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Study of the Influence of the Translational Magnets on the Electrical Parameters of Linear Generators with Rotating Magnets in the Stator Windings

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Abstract. This paper studies the influence of the structural elements on the output electrical parameters of a linear generator with permanent translational and rotating magnets in its stator windings. Dynamic mode simulations with ANSYS R19.1 have been presented, as well as results from experimental studies of a linear generator with rotating stator magnets. Six types of translational magnets have been studied and the optimal variant, in which the output electrical parameters of the generator significantly improve, has been determined. A model has been developed that adequately simulates the operation of the linear generator.

INTRODUCTION

Over the last quarter of a century, various devices have been increasingly used to convert the mechanical energy of sea waves into electrical energy [1]. One variant of these devices are the linear generators, divided into two main types: with and without an iron core in their stator windings. The generators without an iron core are easier to manufacture and cheaper, but the output electrical parameters obtained with them - voltages, currents and powers - are smaller [2,3,4]. The linear generators with an iron core in the windings are more expensive, have low magnetic resistance and better electrical parameters [5,6] but higher harmonics appear with them and the resistance force, resulting both from a reaction toward the current in the stator windings and from the interaction of the magnetic fields, created by the rotational and translational magnets, is greater [2,5,6].

The aim of the present work is to study the influence of the translational permanent magnets on the output electrical parameters of a linear generator with rotating permanent magnets (LGRPM) in the stator windings.

EXPOSITION

The paper studies a linear generator with rotating rare earth / NdFeB32 / magnets in the stator windings with dimensions: diameter drm = 10mm and thickness hrm = 10mm. The design parameters of the stator windings are: diameter D = 50mm; thickness Hc = 16mm; and number of turns N = 1900 with wire diameter 0.2 mm.

The LGRPM constructive diagram, Fig. 1, uses the following notations: 1 - four windings connected in series, 2 - rotating permanent magnets, 3 - translational steel plates and 4 - translational permanent magnets. The steel plates are movable and allow the use of magnets of different thicknesses.

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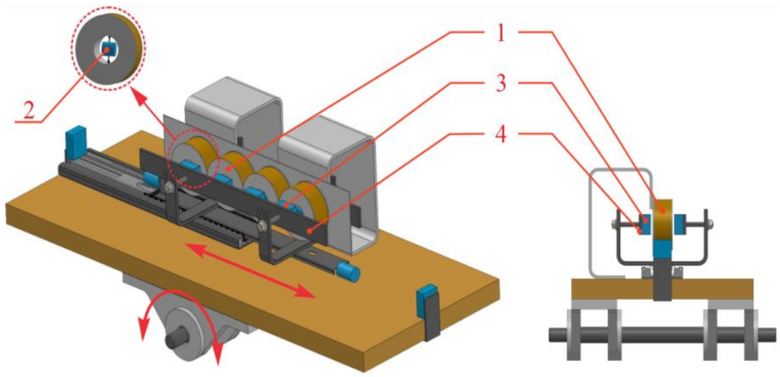

FIGURE 1. Structural diagram of the linear generator with rotating magnets in the stator windings.

Table 1 gives the parameters of the used six types of translational rare earth magnets with dimensions: thickness h_m, width b_m, length l_m and volume V_m.

TABLE1. Dimensions and volume of the translational magnets.

Variant №	h_m (mm)	b_m (mm)	l_m (mm)	V_m (mm^3)
1	2	10	20	400
2	4	10	20	800
3	6	10	20	1200
4	2	20	20	800
5	4	20	20	1600
6	6	20	20	2400

Using ANSYS R19.1, modeling of the LGRPM in dynamic mode was performed for the magnets of the double-sided translator with thickness h_m = 4 and 6 mm. The distribution of the magnetic flux density can be seen in Fig.2 and Fig.4, and the instantaneous form of the induced electromotive force for the four series-connected stator windings – in Fig. 3 and Fig. 5.

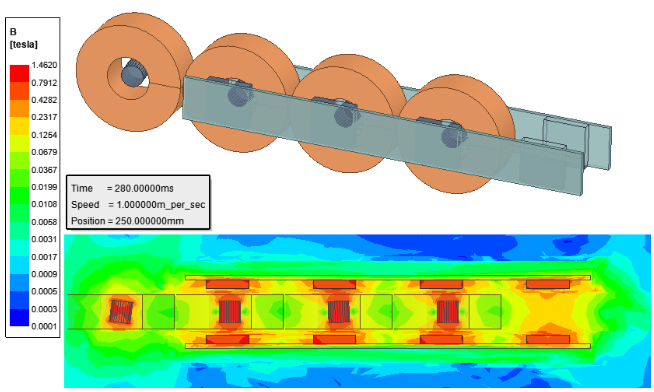

FIGURE 2. Magnetic field of the linear generator at thickness of the translational magnets h = 4 mm.

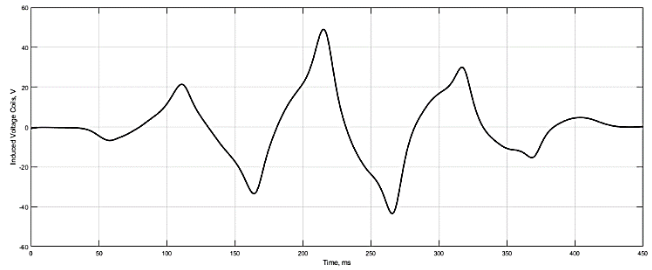

FIGURE 3. Electromotive force of the LGRPM generator at thickness of the translational magnets h = 4 mm.

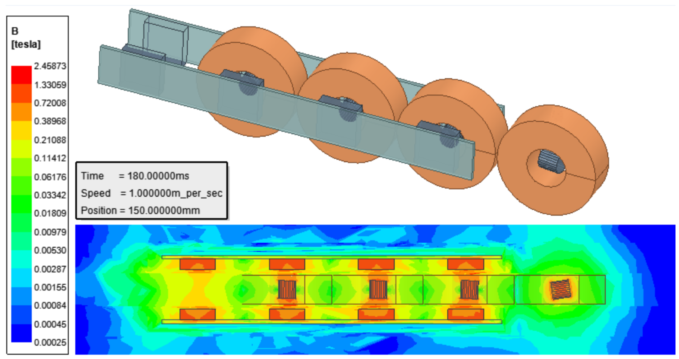

FIGURE 4. Magnetic field of the LGRPM at thickness of the translational magnets h = 6 mm.

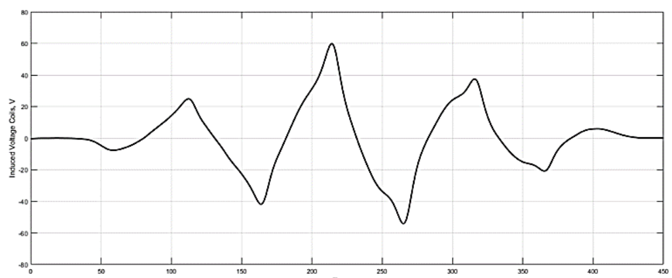

FIGURE 5. Electromotive force of the LGRPM generator at thickness of the translational magnets h = 6 mm.

The active power is calculated using the r.m.s. value of the induced electromotive force in the four windings for idle run mode and the equivalent parameters of the windings [6].

The change of the DC voltages, currents and active powers at active load in the range R_L = 10kΩ to 100kΩ, for the six types of translational magnets is presented in Fig.6, Fig.7 and Fig. 8.

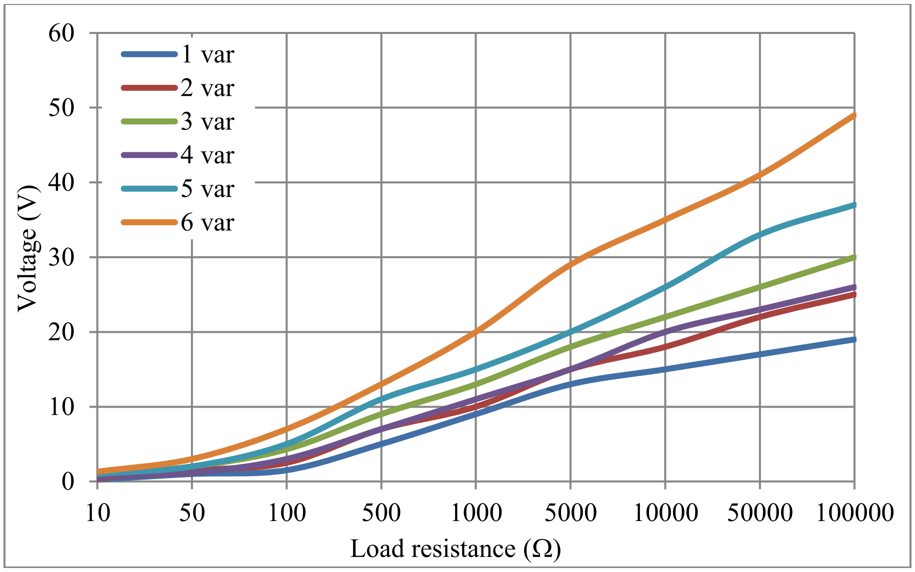

FIGURE 6. DC voltages on the active loads.

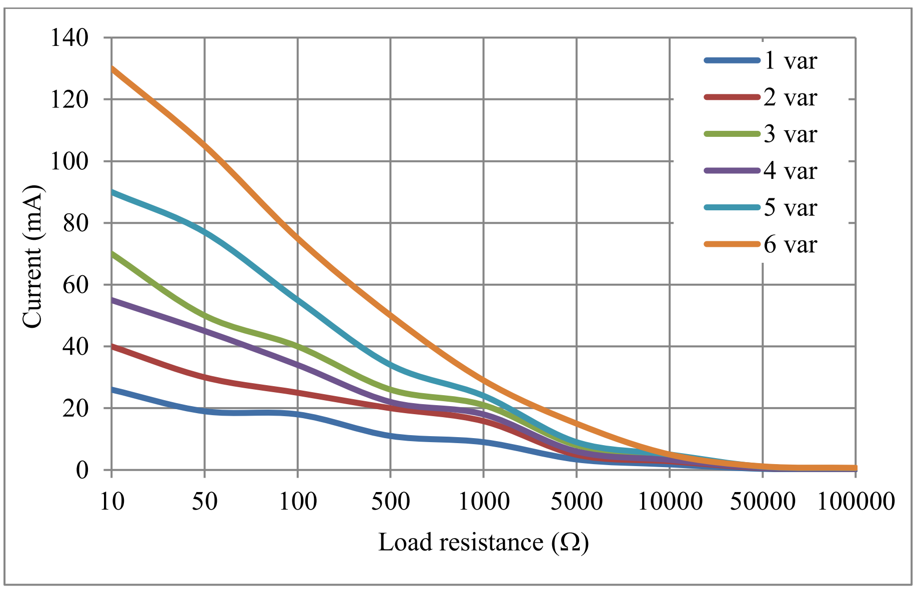

FIGURE 7. Currents through the active loads.

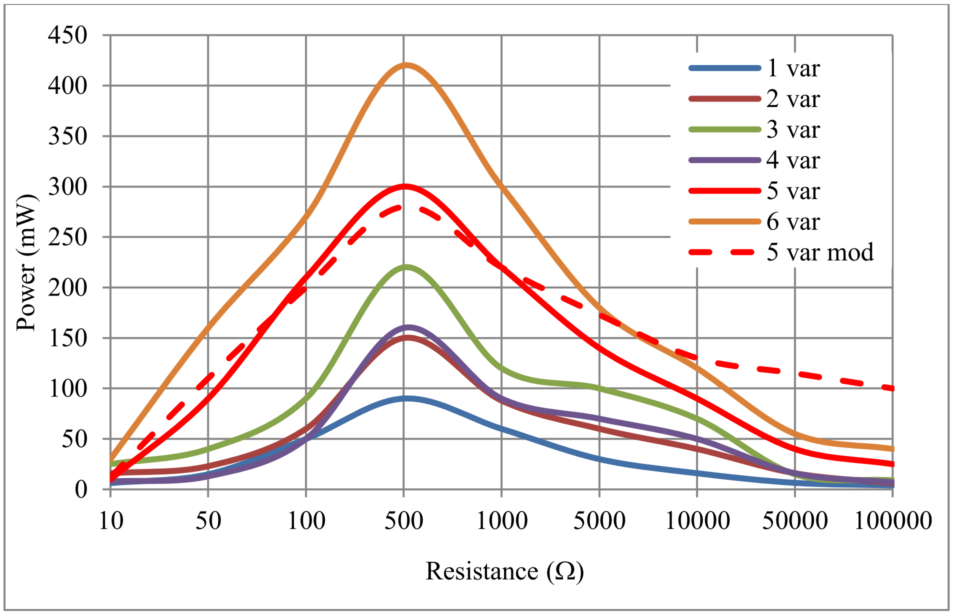

FIGURE 8. Active powers.

As the load resistance increases, the output DC voltages increase and the currents through the active load decrease almost linearly. The highest voltages and currents are observed with the 5th and 6th variants of the translational magnets, i.e., the ones, having the largest volume, 1600 and 2400 mm^2 respectively. The maximum active powers are obtained at a load R_L = 500Ω for all types of translational magnets, and again for the 5th and the 6th variants their values are the highest, 300.4 mW and 420.2 mW, correspondingly.

From the values of the powers, obtained for the 5th variant during the simulation, it can be seen that the LGRPM model is adequate in the range of load resistances from 10 to 4000Ω (Fig. 8).

It can be seen from the relationship between the maximum measured powers and the volume of the translational magnets (Fig. 9) that the increase in the volume linearly increases the maximum measured power.

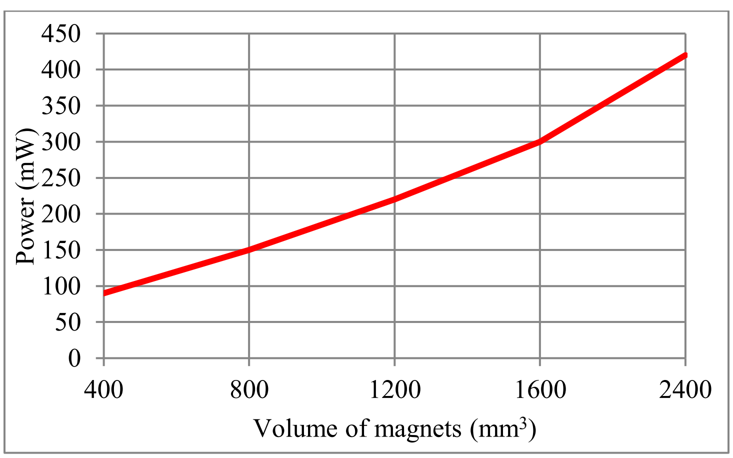

FIGURE 9. The maximum measured power as a function of the volume of the translational magnets.

Table 2 shows the resistance forces F_m, caused by the interaction of the magnetic fields of the translational and rotating stator magnets. The table also presents the measured maximum voltages, currents and powers, as well as the relative power $P_r = P_{max}/F_m$. The maximum relative error δ_{max} between the measured and the obtained from the model powers for the 5th variant has been calculated.

TABLE 2. Magnetic field resistance forces; maximum voltages, currents and powers; relative maximum powers; and relative error.

Variant №	F_m (N)	U_{max} (V)	I_{max} (mA)	P_{max} (mW)	P_r (mW/N)	δ_{max} %
1	6.6	19.2	26.3	89.9	27.27	
2	11.4	25.3	40.3	150.4	26.32	
3	16.4	30.1	71.2	220.3	26.83	
4	10.3	25.9	55.2	159.7	30.77	
5	17.2	36.9	90.1	300.4	34.88	8.32
6	26.8	49.1	130	420.2	31.34	

From table 2 it can be seen that with the increase in the thickness and volume of the translational magnets, the measured voltages, currents and powers increase, but this also leads to an increase in the resistance forces caused by the interaction of the fields, created by the translational and rotating stator magnets. The highest relative power P_r is obtained with the 5th variant and although in this case the maximum power, voltage and current are smaller than those, obtained with the 6th one, the resistance force with the 5th type of translational magnets is lower by 36%. The maximum relative error between the measured and obtained in the simulation power is relatively small, which confirms the adequacy of the obtained model.

Figure 10 shows the resistance forces F_m, originating from the interaction of the fields, created by the translational and rotating magnets and the coefficient of efficiency for the six variants under consideration.

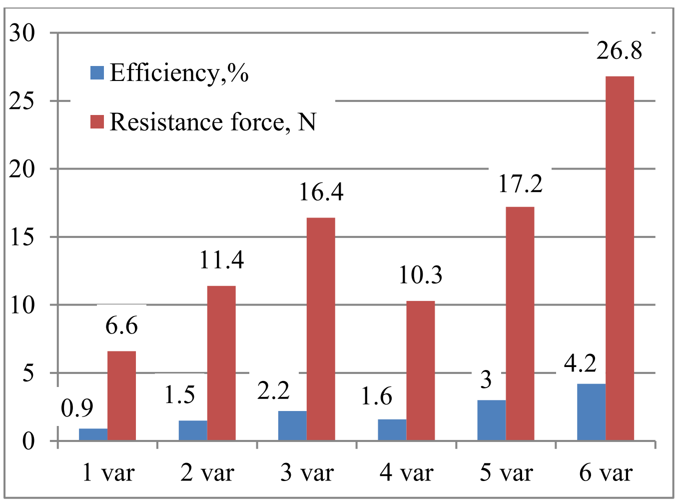

FIGURE 10. Resistance forces and efficiency for the different types of translational magnets.

CONCLUSIONS

From the performed program simulations and the conducted experimental research of linear generators with permanent rotating magnets it has been found that the highest voltages, currents and powers are obtained with the 5th and 6th types of translational magnets, having the largest volume of 1600 mm^2 and 2400 mm^2. The maximum active powers are observed at a load $R_L = 500\Omega$ for all types of translation magnets, and again for the 5th and the 6th variants their values are the highest, 300.4 mW and 420.2 mW, respectively.

As the thickness and volume of the translational magnets increase, the output voltages, currents, powers and efficiency also increase, but this, on the other hand, also leads to an increase in the resistance forces caused by the interaction of the magnetic fields, created by the translational and the rotating stator magnets. The highest relative power P_r is obtained with the 5^{th} variant and although in this case the maximum power, voltage and current are smaller than those, obtained in the 6th one, the resistance force with this variant is 36% lower.

The efficiency for the 5^{th} variant is lower, just 3%, compared to the 4,2% for the 6th variant, but the resistance force is significantly lower - by 36% - and this makes the 5^{th} variant more suitable for practical use.

Both the obtained in the simulation and the measured power values show that the LGRPM model is adequate in the range of load resistances from 10 to 4000Ω (Fig. 8), and the maximum relative error is comparatively small, 8.32%. A 5^{th} variant with dimensions of the translational magnets 20x20x4 mm can be used for practical realization of the linear generator with rotating magnets in the stator windings.

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