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Characteristic Analysis and Experimental Verification for a Double-sided Permanent Magnet Linear Synchronous Generator According to Magnetization Array

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I. Abstract

This paper compares the characteristics of a double-sided small-scale permanent magnet linear synchronous genera-tor (PMLSG) using three different magnetization arrays. Though PMLSGs generally prefer a vertical array, we propose the Halbach array and a horizontal array, which are widely used in permanent magnet devices. For an accurate comparison, the output power, mechanical air-gap thickness, and overall size are all equal. On the basis of analytical two-dimensional field solutions, this study predicts magnetic fields, losses, masses, and output powers of the three arrays. The experimental results are validated extensively by comparing them with finite element analysis results. This result shows the best arrangement of a double-sided small scale PMLSG compared to the experimental results.

II. Structure and Analysis Comparison of the Proposed PMLSG

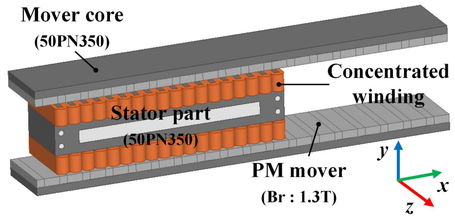

FIG. 1. Structure of a double-sided permanent magnet linear synchronous generator.

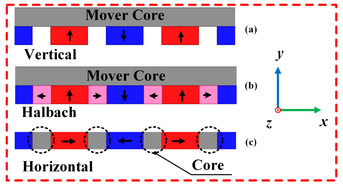

FIG. 2. Typical movers with three types of PM magnetizations for linear generator: (a) vertical, (b) Halbach, and (c) horizontal.

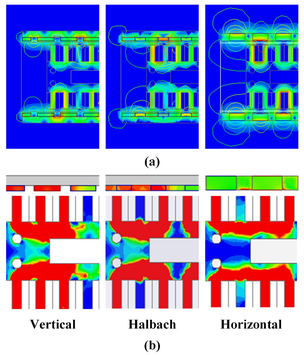

FIG. 3. FEA results of the three types according to magnetization array : (a) flux density and flux line, (b) eddy current loss and core loss density.

- ✓ The PMLSG uses the commonly-used vertical array, the Halbach array, which maximizes efficiency, and a horizontal array that is easy to fabricate.
- ✓ A previous study highlights the excellence of Halbach arrays by using exclusively these arrays in the desig.
- ✓ However, in this paper, we propose an excellent array in a linear generator by comparing the efficiency and mass of three arrays.

III. Characteristic Analysis and Experimental Comparison According to Magnetization Arrays

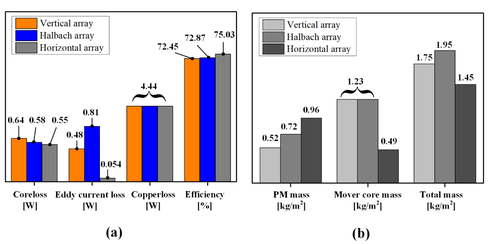

FIG. 4. Analysis results according to magnetization arrays: (a) loss and efficiency, (b) mover mass.

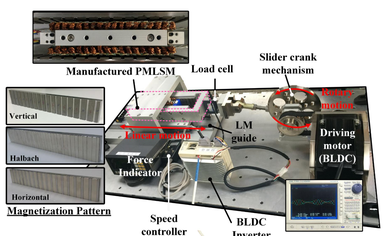

FIG. 5. PMLSG setup for experimental verification.

- ✓ The eddy current is much lower for the horizontal array because of the reduction of magnetic air gaps and size of the model.
- ✓ Therefore, the horizontal array has about 3% higher efficien-cy than the Halbach array.
- ✓ Owing to the amount of horizontal array material used at the rated output of 30 W, the PM mass is high but is compensated by the large differ-ence in the mover core mass, which is 60% smaller than the masses of the vertical and Halbach arrays.
- ✓ As a result, the horizontal array mass is about 26% lower than that of the Halbach array.

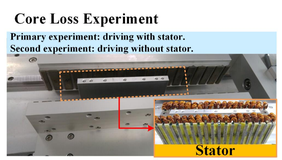

FIG. 6. Core loss experiment.

- ➢ The displacement and velocity of the Fig. 5 are generated by the slider-crank mechanism and are calculated as follows:

$$Disp. = -\frac{D}{2}\cos(2\pi ft)[m] \quad (1)$$

$$V_s = \pi fD\sin(2\pi ft)[m/s] \quad (2)$$

- ➢ Here, D and f are the diameter of the crank and the speed of the driving motor, respectively.

IV. Comparison of FE Analysis and Experimental

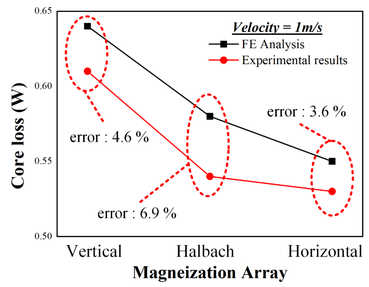

FIG. 7. The core loss results of the FEA and Experimental.

- ✓ In addition, Fig. 6 shows the core loss test method. The core losses are predicted by the difference between when the stator is combined and when it is not combined.
- ✓ As seen in Fig. 7, the FEA results and the experimental results are almost the same in spite of some errors.

TABLE I. Parameters of the Manufactured Prototype PMLSGs

Magnetization array	Vertical	Halbach	Horizontal
Parameter		*Value*	
Stack length		50 mm	
Coil pitch		3 mm	
Slot width		4 mm	
Mover length		324 mm	
Stator length		180 mm	
Air-gap		3 mm	
Turns per coil		20 turns	
Displacement		100 mm	
D		100 mm	
Pole pitch		13 mm	
Rated output power		30 W	
Pole thickness	3 mm	3 mm	6 mm
Over-all height	72 mm	72 mm	68 mm

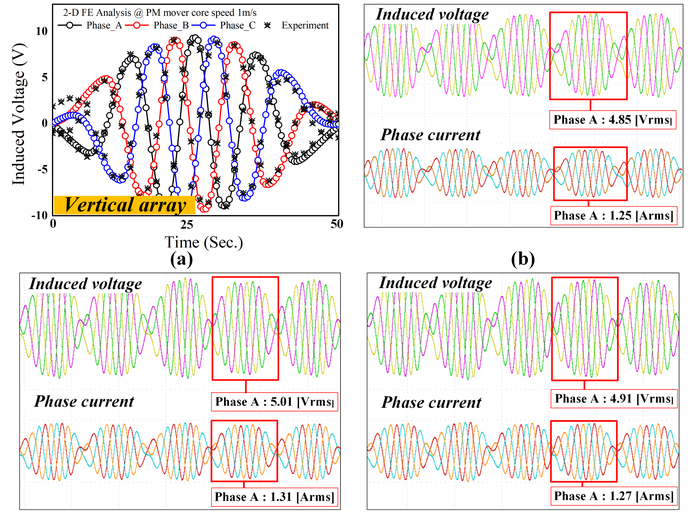

FIG. 8. Induced voltage and phase current experiment results (a) com-parison of experiments with FEA, (b) vertical array, (c) Halbach array, (d) horizontal array.

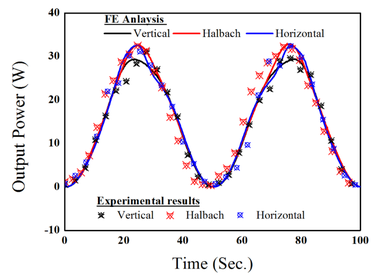

FIG. 9. Comparison of output power results (load resistance = 3Ω).

- ✓ Fig. 9 shows the out-put power of each array. All of the FEA and experimental measurement results are in good agreement.
- ✓ A 3Ω load resistance is required to obtain 30W of output power.
- ✓ Table I shows the parameters of the PMLSG.
- ✓ All specifications are the same except for the pole thicknesses and over-all heights, which are slightly different for the three arrays.
- ✓ This is required to establish the same criteria for an accurate comparison of the three arrays proposed in this paper.

V. Conclusion

- ✓ In this paper, we discussed and compared the characteris-tics of a double-sided PMLSG according to different magneti-zation arrays using FEA.
- ✓ We compared the efficiency and mass while considering the manufacturing process and in-stallation environment.
- ✓ Generally, the Halbach array is regarded to be superior to other magnetization array. However, as observed from the comparison results of the three arrays in this paper, the horizontal array is superior.
- ✓ This is because of the least effect on its efficiency of the eddy current loss and mass of the mover.
- ✓ All results show the superiority of the horizontal array of PMLSG and it will be useful in the design of a linear generator.

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