

Investigation of Fluid Film Bearings for use in Direct Drive Linear Generators in Submerged Wave Energy Converters

Sarah L. Caraher, John P. Chick & Markus A. Mueller
Institute of Energy Systems, School of Engineering & Electronics
University of Edinburgh
Edinburgh, Scotland

ABSTRACT

Many difficulties face the operation of offshore wave energy converters. If a structure is to survive and work effectively with little maintenance the unpredictable, harsh, corrosive environment provides many design challenges. For a double sided iron cored permanent magnet linear synchronous generator in a direct drive system, the difficulties increase. High normal forces exert a strong attractive clamping force between the stator and translator that the machines' bearings must react against. The normal forces are 10 to 20 times higher than the generators shear forces. The design of novel fluid film linear bearings for such a generator is the subject of this paper.

KEY WORDS: Hydrostatic bearings, Permanent magnet linear generators, direct drive, wave energy.

NOMENCLATURE

A_{act}	active area each side of generator
A_p	total area of pad
B	flux density in air gap
B_{rem}	remnant flux density
F_N	normal force
F_S	thrust force
g	effective mechanical gap between stator and translator
h	hydrostatic film clearance
H	displacement from h
H_p	pumping loss per pad
H_f	shear loss per pad
k	hydrostatic stiffness
K	rms electric loading
N	number of bearing pads
PM	Permanent Magnet
P_{ave}	average pressure drop across pad
P_r	recess pressure
t_m	PM thickness
q	volumetric flow rate
w_z	load carrying capacity of pad
σ_S	shear stress
σ_N	normal stress
μ_r	relative permeability magnet

μ_o	relative permeability of free space
v	average generator velocity
ρ	density
η	viscosity

1. INTRODUCTION

Synchronous machines are the preferred choice for direct drive, in both field and permanent magnet (PM) excited topologies. In marine renewables there is some interest in direct drive because of the potential benefits in terms of reliability compared to the use of hydraulic power take off or gearboxes. In wave energy a linear PM synchronous generator was used in the AWS pilot plant off Portugal in 2004 [Polinder et al, 2004] and Uppsala have demonstrated a 10kW linear generator in a heaving buoy type device [Waters et al, 2007]. Polinder et al [2003] compared the main machine topologies for direct drive wave energy – induction, synchronous PM, switched reluctance and variable reluctance PM. He concluded that the linear PM synchronous machine was the best, but his comparison only included the electrical design. There was no assessment of structural mass, reliability, bearing design and manufacturing.

The main challenges for direct drive machines are in the mechanical design, in particular the structural support and bearing system required to overcome large magnetic attraction forces and maintain a physical clearance between moving and stationary sections. This paper addresses the challenge of bearing design for linear PM synchronous machines, similar to that used in the AWS pilot plant. The focus is on the design of fluid film bearings for such generators, because they have the potential to be stable, low maintenance and exhibit low friction operation over a long life in the environments where offshore wave energy converters are most appropriate. Hydrostatic bearings using both sea-water and oil as the fluid will be compared.

2. LINEAR PM GENERATORS

Linear PM generator topologies used within the Archimedes Wave Swing (AWS) and used within the Uppsala device are of conventional structure. Fig.1 shows their generic structure. Magnets are mounted on an iron section, which moves relative to a stationary section made from iron laminations in which copper wire is inserted into slots punched into the iron laminations. Fig. 1 shows a double sided linear