Design and Analysis of a New Double-stator Dual-magnet Linear Magnetic-geared Machine

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***Abstract*—This paper proposes a new double-stator dual-magnet linear magnetic-geared (DSDM-LMG) machine, which adopts a new hybrid structure. It artfully incorporates the magnetic-gearing effect and flux-memory capability together, which can offer the high force output with flux control capability. The keys are the utilization of flux-modulation segments for achieving the gearing effect and the use of dual magnets for controlling the airgap flux density. The finite element analysis is performed to verify the validity of this linear machine.**

***Index Terms*—Dual-magnet, linear machine, magnetic-geared machine, memory machine, flux control.**

I. Introduction

Linear magnetic-geared machines have attracted attention for direct-drive applications since they can offer high force output with the contactless gearing effect [1]-[3]. However, their operating speed range is relatively narrow due to the difficulty in flux control. Flux-memory machines are another attractive candidate with the distinct advantage of magnetic field memory function, which is favorable for wide-speed operation [4]-[6]. However, their development has been biased on the rotational morphology.

The purpose of this paper is to propose a new double-stator dual-magnet linear magnetic-geared (DSDM-LMG) machine. Namely, it adopts the double-stator structure to increase the force production, the flux-modulation segments to produce the magnetic-gearing effect and the dual-magnet structure to achieve the flux-memory capability.

II. Machine Design

Fig. 1 shows the proposed machine structure, which consists of an in-between mover, two stators, and two sets of flux-modulation segments. The mover has 16 effective pole-pair NdFeB PMs mounting on both surfaces. The stators accommodate the armature windings, the AlNiCo PMs and their magnetizing windings. Each set of flux-modulation segments is located between the stator and the mover, which functions to provide flux modulation for achieving the gearing effect, hence amplifying the force or reducing the speed for different industrial applications.

In order to achieve the gearing effect, the pole-pair arrangement of the machine is governed by [1]-[3]: $p_m = N_{fms} - p_s$, and $G_r = (p_s - N_{fms})/p_s$, where p_m is the number of effective pole pairs of the mover, p_s the number of stator armature pole pairs, and N_{fms} the number of flux-modulation segments. For this machine, $p_m = 16$, $p_s = 2$, $N_{fms} = 18$, and $G_r = -8/1$.

The AlNiCo PM is positively utilized to perform online tuning of magnetization. Differing from the NdFeB PM, the AlNiCo PM exhibits nonlinear behavior as shown in Fig. 2(a). Particularly, it can readily be demagnetized and remagnetized, partially or fully. Because of this feature, a piecewise-linear hysteresis model of the AlNiCo PM [6] is incorporated for the finite element analysis as shown in Fig. 2(b).

The proposed machine is particularly suitable for direct-drive linear applications, such as oceanic wave energy converters, free-piston power generators or linear high-force low-speed actuators. Also, its flux-memory capability enables it to provide a wide speed range of operation.

III. Verification Results

Fig. 3 shows the upper airgap flux density waveforms at different magnetizing levels of the AlNiCo PM. It can be found that the airgap flux density is tunable under different magnetizing levels. Also, each waveform shows that it has 16 pole pairs within 360 degrees which correspond to the 2 pole-pair armature field. Thus, it visualizes the gearing effect to change the number of pole-pairs and hence the resulting change in torque or speed. It should be noted that the use of magnetizing current to tune the airgap flux density is not too energy demanding since it is activated only when flux control is required and the desired duration is within milliseconds.

Fig. 4 depicts no-load EMF waveforms at the linear speed of 1 m/s at different magnetizing levels of the AlNiCo PM. As expected, their amplitudes simultaneously increase with the magnetizing currents. Their amplitudes are 36 V, 26 V and 17 V under the full-, half- and zero-magnetizing levels, respectively. It confirms that the EMFs can be effectively controlled or regulated.

Fig. 5 shows the thrust force waveforms at different magnetizing levels of the AlNiCo PM. It can be found that the machine can provide the maximum force up to 1000 N with the full-magnetizing level under the rated armature current of 8 A. Meanwhile, Fig. 6 depicts the static force waveforms under different magnetizing levels of the AlNiCo PM. It illustrates that the proposed machine can achieve the average static forces of 562 N, 382 N and 274 N under the full-, half- and zero-magnetizing levels, respectively.

IV. Acknowledgments

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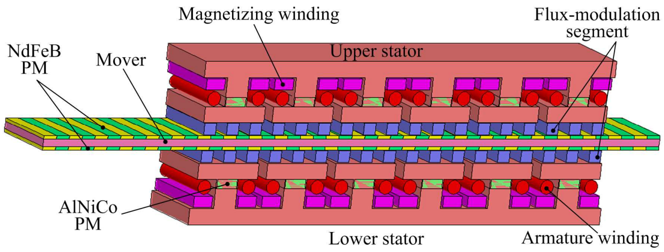

Fig. 1. Proposed DSDM-LMG machine.

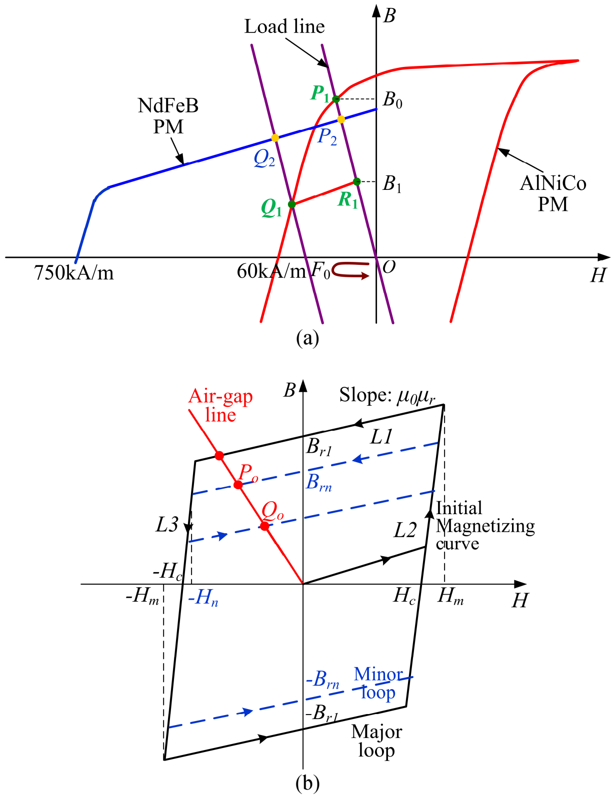

Fig. 2. Operating characteristics of PMs. (a) B-H curves. (b) Hysteresis model of AlNiCo PM.

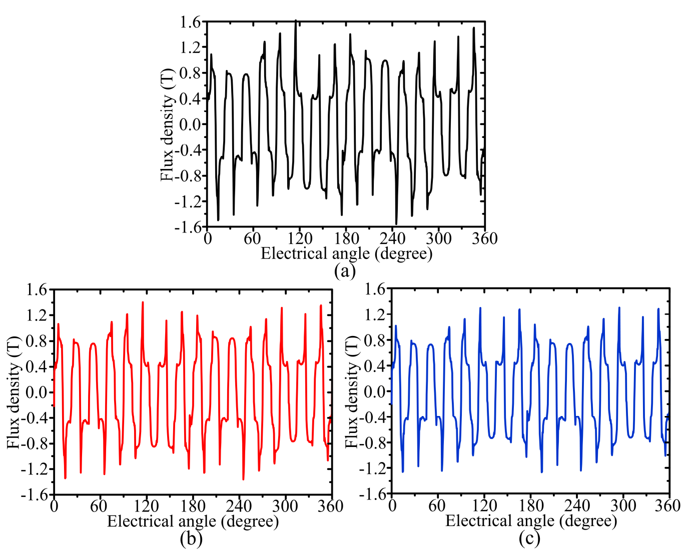

Fig. 3. Airgap flux density waveforms. (a) Full-magnetizing level. (b) Half-magnetizing level. (c) Zero-magnetizing level.

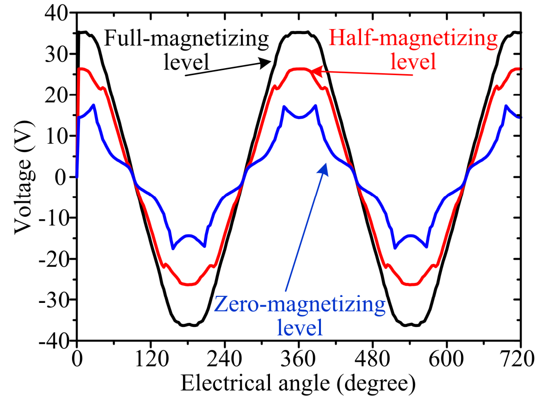

Fig. 4. No-load EMF waveforms under different magnetizing levels.

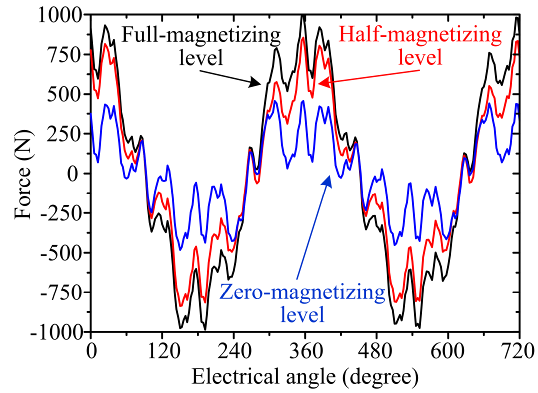

Fig. 5. Thrust force waveforms under different magnetizing levels.

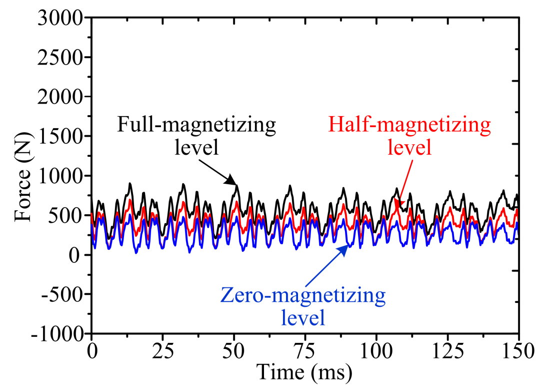

Fig. 6. Static force waveforms under different magnetizing levels.

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