RESEARCH ARTICLE | JANUARY 24 2024

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AIP Conf. Proc. 2980, 030002 (2024)
https://doi.org/10.1063/5.0184281

Determination of the Influence of the Windings on the Electrical Parameters of Linear Generators With Rotating Stator Magnets

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Abstract. The paper studies and models a linear generator with rotating magnets /LGRPM/ in its stator windings. The influence of the parameters of the windings and the air gaps on the output electrical parameters of the generator has been evaluated and thus an optimal design of a LGRPM has been determined. 3D modeling in dynamic mode with ANSYS R19.1 has been performed. Experimental studies have been conducted to verify the created model.

INTRODUCTION

There is a growing interest in new methods and tools for converting mechanical energy from various natural sources into electricity in the development of engineering and technology.

One of the directions of development in the sector are linear generators with permanent magnets, which are used to transform the energy of ocean waves into electricity [1].

Structurally, linear generators are of two types: with and without iron core in the stator windings [2,3,4]. Generators with iron cores in the windings have become more widely used. They have smaller air gaps and hence lower magnetic resistances, which allows for generating more electricity [5]. There are also linear generators with rotating magnets in their stator windings [6].

This paper proposes a linear generator /LGRPM/, in which the iron core in the stator windings is replaced by rotating magnets. The influence of the parameters of the windings and the air gap on the output electrical parameters of the generator is studied and thus an optimal design of this generator is determined.

EXPOSITOIN

The structural scheme of the studied linear generator with rotating magnets in its stator windings is shown in Fig. 1, where the following notations are used: 1 - four series-connected windings, 2 - rotating magnets, 3 - steel plates, 4 - permanent translational magnets. An advantage of this design scheme is that the steel plates are movable and allow the use of windings and translational magnets of different sizes. This creates a different air gap between the windings and the magnets.

The sea waves move in vertical direction the float 1, which, with the help of the rod 2, moves the LGPM, whose movable part 3, where the permanent magnets 4 are located, performs reciprocating motion. This produces an alternating magnetic field, which, in turn, induces an electromotive force in the windings 5.

11th International Scientific Conference "TechSys 2022" – Engineering, Technologies and Systems
AIP Conf. Proc. 2980, 030002-1–030002-7; https://doi.org/10.1063/5.0184281
Published by AIP Publishing. 978-0-7354-4814-8/$30.00

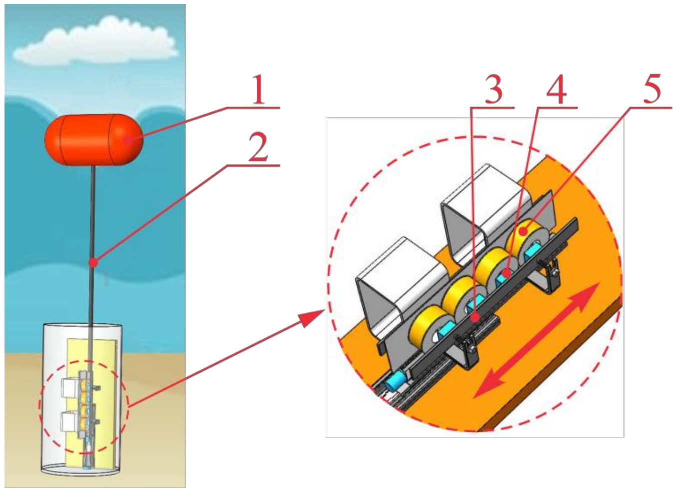

FIGURE 1. Linear generator with rotating magnets in the stator windings.

Table. 1 shows the parameters of the three types of studied stator windings, all with a diameter D = 50mm, but with different thickness Hc. Identical cylindrical rotating magnets with diameter d_{rm}=10mm and thickness h_{rm}=10mm are mounted in these windings. The studied linear generator has two types of translatonal magnets with different thicknesses h_{mt}=2 and 4 mm and length and width of 20 mm.

TABLE 1. Parameters of the studied stator windings.

№	Thickness of the windings H, mm	Diameter of the windings D, mm	Number of turns N	Diameter of the conductor d, mm
1	10	50	1188	0.2
2	16	50	1900	0.2
3	20	50	2370	0.2
4	30	50	3500	0.2

A three-dimensional model of the linear generator with rotating magnets /LGRPM/ in the stator windings in dynamic mode was created with ANSYS R19.1.

Figures 2 and 3 present the magnetic field distribution, obtained from the modeling, for: stator windings with thicknesses H=10 and 16 mm; translational magnets with thicknesses h=2 and 4 mm, length and width of 20 mm.

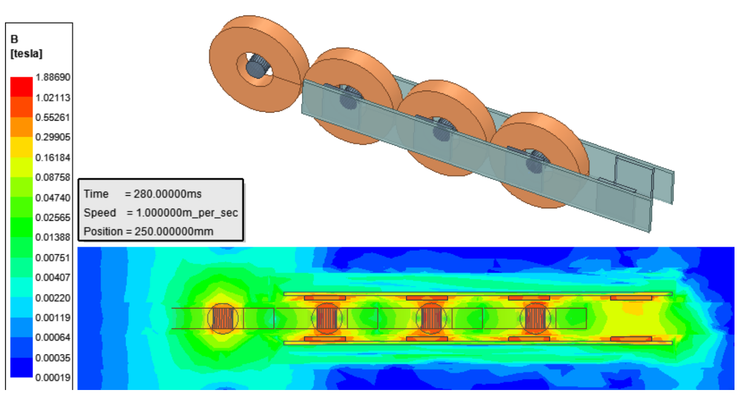

FIGURE 2. Distribution of the magnetic field for stator windings with a thickness of H = 10 mm and magnets of the double-sided translator with a thickness of h = 2 mm.

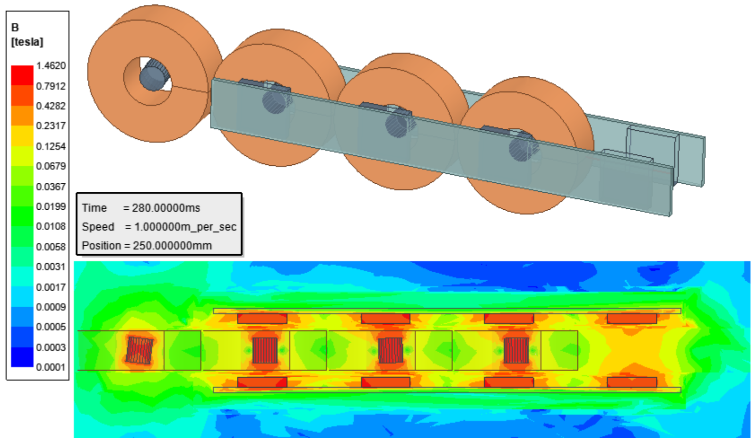

FIGURE 3. Distribution of the magnetic field for stator windings with thickness H = 16 mm and magnets of the double-sided translator with thickness h = 4 mm.

With the help of ANSYS R19.1 the induced electromotive force in the of 4 series-connected windings was also simulated in its instantaneous form $e_c(t)$ and shown in the following Figures, respectively: in Fig. 4 - for stator windings with a thickness H=10 mm and magnets of the double-sided translator with a thickness h= 2 mm; in Fig.5 - for stator windings with a thickness H=16 mm and magnets of the double-sided translator with a thickness h=4 mm.

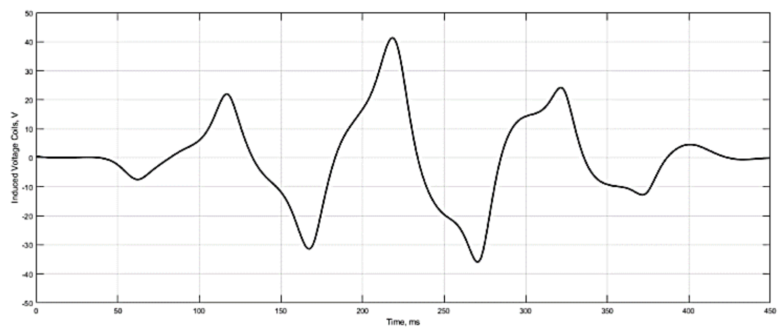

FIGURE 4. E.m.f. in the case of stator windings with thickness H=10 mm and magnets of the double-sided translator with thickness h=2 mm.

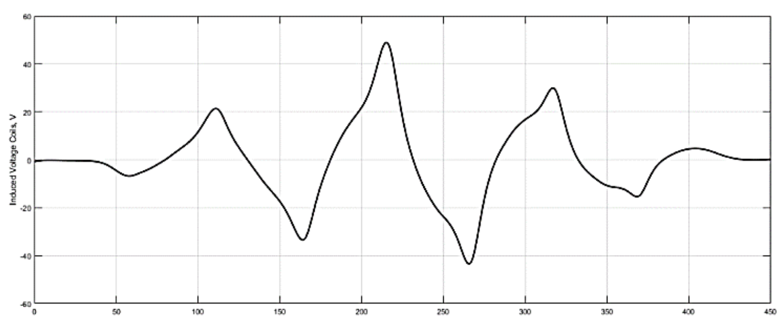

FIGURE 5. E.m.f. in the case of stator windings with thickness H=16 mm and magnets of the double-sided translator with thickness h=4 mm.

The current, voltage and power consumption in the active load were calculated using the effective value E of the induced electromotive force in the four windings and their equivalent parameters [6].

EXPERIMENTAL RESEARCH

The voltages, currents and active powers of the LGRPM with stator windings with thicknesses H_C =10, 16, 20 and 30 mm and translational magnets with thickness h_{mt}=2mm, length and width of 20mm, are presented in Figures 6, 8 and 10. Figures 7, 9 and Fig. 11 show the same values, but for translational magnets with thickness h_{mt}=4 mm and length and width of 20 mm.

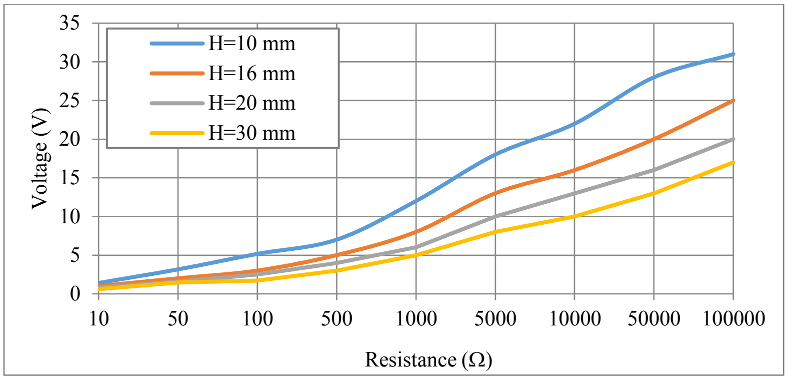

FIGURE 6. Voltages for stator windings with thicknesses H=10, 16, 20 and 30 mm and translatonal magnets with thickness h=2 mm.

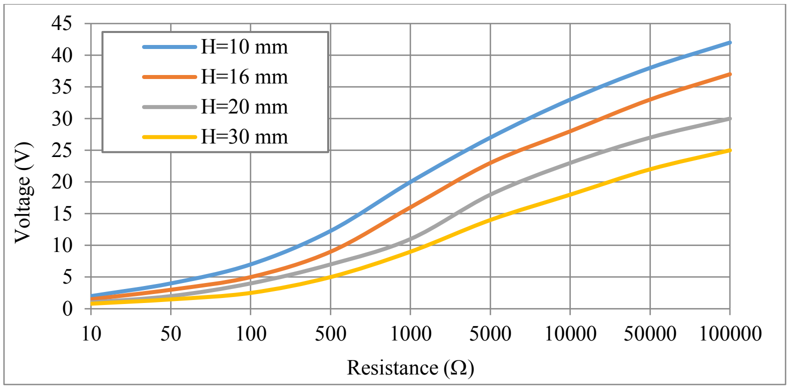

FIGURE 7. Voltages for stator windings with thicknesses H=10, 16, 20 and 30 mm and translatonal magnets with thickness h=4 mm.

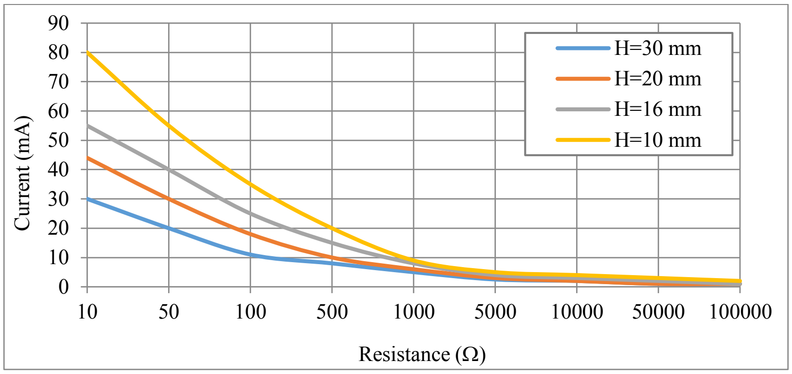

FIGURE 8. Currents for stator windings with thicknesses H=10, 16, 20 and 30 mm and translatonal magnets with thickness h=2 mm.

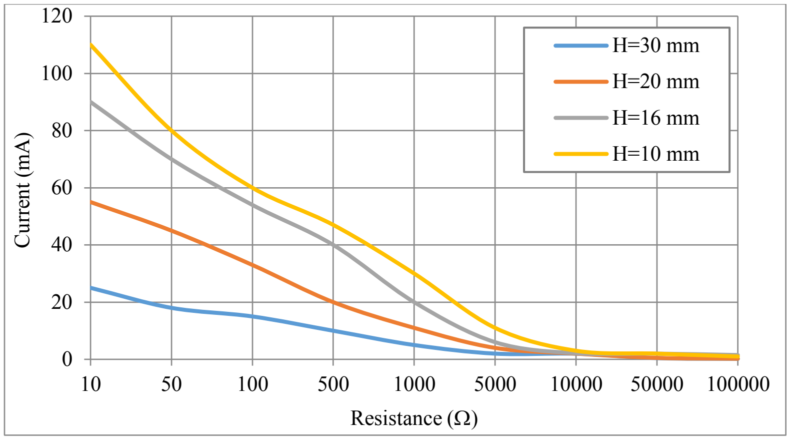

FIGURE 9. Currents for stator windings with thickness H=10, 16, 20 and 30 mm and translatonal magnets with thickness h=4 mm.

The powers, obtained from the modeling, show that the LGRPM model is adequate in the range of load resistances both from 10 to 1000Ω for translatonal magnets with thickness h=2 mm (Fig. 10), and from 10 to 5000Ω for translatonal magnets with thickness h = 4mm (Fig. 11).

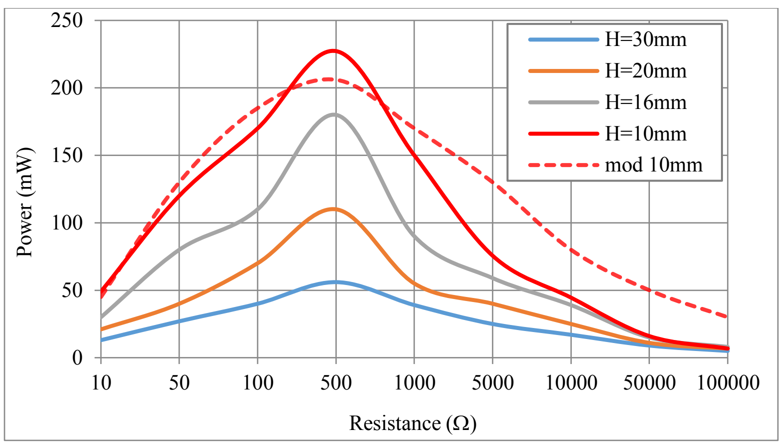

FIGURE 10. Power for stator windings with thicknesses H=10, 20 and 30 mm and translatonal magnets with thickness h=2 mm.

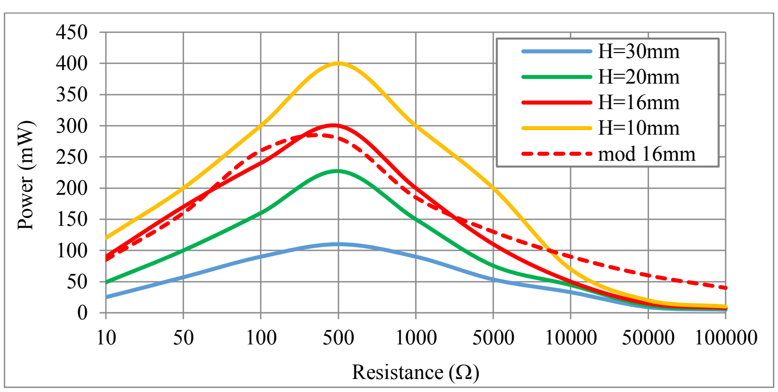

FIGURE 11. Active power for stator windings with thicknesses H=10, 16, 20 and 30 mm and translatonal magnets with thickness h=4 mm.

Eight variants with four thicknesses of the windings H and two thicknesses of the translational magnets h are shown in Table 2, together with the resistive forces F_m caused by the interaction of the fields of the translational and rotating magnets in the stator windings. The same table presents the air gaps *l*, the maximum currents and powers, as well as the relative errors δ_{max} between the measured and obtained from the model powers in the 1st and 6th variant.

TABLE 2. Resistive forces of the magnetic field. Maximum currents, powers and relative errors.

№	H, mm	h, mm	l, mm	F_m, N	I_{max}, mA	P_{max}, mW	δmax, %
1	10	2	4	8.2	80.1	227.2	9.67
2	16	2	10	7.2	55	177	
3	20	2	14	6.4	44.3	110.1	
4	30	2	24	4.4	29	56.4	
5	10	4	4	14.6	111	400.3	
6	16	4	10	13.6	90	303	8.94
7	20	4	14	11.8	54.5	228.3	
8	30	4	24	9.1	24.1	110.2	

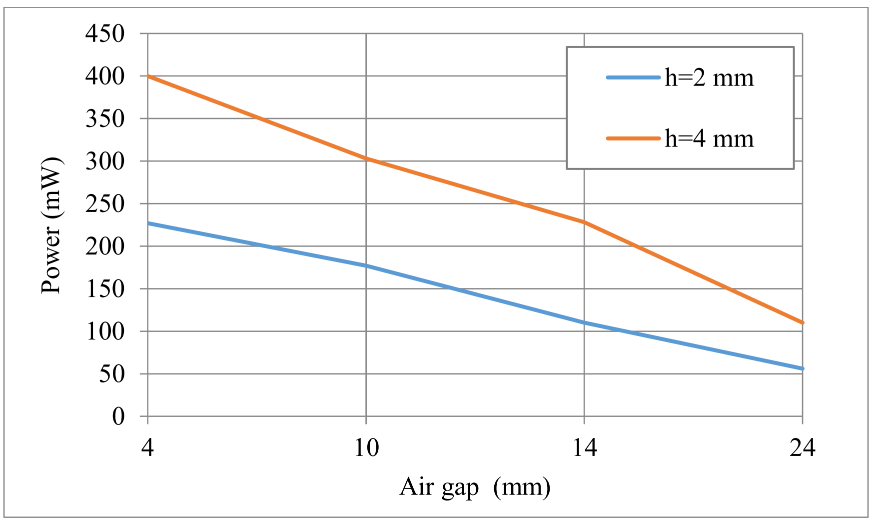

FIGURE 12. Dependence of the active power on the air gap for translatonal magnets with thicknesses h = 2 and 4 mm.

As the air gaps increase, the generated powers decrease, following a linear law for the two thicknesses of the translational magnets, Fig.12.

With a decrease in the air gaps, the resistive forces, resulting from the interaction of the fields of the rotating and translational magnets, increase. The increase in the thickness of the magnets also leads to an increase in these resistive forces.

The highest voltages, currents and powers are obtained at 10 mm thickness of the windings - variants 1 and 5, for powers of 227.2 mW and 400.3 mW, respectively. The resistive force F_m from the interaction of the fields of the magnets in the 5th variant is large and therefore variant 6 is more suitable for practical realization instead.

CONCLUSIONS

From the performed three-dimensional modeling in dynamic mode in ANSYS R19.1 and the conducted experimental research it was established that the decrease in the thickness of the stator windings leads to a significant increase of the obtained currents, voltages and powers, which can be seen with both types of translational magnets (thickness of 2 or 4 mm). The decrease in the air gaps increases the resistive forces caused by the interaction of the fields of the magnets. The highest currents, voltages and powers are obtained in variants 1 and 5, when the thickness of the stator windings is H_C=10mm. Increasing the thickness of the translational magnets from 2 to 4 mm leads to a double increase in the obtained voltages, currents and powers.

It can be seen from the obtained from modeling powers, that the LGRPM model is adequate in the range of load resistances from 10 to 1000Ω.

The most suitable for practical implementation of LGRPMs are variants 1 and 6 with winding thicknesses of 10 and 16 mm, air gaps of 4 and 10 mm and thicknesses of the translational magnets 2 and 4 mm. The resistive forces F_m, resulting from the interaction of the fields of the translational and rotation magnets in them are relatively small and thus a greater acceleration of the translator is achieved. This leads to a significant increase in the voltages, currents and powers.

ACKNOWLEDGMENTS

The authors would like to thank the Research and Development Sector at the Technical University of Sofia for the financial support.

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