Fundamental studies of helical-type seawater MHD generation system

Takeda, Minoru
Okuji, Yasuaki
Akazawa, Teruhiko
Liu, Xiaojun
Kiyoshi, Tsukasa

(Citation)
IEEE transactions on applied superconductivity,15(2):2170-2173

(Issue Date)
2005-06

(Resource Type)
journal article

(Version)
Version of Record

(URL)
https://hdl.handle.net/20.500.14094/90000216

Fundamental Studies of Helical-Type Seawater MHD Generation System

Minoru Takeda, Yasuaki Okuji, Teruhiko Akazawa, Xiaojun Liu, and Tsukasa Kiyoshi

***Abstract*—A new MHD (magnetohydrodynamics) generator based on electromotive force using seawater, that is, a helical-type seawater MHD generator with a 7 T solenoid superconducting magnet, is designed, constructed and tested. The constructed generator contains a helical insulation wall made of polyvinyl chloride 140 mm long and 100 mm in diameter, an anode rod made of SUS316 1350 mm long and 10 mm in diameter, and a cathode pipe made of SUS316 260 mm long and 100 mm in diameter. In the experiment, electromotive force and generator output are measured in terms of average flow velocity (0–5.6 m/s) and magnetic field (0–7 T) using artificial seawater (3.4% NaCl aqueous solution). As a result of the experiment, it was found that the electromotive force increases proportionally to average flow velocity and magnetic field, and that the generator output increases quadratically to average flow velocity and magnetic field over certain points. Experimental values are discussed by comparing the theoretical values and computed values.**

***Index Terms*—Helical flow, MHD generator, seawater, solenoid superconducting magnet.**

I. Introduction

Seawater MHD (magnetohydrodynamics) generation is a unique system that not only directly transforms the kinetic energy of seawater flow into electric energy but also generates hydrogen gas as a by-product. In our work, experimental and computational studies of the seawater MHD generator using a superconducting magnet have been performed as part of applying superconductivity to maritime sciences. So far, the linear-type seawater MHD generator with a dipole superconducting magnet has been constructed, and the experiments of power generation were successfully accomplished [1].

In MHD generation, applied magnetic field is an important factor for the generator output and efficiency. The linear-type generator has the problem of requiring strengthening and enlargement of the superconducting magnet. In order to solve this problem, the use of a solenoid superconducting magnet is expected to be reasonable. We designed a new helical-type seawater MHD generator using a solenoid superconducting magnet, taking a hint from the experimental results for a helical-type MHD ship [2]. The purpose of the present work is to construct and test the helical-type seawater MHD generator with a solenoid superconducting magnet.

Manuscript received October 4, 2004. This work was supported in part by the Fundamental Research Developing Association for Shipbuilding and Offshore, and Hyogo Science and Technology Association, Japan.

M. Takeda, Y. Okuji, and T. Akazawa are with the Faculty of Maritime Sciences, Kobe University, Kobe, Hyogo 658-0022, Japan (e-mail: takeda@maritime.kobe-u.ac.jp).

X. Liu and T. Kiyoshi are with the Tsukuba Magnet Laboratory, National Institute for Materials Science, Tsukuba, Ibaraki 305-0003, Japan (e-mail: KIYOSHI.Tsukasa@nims.go.jp).

Digital Object Identifier 10.1109/TASC.2005.849604

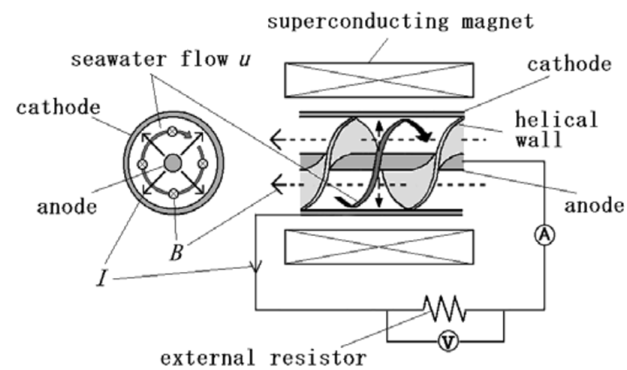

Fig. 1. Principle of the helical-type seawater MHD generation.

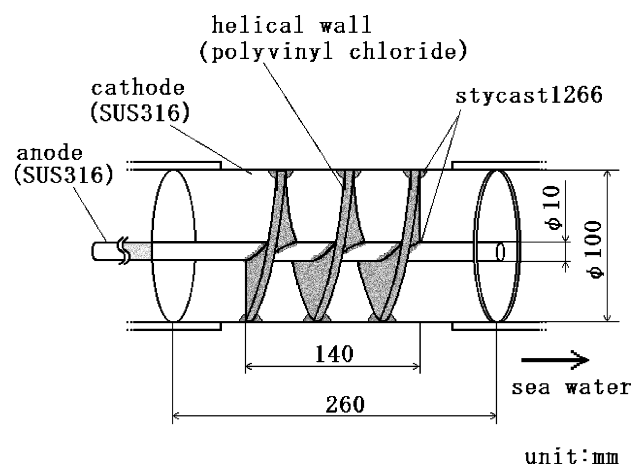

Fig. 2. Schematic diagram of the helical-type seawater MHD generator.

II. Principle of Helical-Type MHD Generation

Fig. 1 shows the principle of helical-type MHD generation. The MHD generator consists of double-cylindrical coaxial electrodes, a helical insulation wall and a solenoid superconducting magnet. As shown in this figure, when seawater rotates around an anode in the presence of magnetic field B parallel to the coaxial direction, electromotive force is generated according to Fleming's right-hand rule. Electromotive force V_e is expressed as

$$V_e = uBD\sin\theta \tag{1}$$

where u is the flow velocity, D is the distance between the electrodes and θ is the angle between the direction of the magnetic

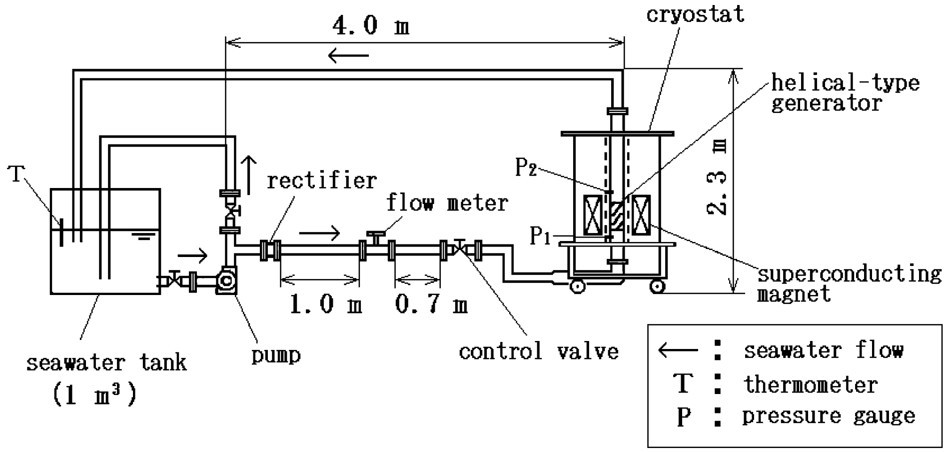

Fig. 3. Schematic diagram of the experimental setup.

field and that of seawater flow. When D and $\sin\theta$ are constant, V_e is proportional to u and B. When electromotive force V_e exceeds electrolysis voltage V_d, electric power P can be generated due to electric current I. Electric power P can be obtained

$$P = \frac{1}{R_{ex} + R_{in}} K(V_e - V_d)^2 \tag{2}$$

$$K = \frac{R_{ex}}{R_{ex} + R_{in}}. \tag{3}$$

Here, R_{ex} is the external load, R_{in} is the internal load (the resistance of seawater), and K is the load factor. In the case of $R_{ex} = R_{in}$, the electric power P is maximum.

III. Experimental Apparatus

Fig. 2 shows the schematic diagram of the helical-type seawater MHD generator. The helical wall made of polyvinyl chloride has a spiral shape with a pitch number of 2.5 and length of 140 mm. The pitch number of 2.5, which means 2.5 rotations of the helical wall, was decided on the basis of the results for the helical-type MHD ship [2]. The anode was a cylindrical rod 10 mm in diameter and 1350 mm long. The cathode was a cylindrical pipe 100 mm in outer diameter, 1.5 mm in thickness and 260 mm long. These electrodes were made of SUS316, which is nonmagnetic and corrosion resistant. The stycast1266 was used as an adhesive in assembling the generator.

Fig. 3 shows the schematic diagram of the experimental system for the seawater MHD generator. The system consists of units such as the generator, a cryostat with a 7 T solenoid superconducting magnet [3], a seawater tank (1 m^3), a seawater circulation pump (CMP6-63.7, TERADA PUMP MFG, CO., LTD.), a flowmeter (UZG-VTS2-L, NIPPON FLOW CELL CO., LTD.), a pressure gauge (PMS-5WE-500k, TOYODA MACHINE WORKS, LTD.), and a thermometer.

IV. Experimental Results and Discussion

A. Experiment of Flow Loss

In the preliminary experiment, flow loss of the generator was investigated in zero magnetic field. The amount of seawater flow Q, inlet pressure of the generator P_1 and outlet pressure P_2 were

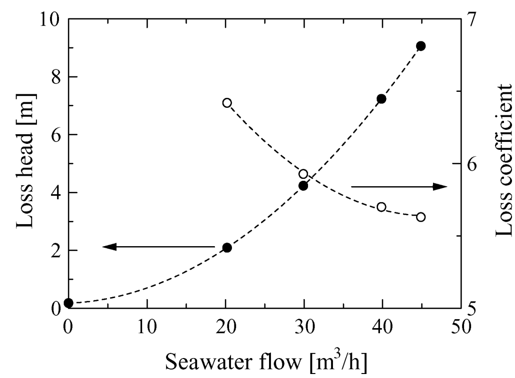

Fig. 4. Flow dependence of loss head and loss coefficient.

measured with flowing artificial seawater (3.4% NaCl aqueous solution, specific gravity of 1.03), using the flow system shown in Fig. 3; measurements were made both with the generator and without the generator. Using the results of the experiments of flow loss, loss head h and loss coefficient ζ were calculated using

$$h = \frac{\Delta P - \Delta P'}{\rho g} = \zeta \frac{\langle u \rangle^2}{2g} \tag{4}$$

$$\Delta P = P_1 - P_2 \qquad \Delta P' = P_1' - P_2' \tag{5}$$

where ρ is the density of artificial seawater, g is the gravitational acceleration, $\langle u \rangle$ is the average flow velocity which was estimated as the amount of sample flow divided by the cross section of the helical flow inside the generator, ΔP is the pressure difference between P_1 and P_2 with the generator and $\Delta P'$ is the pressure difference without the generator.

Fig. 4 represents the flow dependence of the loss head and loss coefficient. The loss head increased with increasing seawater flow; the loss head was 9.0 m and the loss coefficient was 5.6 at the maximum seawater flow of 45 m^3/h. The large loss head was thought to be caused by the complex flow induced by the presence of the helical wall.

B. Experiment of Power Generation

Experiments of the electromotive force and generator output were carried out in order to elucidate the fundamental character-

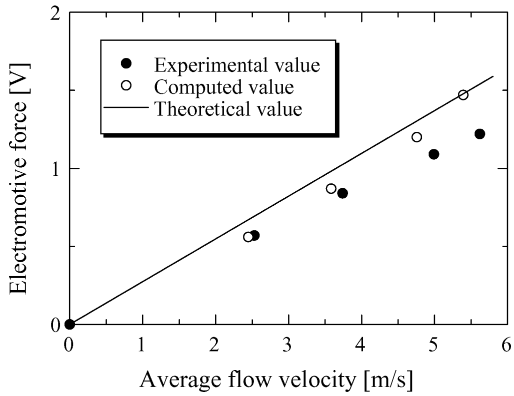

Fig. 5. Relationship between electromotive force and average flow velocity with $B = 7$ T.

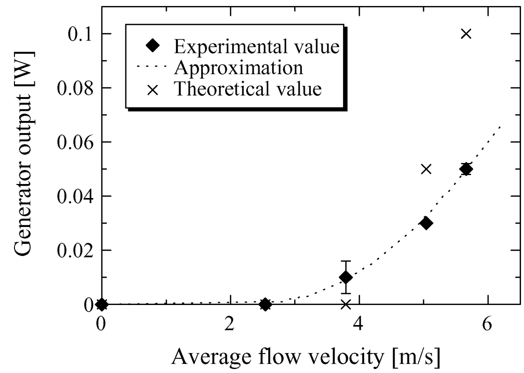

Fig. 7. Relationship between generator output and average flow velocity with $B = 7$ T. Dotted line shows an approximation of experimental values.

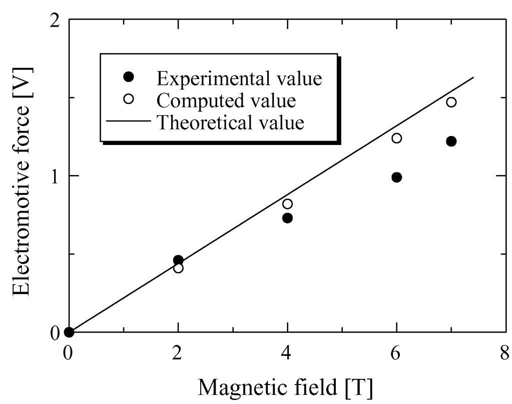

Fig. 6. Relationship between electromotive force and magnetic field with $\langle u \rangle = 5.6$ m/s.

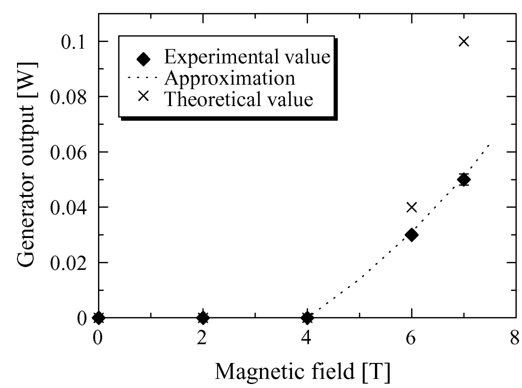

Fig. 8. Relationship between generator output and magnetic field with $\langle u \rangle = 5.6$ m/s. Dotted line shows an approximation of experimental values.

istics of the helical-type seawater MHD generator using a NaCl aqueous solution (3.4%). The electromotive force was measured with various sample flow (0–45 m^3/h) and magnetic field (0–7 T). The generator output was also measured in a similar way using an external load (1 Ω resistor).

Fig. 5 represents the dependence of electromotive force on the average flow velocity in the magnetic field of 7 T. The theoretical values were calculated using (1) with the average flow velocity and an average magnetic field of 90% of the maximum value. The computed values were obtained by FEM (finite element method) with a three-dimensional model [4]. As shown in Fig. 5, the electromotive force increased linearly with increasing average flow velocity in a constant magnetic field. In addition, the theoretical values agreed with the computed values; the experimental values were 30% lower in magnitude than the theoretical values and the computed values at the maximum average flow velocity. Similar results were obtained even when the magnetic field was varied, except at low magnetic fields.

Fig. 6 shows the dependence of electromotive force on the magnetic field with the average flow velocity of 5.6 m/s. The electromotive force increased proportionally to magnetic field with a constant average flow velocity. In addition, the experimental values were 30% lower in magnitude than the theoretical values and the computed values in high magnetic fields. The reason why the experimental values of electromotive force in terms of average flow velocity and magnetic field were less than the theoretical values and computed values was explained in terms of the influence of cavitation induced inside the generator. Indeed, vibration and noise, most likely due to cavitation, were observed during the experiment.

Fig. 7 shows the dependence of generator output on the average flow velocity in a magnetic field of 7 T. The theoretical values were calculated using (2) with the internal load and the electrolysis voltage. The generator output increased quadratically to average flow velocity over certain points. When the average flow velocity was kept at the maximum value (5.6 m/s), the generator output of 0.05 W, which was half the theoretical value, was attained.

Fig. 8 represents the dependence of generator output on the magnetic field with the average flow velocity of 5.6 m/s. The generator output increased quadratically to magnetic field over certain points. A gap between the experimental value and theoretical value is also seen in Fig. 8. This gap is thought to be caused by the cavitation mentioned above; there is a possibility of increasing the internal load by decreasing the surface area of electrodes in contact with seawater under the influence of cavitation.

In this experiment, the electromotive force and the generator output were small under the influence of a large flow loss of the generator. Flow rectifier will be installed at the inlet and outlet of the generator to decrease the flow loss.

V. Summary

Our results can be summarized as follows.

1. The helical-type seawater MHD generator with a 7 T solenoid superconducting magnet was constructed and tested.
2. The loss head of the generator was 9.0 m at the maximum seawater flow of 45 m^3/h in zero magnetic field.
3. The electromotive force increased linearly with increasing average flow velocity and magnetic field. The experimental values were smaller than the theoretical values and the computed values.
4. The generator output increased quadratically to average flow velocity and magnetic field over certain points. The generator output of 0.05 W, which was half the theoretical value, was attained in the case of seawater flow of 45 m^3/h (average flow velocity of 5.6 m/s).

References

[1] A. Iwata and Y. Saji, "Ocean current power generator by superconducting MHD method," *Teionkougaku*, vol. 15, no. 6, pp. 317–328, 1980.

[2] K. Nishigaki, C. Sha, M. Takeda, Y. Peng, K. Zhou, A. Yang, D. Suyama, Q. J. Qing, L. Yan, T. Kiyoshi, and H. Wada, "Elementary study on superconducting electromagnetic ships with helical insulation wall," *Cryogenics*, vol. 40, no. 6, pp. 353–359, 2000.

[3] M. Takeda, Y. Okuji, and T. Akazawa, "Fundamental studies on helical-type seawater MHD generation system" (in Japanese), *Rev. Faculty of Maritime Sciences,* Kobe University, no. 1, pp. 125–130, 2004.

[4] X. Liu, T. Kiyoshi, and M. Takeda, "A simulation on an MHD power generation system using seawater," in *Symp. New Magneto-Science 2003, Proc. 7th Meeting*, pp. 194–196.