Conceptual design of a linear generator suitable for marine energy power generation

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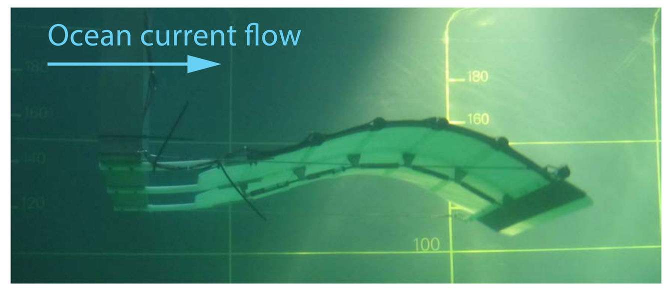
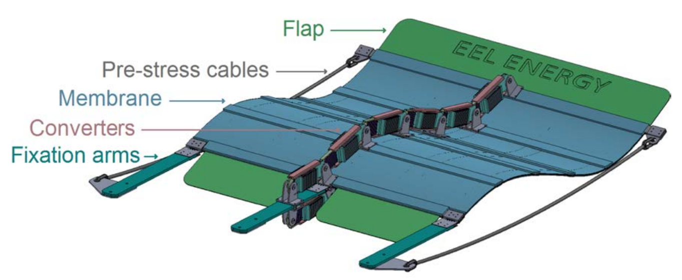
Introduction

The global trend of environmental protection since the beginning of this century has focused attention on the development of renewable energy as an alternative to the increasing consumption of depletable energy. Surrounded by the sea on all sides and having the sixth largest exclusive economic zone in the world, Japan has a promising future in marine energy power generation as a renewable energy source. The purpose of this research is to develop a practical marine power generation system. Among the main types of marine power generation, we are focusing on tidal current power generation, which is relatively small-scale, easy to handle, and not easily affected by weather conditions.

The undulator type tidal current power generation system recently proposed by EEL Energy converts tidal currents into membrane swells and generates electricity without using a rotating turbine [1]. Therefore, the system is capable of generating practical power even at low flow velocities of less than 2 m/s. In this presentation, we show about our conceptual design of a linear power generation module suitable for the undulator type tidal current power generation system.



Operation test of undulator type tidal current generator



Structure of undulator type tidal current generator

"Numerical modelling of an undulating membrane tidal energy converter", Martin Träsch, et al., Int. Mar. Energy J., 3 [3] (2020) pp.119-126.

Linear Power Generation Module

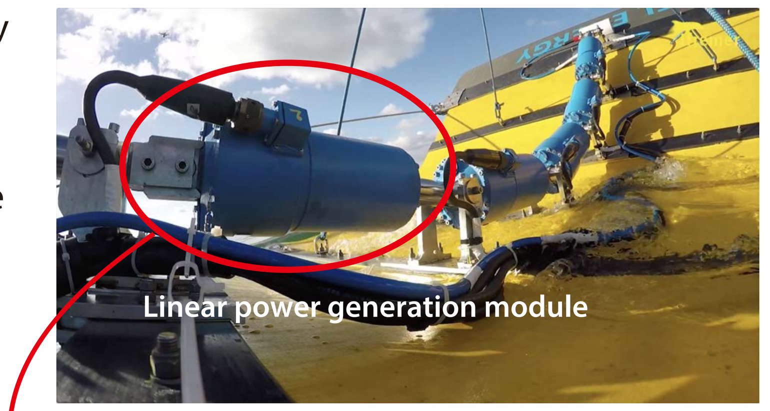
We tried to improve the power generation output by solving the following problems :

§ Short stroke

Power is generated by capturing the deflection of the membrane, so the amount of displacement is small.

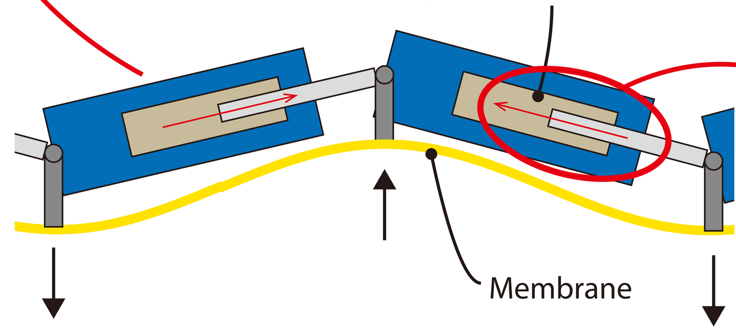
§ Secure braking force

Due to the density of seawater, which is 840 times greater than that of air, the drag force is large, which may cause damage.



https://youtu.be/phvpowdyMgw
30 kW-class prototype generator by EEL Energy

Due to the reduced power output caused by the short stroke we needed to devise a way to increase the power output. To control fluid losses, the linear power generation module placed on top of the membrane should be small, and we could not design multiple single units to increase the output power. So we consolidated multiple single units into one to increase the output power with miniaturization of the linear power generation module. The proposed generator has a multilayer structure with two layers of armature sandwiched between three layers of field magnetons. The improvement in power performance when HTS material is used in generators has been demonstrated by the following previous researchers [2-3].



Schematic of linear power geneation modules

FEM Analysis

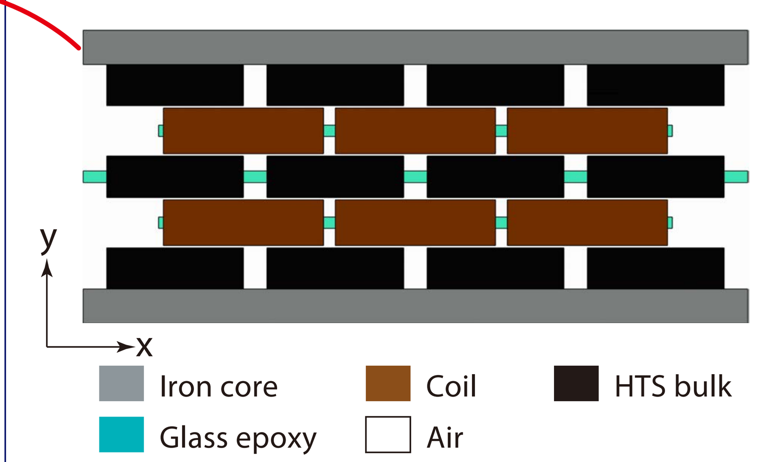
In this presentation, we present the results of a conceptual design of a 5 kW output linear generator module that is compatible with EEL Energy's 30 kW class undulator type tidal current generator.

- A FEM electromagnetic field analysis of the design model was performed using COMSOL Multiphysics® Version 5.6.
- From Maxwell equations we obtained the following expressions that we used for the analsysis :

$$\boldsymbol{B} = \nabla \times \boldsymbol{A},\ \boldsymbol{E} = -\left(\nabla \phi + \frac{\partial \boldsymbol{A}}{\partial t}\right)$$

- Coils were modeled using the following equations : $\boldsymbol{J} = \sigma \boldsymbol{E} + \sigma \boldsymbol{v} \times \boldsymbol{B} + \boldsymbol{J_e},\ \boldsymbol{J_e} = \frac{N(V_{cir} + V_{ind})}{SR_{coil}} \boldsymbol{e_{coil}}$

  Whereby, $\boldsymbol{J}$, $\boldsymbol{B}$, $\boldsymbol{E}$, $\boldsymbol{J_e}$, V_{cir}, V_{ind} and S are Current density, Magnetic flux density, Electric field, and externally generated current density, coil voltage from the circuit, induced voltage and coil cross section area.
- Lorentz force equations were used to compute the electromagnetic force created when the translator moves : $\boldsymbol{F} = q(\boldsymbol{E} + \boldsymbol{v} \times \boldsymbol{B})$
- Three layers of HTS pole magnets act as stator while two layers of armature coil act as the translator which moves back and forth at maximum speed of 0.4m/s.
- An Electrical Circuit was added to the model and a load resistor was added to the electrical circuit to simulate load so that the output power could be computed.

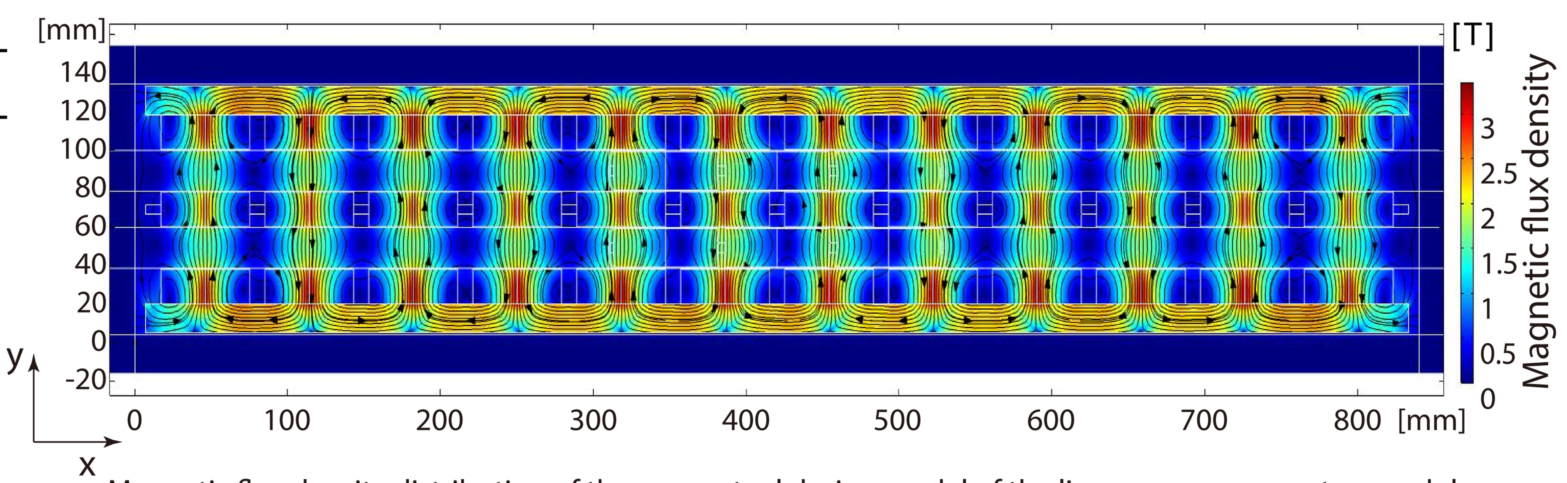


Conceptual design model of a linear power generation module

Result and Discussion

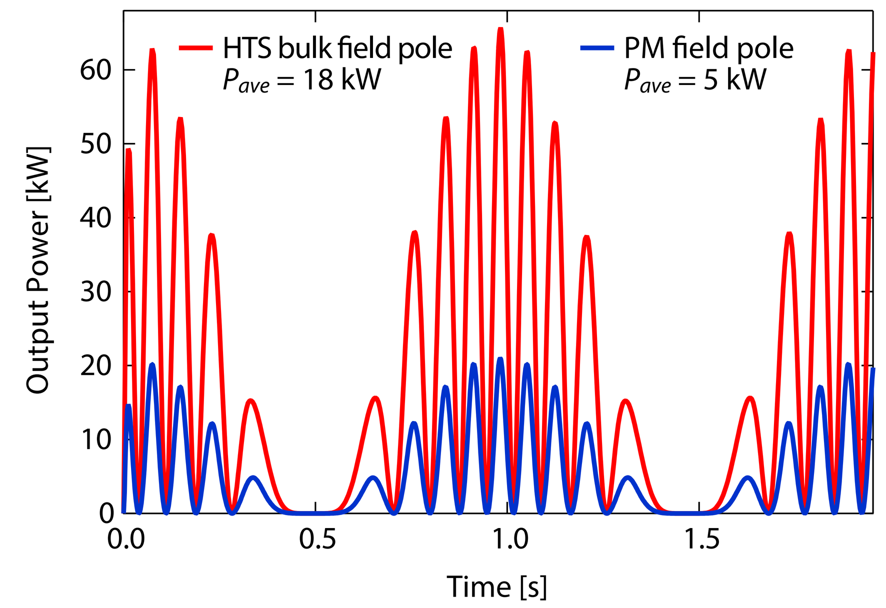
Conditions of analysis of the conceptual design model

Item		Value
Active stroke length [mm]		310
Dimensions of module [mm]		840 x 130
HTS bulk	Type	ReBCO
	Magnetic flux density [T]	2
	Dimensions [mm]	58 x 58 x 18
PM (to be compared)	Type	N50
	Magnetic flux density [T]	1.4
	Dimensions [mm]	58 x 58 x 18
Armature	Type	Copper
	Self inductance [μH]	650
	Dimensions [mm]	ø68 x 20
Number of field pole		36
Number of armature		6
Airgap length [mm]		1
Maximum speed of module [m/s]		0.4



Magnetic flux density distribution of the conceptual design model of the linear power generaton module

This is the magnetic flux density distribution obtained when HTS bulk is used as the field pole in our conceptual design model of a linear power generation module. We envisioned using GdBCO bulk, and in this case the maximum magnetic flux density is observed on the surface of the bulk is 2.02 T. At that time, the HTS bulk will have cooled down to around 77K (We won't discuss the cooling method here, but it should be conduction cooled). This is the magnetic flux density that is involved in power generation. By placing the iron yokes above and below the field poles, we have increased the internal flux density. It is believed that the magnetic flux density inside this iron yoke has generally reached saturation, effectively drawing out the magnetic force emitted by the HTS bulk and contributing to increased power generation.



Output power generated when HTS is used and when PM is used

The output power obtained when the membrane pulled the field poles by the tidal current and it moved horizontally at a maximum of 0.4 m/s is shown in the figure. The results show that when HTS bulk is used the output power is about 3 times the output power obtained when PM is used. The high output power when HTS bulk is used is achieved due to the high magnetic flux density characteristic of HTS bulk. Employing HTS bulk instead of PM works effectively to obtain large power in such a low-speed, short-stroke linear power generation module.

Conclusion

A conceptual design of a linear generator suitable for marine energy power generation was proposed in this study. A short stroke linear power generation module is presented. HTS bulks as field pole magnets and a multilayer structure were adopted to increase the outpower in response to the power reduction by the short stroke. In addition, HTS bulk was adopted because it is expected to generate a high magnetic flux density which is associated with high electromagnetic braking force. The electromagnetic braking force can be used as a damper to withstand tidal current.

This work has been partially supported by SECOM Science and Technology Foundation and JSPS KAKENHI Grant Numbers 21H01541.

References

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