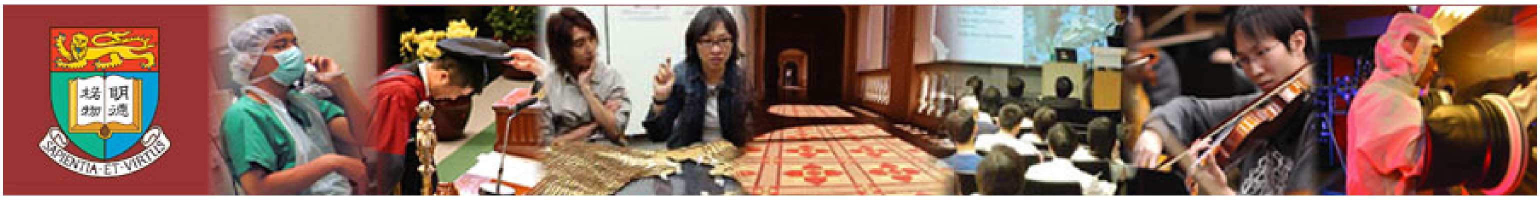

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Design of a hybrid excitation permanent-magnet linear vernier generator for wave energy extraction

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1. Introduction

Because of its abundant, green and untapped features, exploration of oceanic wave energy becomes more and more attractive in recent years [1]. The direct-drive wave energy harvesting technology which directly harnesses the wave vertical movement to drive a linear reciprocating generatoris accepted widely in recent years [2]. Among various linear generator topologies, the permanent magnet linear vernier (PMLV) generator which exhibits a high power, high thrust and high efficiency capability are promising for capturing the low-frequency and high-force wave energy [3].However, due to the intermittent and stochastic nature of wave power, PM generator which only uses PM for excitation is insufficient to provide the flexible reactive power and voltage control. The purpose of this paper is to propose a hybrid excited permanent magnet linear vernier generator for extracting wave power. By equipping a set of DC winding for an auxiliary excitation, it shows a good capability for the air-gap flux control.

2. Proposed Linear Generator

Fig. 1(a) shows a single module of the proposed linear generator configuration. Unlike the conventional machine structure, its stator consists of a pair of identical stator teeth which are connected by the stator yoke. The armature winding embraces with the stator teeth while the DC field winding embraces with the stator yoke through the middle of stator tooth pair. Correspondingly, the mover is also mounted with two groups of PMs with iron poles interleaving between them. PMs have the same magnetization direction in the same group and the opposite magnetization direction in the different group. There are mainly two flux paths in the proposed linear generator: one is the flux generated by PMs which passes PM poles, rotor yoke, stator teeth and stator yoke as shown in Fig. 1(b); the other one is the flux excited by DC field winding which passes iron pole pieces, rotor yoke, stator teeth and stator yoke as shown in Fig. 1(c). The realization of the flux-control capability is that the DC field winding flux superposes on the PM flux to create a variable air-gap flux. When the flux provided by DC field winding flows in the same direction as that of the flux provided by PMs, the air-gap flux can be strengthened. When the flux provided by DC field winding flows in the opposite direction as that of the flux provided by PMs, the air-gap flux is weakened correspondingly [4], [5].

3. Analysis

Since the flux path of the proposed linear generator is inherently three-dimensional (3-D), the 3-D finite element method (FEM) is adopted for the field analysis. Fig. 2(a) shows the field distribution when there is no injected current in the DC field winding. It can be found that the flux path is closed by PM poles and there is little flux flowing through the iron poles. Fig. 2(b) and Fig. 2(c) shows the field distribution of air-gap flux strengthening and weakening with 1000 A-turns respectively. The DC field winding provides an extra excitation source which increases or decreases the resultant flux flowing through the magnetic circuit of the proposed generator, therefore, the air-gap flux control can be achieved. Fig. 2(d) gives the air-gap flux density of the aforementioned three cases. The air-gap flux densities under the iron pole are nearly 0, 0.5 T and -0.4 T for no flux control, flux strengthening and flux weakening. It verifies that the air-gap flux is controlled via the iron poles of the mover which has little demagnetization risk to PMs. The no-load induced voltage waveforms are illustrated in Fig. 2(e). By flux strengthening, the voltage amplitude can be enlarged by 2 times; by flux weakening, the voltage amplitude can be reduced to 15% of the original one. The detailed design, mathematical modeling, analysis and experimental verifications will be given in the full paper. This work was supported by a grant (Project No. MYRG067(Y1-L2)-FST13-CTW) from Research Council of the University of Macau, Macao Special Administrative Region, China and a grant

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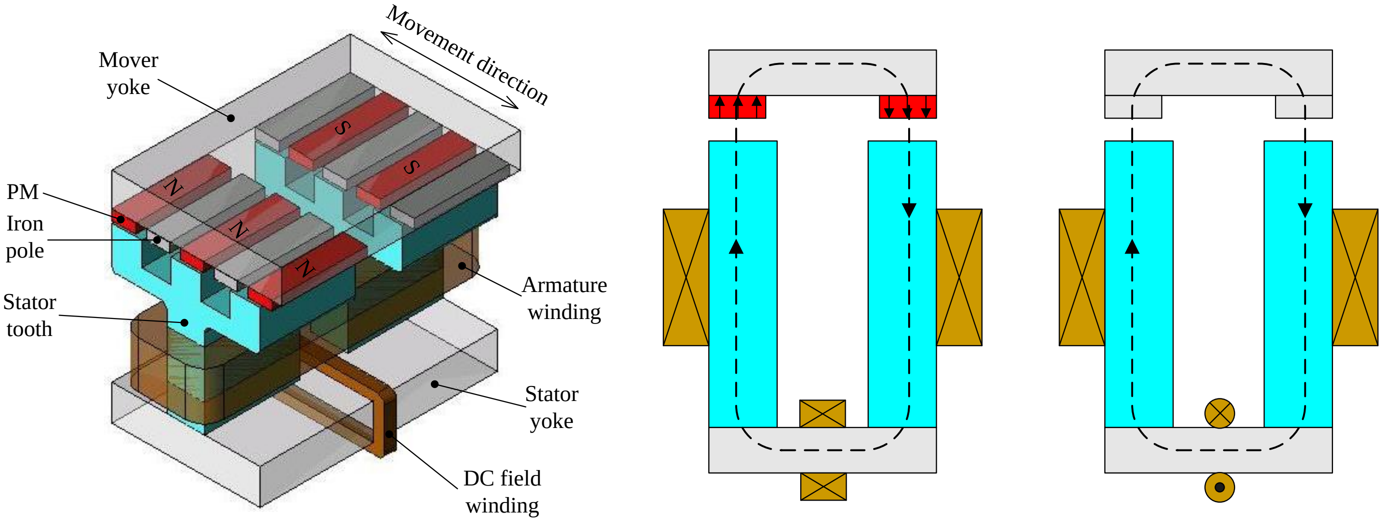

(a) (b) (c)

Fig. 1. Proposed linear generator. (a) A single module of the proposed generator. (b) Flux path excited by PMs. (c) Flux path excited by DC field winding.

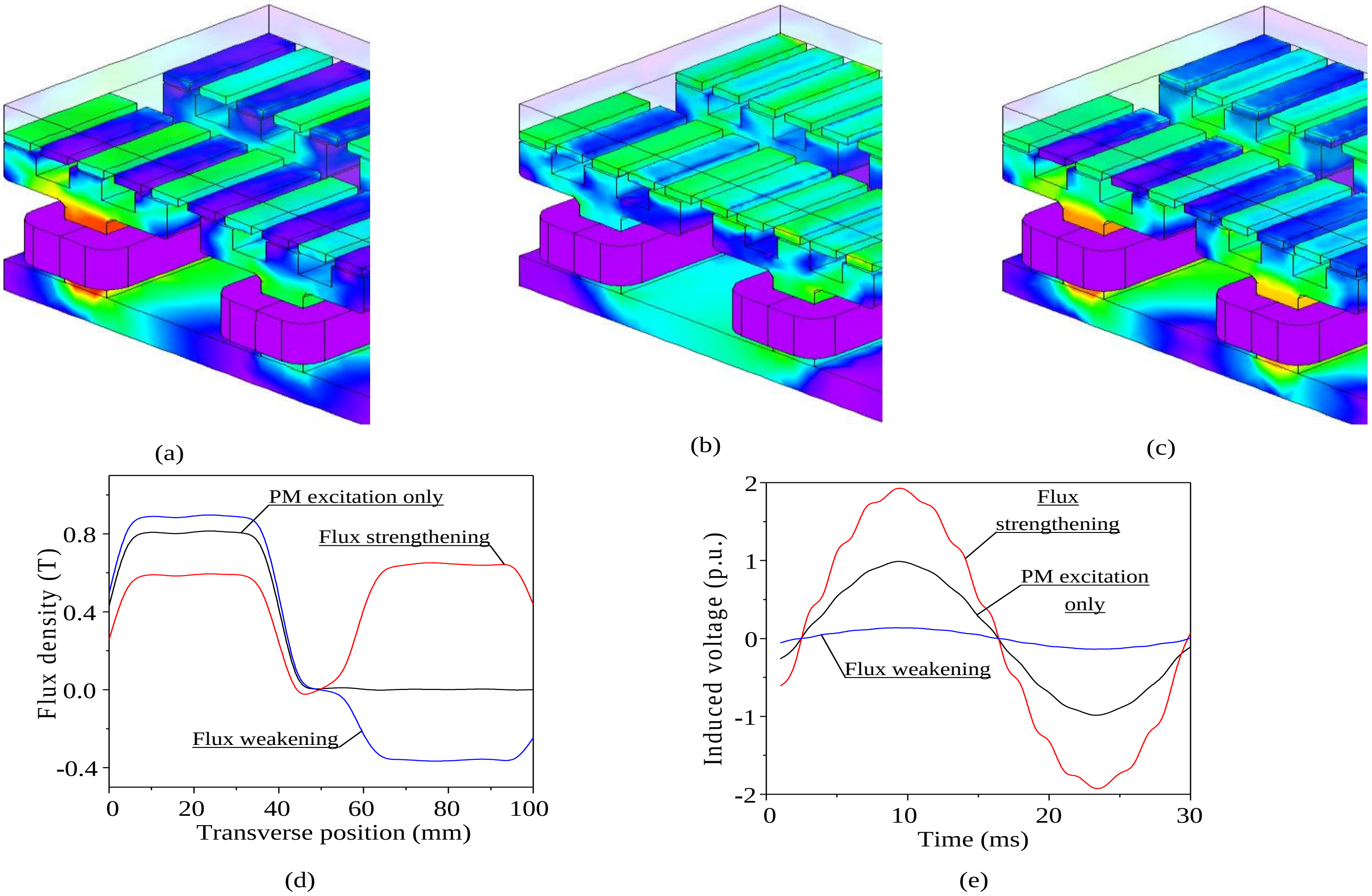

Fig. 2. Analysis results. (a) Field distribution under PM excitation. (b) Field distribution under flux strengthening. (c) Field distribution under flux weakening. (d) Air-gap flux density. (e) No-load induced voltage waveforms.