Chapter 7
Performance of PM Linear Generator Under Various Ferromagnetic Materials for Wave Energy Conversion

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ABSTRACT

This chapter examines the influence of the various ferromagnetic materials on the performance of a single-phase tubular permanent-magnet linear generator (TPMLG) for wave energy conversion. Four ferromagnetic materials were considered in this study. They are non-oriented electrical steel, Permalloy (Ni-Fe-Mn), Accucore, and Somaloy 700. The generator equipped with a tubular stator carries a single coil and employs a quasi-Halbach magnetized moving-magnet translator. Therefore, in order to obtain an accurate performance analysis, the nonlinear time-stepping finite-element analysis (FEA) technique has been used. The electromagnetic characteristics, including the magnetic field distributions, flux-linkage, winding inductance, electromagnetic force, and electromotive force (EMF) have been investigated. It is shown that a generator whose stator is fabricated from soft magnetic composite (SMC) materials has potential advantages in terms of ease of manufacture, highest force capability, lower cost, and minimum eddy-current loss.

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INTRODUCTION

Nowadays, the consensus on the electric linear machines (ELMs) to replace their rotary counterparts has been gradually fostered. By using ELMs numerous advantages are possible, such as high efficient energy generation, the direct-drive system as well as simple structure (Lee, Kim, Jun, & Lee, 2011).

ELMs produce linear motions directly without mechanical transmission means. Thus, it can significantly simplify the structure of the system and improve the working efficiency. These machines have been used in widespread applications, such as in wave energy generation, automotive applications, robotics, medical operation, and reciprocating compressors (Feng et al., 2015; Zheng, Huang, Gao, & Chang, 2015; Abdalla, Ibrahim, & Mohd Nor, 2014). Among the ELMs, the tubular permanent-magnet linear machine (TPMLM) has superior merits, such as high efficiency, high power density, and remarkable force capability due to the lack of end-windings. Moreover, the net attractive force between the stator and translator is zero (Niu, Ho, & Fu, 2011).

The TPMLM can possibly be broken down into three categories, such as moving-coil, moving-iron, and moving-magnet. However, moving-coil TPMLM suffers from numerous demerits, such as limited access to moving-coil, difficulty in dissipating the heat from the coil and the fragility of the connections and flying leads, as well as the limited stroke. The moving-iron type is rarely used due to the heavy moving mass, relatively poor energy conversion, and low force density. Therefore, because of the copper coil directly wound around the yoke of the moving-magnet TPMLM accordingly the high force density can be obtained, thus, this kind of TPMLM it seems to be more suitable for the linear energy conversion (Ibrahim, 2009; Si, Feng, Su, & Zhang, 2014; Wang, Howe, & Lin, 2008).

The appropriate selection of the materials for the ELMs represents a significant role in the development and performance of the machine. The hard-magnetic materials of both high coercivity and high remanence at a wide range of temperature and affordable cost have an important role in the performance of ELMs. The rare-earth elements, such as neodymium-iron-boron (NdFeB) and samarium-cobalt (SmCo), can be considered as the best choice for the permanent-magnet (PM). As a comparison, the SmCo have better chemical properties, whereas, NdFeB is superior in terms of physical properties. The fact that, the PMs of the two groups have complementary characteristics to each other as well as their energy product is high, thus; they are possible to be used in the new technical designs of TPMLMs. Moreover, rare-earth PM materials have superior merits as compared with the conventional ferrite PMs; they can reduce the volume of the required PMs and have significantly higher flux densities (Gieras, 2008; Shahgholian & Shafaghi, 2010).

The soft magnetic composite (SMC) materials are gaining much attention when the high efficiency and manufacturing of the complex design of electrical machine are required. When comparing SMC materials with non-oriented electrical steel, the SMC materials have lower total magnetic losses at high frequency due to the iron particle insulation, which lowers the eddy current loss component. The use of the SMC materials offers near-net-shape, low-cost manufacture and good utilization of the available space to achieve a compact design. Besides, decreasing the hysteresis loss is considered as an important objective in the SMC development (Castro & Landgraf; Ibrahim, 2009).

Therefore, in order to have an efficient energy conversion system, the simplicity, affordability and force capability, are highly desirable features. Basically, the performance of the TPMLMs can be well improved by using a right selected materials (Chen, Fan, & Lu, 2008; Tavana, Shoulaie, & Dinavahi, 2012). Besides, the usage of quasi-Halbach magnetization in the TPMLM offers numerous attractive