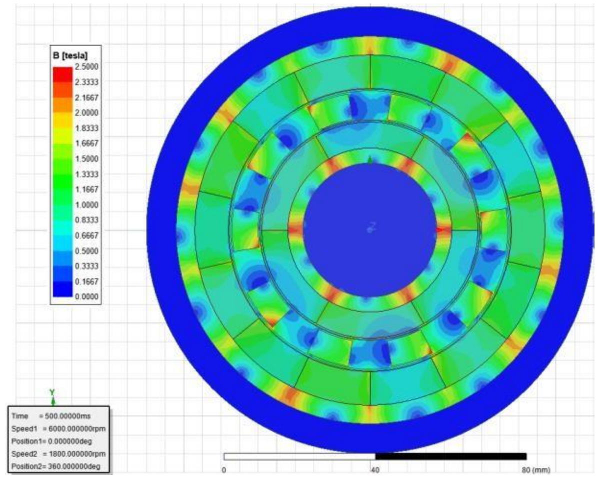

Fig.7. Distribution of magnetic flux density for the magnetic gear

Considering the moving inner rotor representing the input shaft and the moving carrier representing the output shaft, torque values were calculated for these components. Figure 8 presents the input and output torque curves of the magnetic gear model for 500 ms. The torque ripple in the input and output torques of the magnetic gear can be calculated using Equation (6):

$$T_{ripple} = \frac{T_{max} - T_{min}}{T_{avg}} \tag{6}$$

In Equation (6), T min, T max, and T avg respectively denote the minimum, maximum, and average torque values. The torque ripple percentage is 17.52% for the input torque and approximately 5% for the output torque.

As shown from Figure 8, when observing the torque values between the input and output shafts, the output torque is 35.98 Nm, while the input torque is 11.75 Nm, resulting in a transmission ratio of 3:1. To minimize fluctuations in torque profiles, the numbers of poles in the inner and outer rotors should be prime. Torque ripple in magnetic gears is a result of modulation between magnetic pole rotors, primarily originating from magnetic flux harmonics. It is largely dependent on the chosen pole numbers. Significant torque ripple could render the magnetic gear practically unusable.

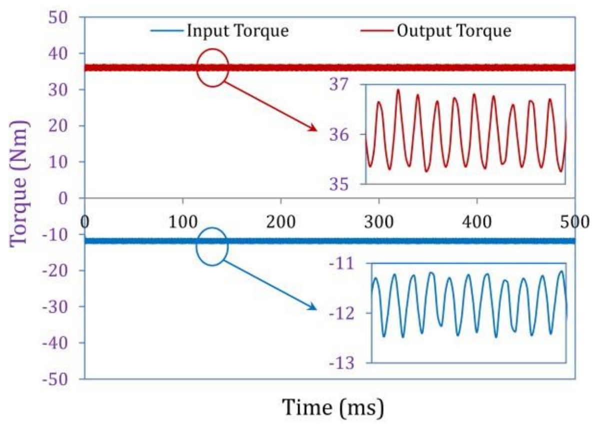

Fig.8. Torque variation for the magnetic gear inner rotor and carrier sections

Hence, studies in the literature underscore that magnetic gears with whole-number pole pairs exhibit high torque ripple.

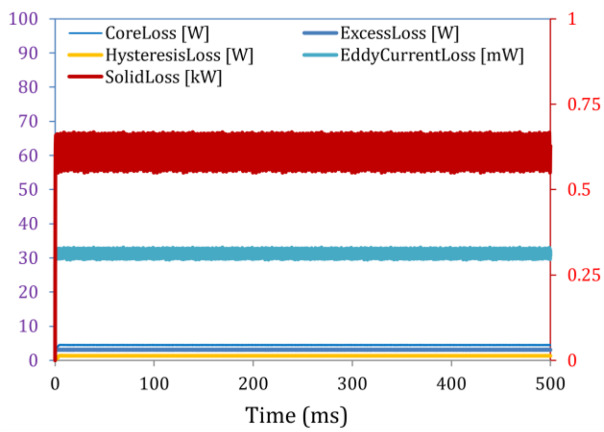

Fig.9. Core and hysteresis-eddy losses for the magnetic gear

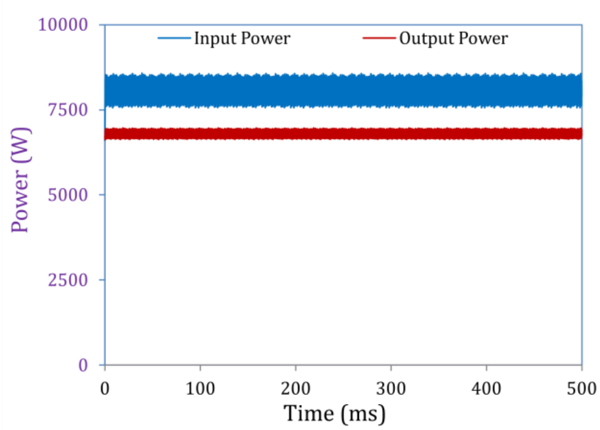

Fig.10. Power values for the input and output shafts of the magnetic gear

Magnetic gears are known to have high efficiencies due to limited mechanical losses, primarily attributed to bearing friction. However, apart from mechanical losses, there will be additional losses induced by the time-varying magnetic field. These additional losses encompass iron losses, hysteresis, and eddy current losses. Figure 9 shows the losses related to the core and hysteresis-eddy effects in the magnetic gear. When the eddy current losses are analyzed, it becomes evident that the SMC material contributes to a relatively low value, around 31.4 mW. Additionally, the solid loss, which signifies the resistive loss in solid conductors, accounts for 615.817 W.

Using the axial torque values and angular velocities of the magnetic gear, the power values for the input and output shafts were plotted in Figure 10. Analyzing these power values reveals that torque transmission occurs with an efficiency of 84.71%, as demonstrated in Figure 11.

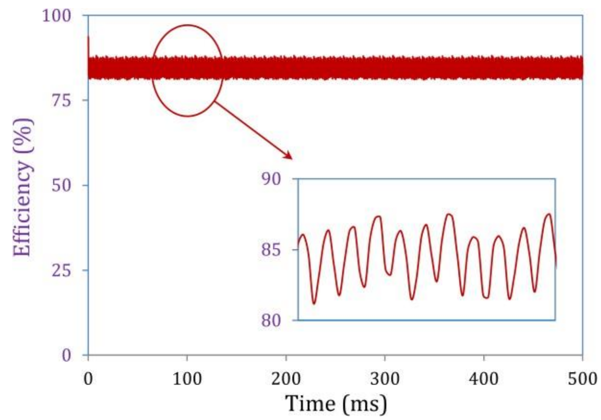

Fig.11. Efficiency of the magnetic gear

IV. CONCLUSION

Within the scope of this study, the development of a low-volume, high-efficiency magnetic gear power transmission system has been addressed as an alternative to the traditional belt and pulley power transmission system for both conventional and next-generation vehicles. In the proposed magnetic gear structure, the outer rotor remains fixed, while the carrier and inner rotor are designated as the output and input shafts, respectively. By constructing the magnetic gear core with SMC material, three-dimensional flux flow has been enabled, thus ensuring low eddy current losses. As a result of the analyses, power transmission has been achieved between the drive system and the Lundell alternator with a power value of 6.7 kW, at a ratio of 3:1, and with an efficiency of 84.73%. In conclusion, magnetic gear systems offer a valuable solution for increasing transmission efficiency, eliminating mechanical contact, and minimizing energy losses in torque transmission. With the advancement of technologies, the utilization of magnetic gear systems is becoming more widespread in various industrial applications, and it is anticipated to play an even more significant role in the future.

REFERENCES

[1] K. Atallah, D. Howe. “A novel high performance magnetic gear.” K. Atallah, D. Howe. "A novel high performance magnetic gear." IEEE transactions on magnetics, vol.37. 4, 2001, pp 2844-2846.

[2] P. O. Rasmussen, T. O. Andersen, F. T. Jorgensen, O. Nielsen, "Development of a high-performance magnetic gear," IEEE Transactions on Industry Applications, vol. 41. 3, 2005, pp. 764-770.

[3] J. W. K. Atallah, D. Howe, "A high-performance linear magnetic gear," Journal of applied physics 97, vol. 10. 516, 2005.

[4] S. Nielsen, R. K. Holm, N. Berg, P. O. Rasmussen, "Magnetically geared conveyor drive unit - an updated version," IEEE Energy

Conversion Congress and Exposition (ECCE), 2020.
[5] L. Jian, K. T. Chau, "Analytical calculation of magnetic field distribution in coaxial magnetic gears," Progress in Electromagnetics Research, vol. 92, 2009, pp. 1-16.
[6] A. B. W. Hafla, W. Rucker, "Efficient design analysis of a novel magnetic gear on a high performance computer," The International Journal for Computation and Mathematics in Electrical and Electronic Engineering, vol. 26. 3, 2007, pp. 712-726.
[7] K. T. Chau, Z. Zhang, "Novel design of double-stator single-rotor magnetic-geared machines," IEEE Transactions on Magnetics, vol. 48. 11, 2012, pp. 4180-4183.
[8] P. Alotto, E. Armando, "Design, Analysis and Realisation of a Magnetic Gear Prototype with Experimental Validation," 23rd International Conference on the Computation of Electromagnetic Fields, 2022.
[9] L. Dimauroa, E. Bonisolia, M. Velardocchiaa, M. Repettob, P. Alottoc, M. Filippinic, R. Torchioc "Magnetic gearbox for automotive power transmissions: an innovative industrial technology," Engineering Science and Technology an International Journal, 2023.
[10] D. Wong, H. Baninajar, B. Dechant, J. Bird, "Designing a Magnetic Gear for an Electric Aircraft Drivetrain," IEEE Energy Conversion Congress & Expo, 2020.
[11] S. C. K. Atallah and D. Howe, "High-performance magnetic gears," Journal of Magnetism and Magnetic Materials, 2004, pp. 272-276.
[12] G. Duan, T. Gupta, E. Sutton, M. Wang; M. C. Gardner, "Cycloidal Magnetic Gear Combining Axial and Radial Topologies," IEEE Transactions on Energy Conversion Vol.37, 3, 2022, pp.1-1.
[13] M. Filippini, P. Alotto, V. Cirimele, M. Repetto, C. Ragusa, L. Dimauro, E. Bonisoli, "Magnetic Loss Analysis in Coaxial Magnetic Gears," Journals Electronics Vol. 8, 11, 2019.
[14] N. Frank, H. Toliyat, "Gearing ratios of a magnetic gear for marine applications," in IEEE Electric Ship Technologies Symposium, ESTS., 2009.
[15] N. Frank, H. Toliyat, "Gearing ratios of a magnetic gear for wind turbines," in IEEE International Electrical Machines and Drives Conference, IEMDC'09., 2009.
[16] M. F. A. Halim, E. Sulaiman, M. Jenal, R. N. F. K. R. Othman, S. M. N. S. Othman, "Preliminary analysis of eddy current and iron loss in magnetic gear in electric vehicle," International Journal of Electrical and Computer Engineering (IJECE) 12(2):1161, 2022.
[17] Y. Tian, G Liu, W. Zhao, J. Ji, "Design and Analysis of Coaxial Magnetic Gear Considering Rotor Losses," IEEE Transactions on Magnetics 51(11):1-1, 2015.
[18] E.J. Park, S.Y. Jung, Y.J. Kim, "Comparison of Magnetic Gear Characteristics Using Different Permanent Magnet Materials," IEEE Transactions on Applied Superconductivity Vol. 30, 4, 2020.
[19] E. Mese, M. Ayaz, M. Tezcan, K. Yilmaz, "Design of dual winding permanent magnet synchronous machines for hybrid electric vehicle accessory drives." International Journal of Vehicle Design, 69(1-4), 185-207, 2015.
[20] Y. Öner, "Rüzgar türbinleri icin; düşük hızlı, sürekli mıknatıslı, yumuşak manyetik kompozit malzemeli, senkron generator tasarımı, optimizasyonu ve üretimi," Doktora Tez, 2013.
[21] O. Ocak, "Sürekli mıknatıslı senkron motorlarda moment kalitesini artırmaya yönelik melez mıknatıs yerleşimli yeni bir rotor yapısı tasarımı ve deneysel doğrulaması," Doktora Tez, 2021.
[22] Kocaer, T. & Öner, Y. (2022). Axial Flux Motor Design for Ventilation Fans Used in The Automotive Industry . Balkan Journal of Electrical and Computer Engineering , 10 (3) , 295-299.

BIOGRAPHIES

KADİR YILMAZ received the B.S. and M.S. degrees from the Department of Electrical Education, Gazi University, Ankara, Turkey, in 1996, 1999. He received PhD degree in 2004 from the Department of Electrical Education, Kocaeli University. Since 1999, he has been working with the Energy Systems Engineering Department, Kocaeli University. His research interests include design of electrical machine, electromechanical nergy conversion, simulation and modeling of electrical machine.

TANER DİNDAR received the B.S. and M.S. degrees from the Department of Electrical Education, Marmara University, Istanbul, Turkey, in 2009, 2012. Since 2012, he has been working with the Department of Electronic and Automation, Ankara University. His research interests include design of electrical machine, magnetic gear and energy systems.

MURAT AYAZ received the B.S., M.S., and Ph.D. degrees from the Department of Electrical Education, Kocaeli University, Kocaeli, Turkey, in 2005, 2008, and 2015, respectively. From 2009 to 2015, he was worked as a Research Assistant with the Electrical Education Department, Kocaeli University, where he is currently an Associate Professor with the Electric and Energy Department. He has several studies on electric machine design and industrial automation system design. His research interests include electric machines, electromechanical systems, hybrid electric vehicles, and industrial automation systems.

SERKAN AKTAŞ received his M.Sc. and Ph.D. degrees in the Department of Machinery Technology and Biomedical Engineering, in 2009 and 2021, respectively, at Kocaeli University, Kocaeli, Turkey. He has been working as an Assistant Professor at the Uzunciftlik Nuh Cimento Vocational High School at Kocaeli University. His research fields are CAD-CAM-CNC technologies, manufacturing technologies, machine design, biomechanics.

SERKAN SEZEN received the B.S. , M.Sc. and Ph.D. degrees in Electrical Education from Kocaeli University, Kocaeli, Turkey, in 2003, 2006 and 2015 respectively. He worked at the Department of Electronics & Automation, Edremit Vocational School, Balikesir University, Balikesir, Turkey, between 2007-2019. He is currently Assistant Professor at Department of Electric&Energy, Uzunçiftlik Nuh Çimento Vocational School, Kocaeli University. His research interests are renewable energy, power electronics, control theories and electrical machines.