Characteristics of Electric Generation Based on Motion of Magnet Capsule By Pulsating Flow in U-tube

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Abstract: Previously, we reported avout MHD system for tidal energy conversion. But this system needs various future technologies which are difficult to realize at prsent. Then we proposed a more practical device for tidal energy conversion system by using Lenz' law. Here, induced current is generated at the outside coil of U-tube in which magnet capsule oscillates by pulsating flow caused by tidal wave. Theoretical and experimental studies show the propriety of the prediction to this system. However, large scale estimations of prototype of this system only, indicated less power production that might just be suitable for sensor applications. Further investigation is suggested therefore, by adding some devices to improve the power output of the system.

Key words: Tidal Energy Conversion, Magnet Capsule, Magnetic Flux, Induction

1 Introduction

Ordinary MHD generator had been studied by many researchers[1-3]. In our previous work, we clarified the characteristics of this system and reported about hydrogen gas generator with tidal wave energy[4]. However, very strong magnetic flux and large physical size were related to this facility. On the other hand, this similar pulsating flow in U-tube by this tidal wave might be useful to the ordinary induced current method by Lenz' law such as ordinaty dynamo. But this problem of dymamic characteristics of the interaction of pulsating hydraulic pressure and magnetic force by the generating current had been scarcely studied in detail. Thus, the aim of this study is to clarify the caracteristics of this induction type generator for tidal energy conversion system.

2 Nomenclature

A cross-sectional area

a_1	internal radius of coil
a_2	external radius of coil
Br	magnetic flux
D	diameter
e	generating voltage
F	force
g	acceleration due to gravity
H^*	wave height
I	generating current
L_i	coil inductance
L_c	coil length
M_m	mass of magnet
m_d	number of coil
m	magnetic moment
n_c	numver of coil turns
P	pressure
R_i	internal electric resistance
R_{ex}	external electric resistance
t	time
x	displacement
$\dot{x}$	velocity
$\ddot{x}$	acceleration
Z	power generating capacity
ζ	loss coefficient
μ_f	coefficient of friction
ρ	density
ω	angular frequency

3 Basic sheme

Figure 1 shows the schematic diagram of the system. It consists of a magnet capsule and coil assembly in U-tube. Tidal wave pressure is transferred on both ends of the U-tube which induces oscillatory flow of the liquid and magnet capsule system. The induced current flowed from the coil to the external circuit accorcding to Lenz' law.

4 Theoretical Procedure

With m_d number of coils as shown in Fig.1, the basic voltage equation is written as

$$L_i\dot{I} + (R_i + m_d R_{ex})I = m_d e \tag{1}$$

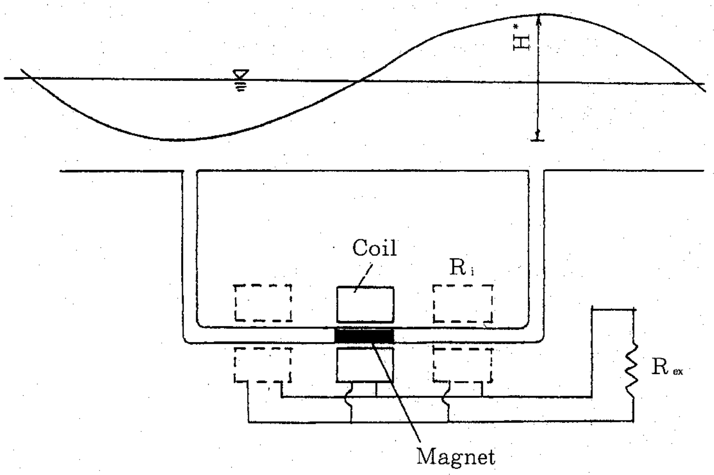

Fig. 1 Schematic diagram of induction type electric generator system using tidal wave energy

where L_i is coil inductance, I is generating current, R_i and R_{ex} respectively, are internal and external resistances of the circuit, and e is generating voltage (ep.(4)) by Lenz'law.

The motion of magnet capsule in the pipe depended upon the forces of the pressure difference ΔP_f (ep.(9)), the drag force due to induced magnetic field F_m (ep.(6)), the friction force between the magnet capsule and the pipe wall F_f (ep.(7)), and the spring force settled for support F_k (ep.(8)). The equation of motion of the magnet casule is written as

$$M_m \ddot{x}_m = A_m \Delta P_f - F_m - F_f - F_k \tag{2}$$

where M_m and A_m, are the mass and cross-sectional area of magnet capsule, respectively.

The equation of motion of the water column in U-tube is written as follows

$$\rho_w L_d \ddot{x}_w = (-m_d \Delta P_f - \rho_w \zeta \mid \dot{x}_w - \dot{x}_m \mid (\dot{x}_w - \dot{x}_m)/\ 2 - 2\rho_w g x_w$$

$$+ P^* \sin(\omega t) \tag{3}$$

Where $P_w = \rho_w g H^*/2$, H^* is wave height (crest to trough), and ζ is loss coefficient.

In ep.(1), by integrating the radial component of magnetic flux Br at the radial a-direction and axial y-direction of coil, the generating voltage e is

$$e = \sum^{m+m-} \int_{a_1}^{a_2} \int_{-x}^{Lc-x} (2\pi a n_c Br \dot{x}_m)\, dady = -1/2\ m n_c \dot{x}_m f(x_m) \tag{4}$$

where n_c is number of coil turns, a_1 and a_2, respectively, are the internal and external radius of coil, L_c is coil length, and m is magnetic moment. Here,

$$f(x_m) = (Rr_1 - Rr_2) \tag{5}$$

where

$$Rr_1 = x_1 \ln(s_1/s_2) + (L_c - x_1)\ln(s_3/s_4)$$

$$Rr_2 = x_2 \ln(s_5/s_6) + (L_c - x_2)\ln(s_7/s_8)$$

$$x_1 = x_m + 0.5L_c - 0.5L_m$$

$$x_2 = x_m + 0.5L_c + 0.5L_m$$

$$x_3 = 0.5L_c + 0.5L_m - x_m$$

$$x_4 = 0.5L_c - 0.5L_m - x_m$$

$$s_1 = A_2 + (A_2^2 + x_1^2)^{1/2}$$

$$s_2 = A_1 + (A_1^2 + x_1^2)^{1/2}$$

$$s_3 = A_2 + (A_2^2 + x_3^2)^{1/2}$$

$$s_4 = A_1 + (A_1^2 + x_3^2)^{1/2}$$

$$s_5 = A_2 + (A_2^2 + x_2^2)^{1/2}$$

$$s_6 = A_1 + (A_1^2 + x_2^2)^{1/2}$$

$$s_7 = A_2 + (A_2^2 + x_4^2)^{1/2}$$

$$s_8 = A_1 + (A_1^2 + x_4^2)^{1/2}$$

$$F_m = 1/2\, mnf(x_m)\, I \tag{6}$$

$$F_f = \mu_f M_m g \,\mathrm{sgn}(\dot{x}_m) \tag{7}$$

$$F_k = kx_m \tag{8}$$

where L_m is length of magnet, μ_f is the maximum friction coefficient of magnet capsule and wall, x_m is displacement of magnet, and k is spring constant.

The expression for ΔP_f is written as follows[5]

$$\Delta P_f = C_d \rho_w / (1-q^2)^2 \tag{9}$$

where

$$C_d = f_{x1} f_{x2} \tag{10}$$

$$f_{x1} = (0.2881 - 1.32q + 3.467q^2 - 2.359q^3) / (1-q) \tag{11}$$

$$f_{x2} = 0.7095 + 0.004836L_{cd} - 9.537L_{cd}{}^2/10^8 + 2.235L_{cd}{}^3/10^7$$

$$L_{cd} = L_m / D_m$$

$$q = D_m / D_p$$

where D_m is diameter of magnet, and D_p is diameter of duct.

Finally, eps.(1)-(3) were solved simultaneously using Runge-Kutta method, and the propriety was confirmed by the experiment.

5 Experimental Procedure

Figure 2 shows the schematic diagram of the experimental apparatus. Intermittent air pressure using compressor with timer was metered into the U-tabe. The spring constant k of the supporting spring was 11 g/mm. The magnetic moment m of the permanent magnet(50mm, length; 10mm, diameter) was 30 x 10^{-7} A-m^2. The coil (30mm, external

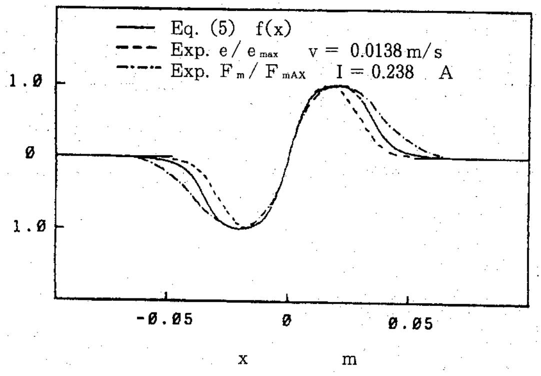

Fig. 2 Generating voltage and magnetic force to axial direction of coil

diameter; 47mm, width) turning number was 2500. The diameter of the coil wire was 0.5mm and its internal resistance and inductance were 63.3 ohm and 0.055 H, respectively. Acryclic transparent U-tube, 15 mm(external diameter) and 10.5mm (inner diameter), was used to observe the motion using a video camera recorder. The generating voltage was recorded using the so-called thermal array corder and the data were outputted in a personal computer through A/D converter.

6 Experimental results and discussion

The propriety of eq.(5) was confirmed by the experiment wherein the tested permanent magnet as capsule was inserted into the coil at constant speed using a lathe bed. The generating voltage under this motion is shown in Fig. 3. The solid line indicates the calculated value of eq.(5). The broken line is the experimental value. On the other hand, as the magnet was inserted vertically into the coil(connected from external power source) and standing on top of the weighing balance, the generated push or pull force was measured as shown in Fig.4 and indicated by dot and broken line in Fig.3.

Figure 5 shows the comparison between the calculated and experimental results. The results indicated a reasonable agreement between the two. Thus, an estimation of simulation characteristics of a large prototype can be considered.

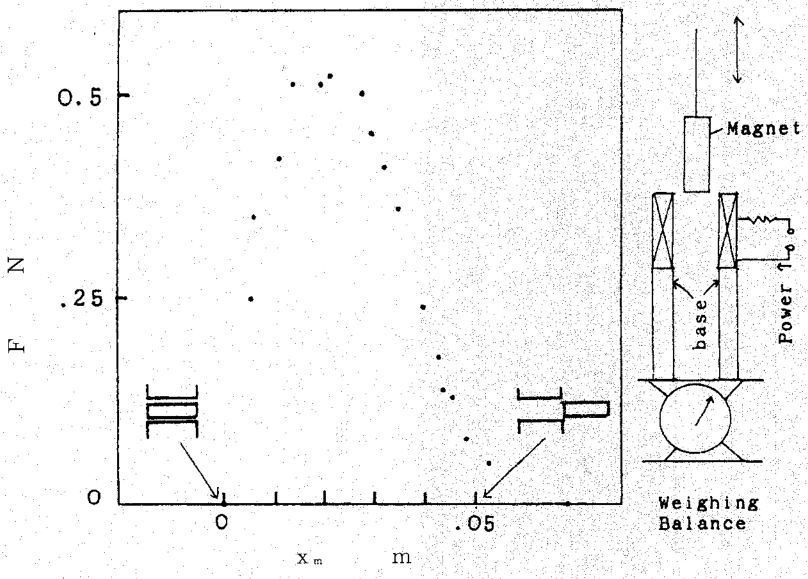

Fig. 3 Magnetic force between coil and magnet

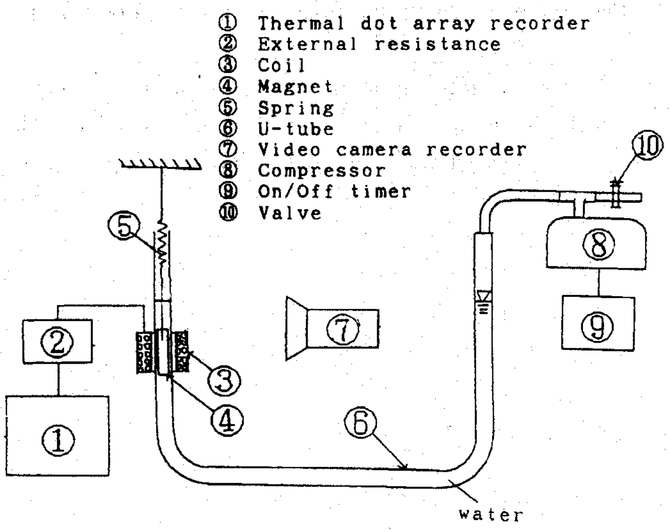

Fig. 4 Schematic diagram of experimental apparatus

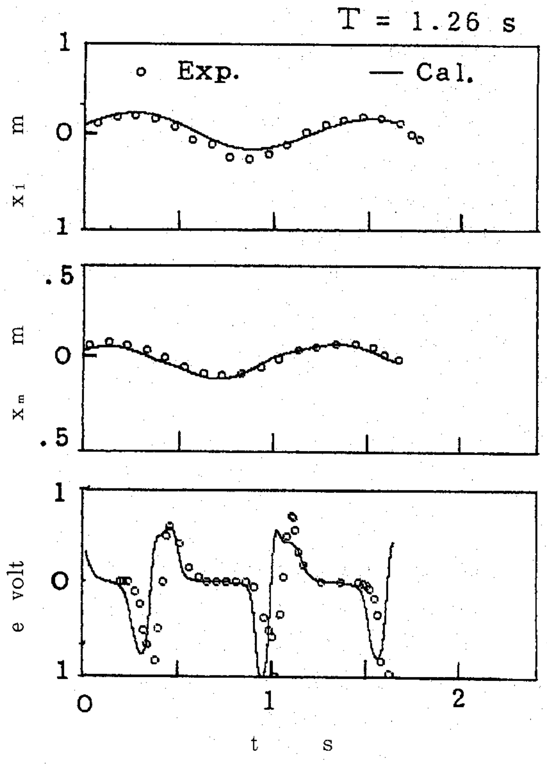

Fig. 5 Motion of water column x_l, magnet capsule x_m, and generating voltage e in pulsating flow in U tube

7 Prediction of Characteristics on Large Scale Prototype

Table 1 shows the input conditions used in the calculation. Only one side of the U-tube as shown in Fig.1 was used. Figure 6 shows one case of calculation result where small output current was indicated but apparently large voltage. The power generating capacity Z can be obtain as follows

$$Z = \int_0^t (I^2 R_{ex}) dt \tag{12}$$

As shown from Figs. 7 to 10, a very small order of magnitude of Z O (10^{-4}) kWh/day was obtained.

Table 1 Reference value of parameters

a_1	internal radius of coil	0.10	m
a_2	external radius of coil	0.15	m
D_m	diameter of magnet	0.14	m
D_p	diameter of duct	0.16	m
L_d	length of duct	330.0	m
L_m	length of magnet	0.10	m
L_i	coil inductance	7.5	H
L_c	length of coil	0.10	m
m_d	number of coil	15	
M_m	mass of magnet	6	kg
R_i	internal resistance	110	ohms
R_{ex}	external resistance	100	ohms
T	wave period	10	s
μ_f	permeability of magnet	$4\pi \times 10^{-7}$	

8 Conclusion

From the calculation results, it was concluded that in the case of large turning number and small wire in coils, small current but apparently large voltage can be easily obtained which can be used for sensors applications. However, in terms of power production, this system might not be more effective unless another idea, that is, by using booster[4)] or condenser in electric circuits will be considered.

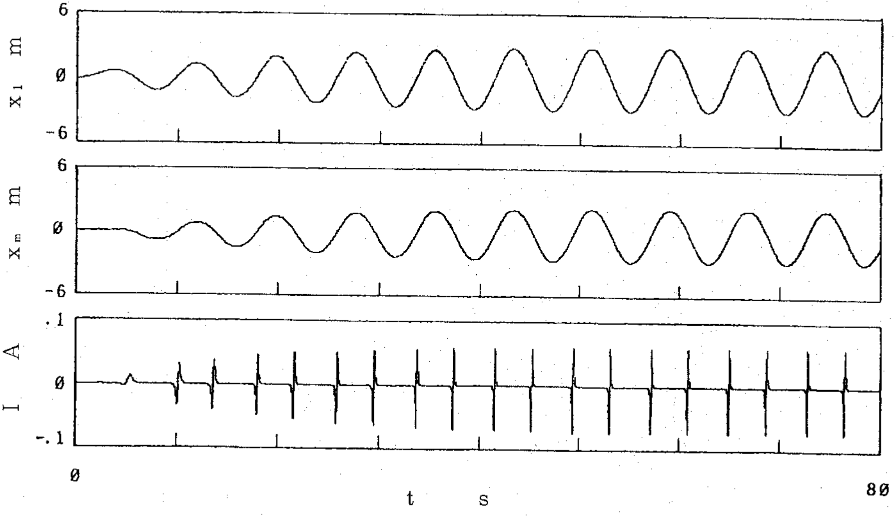

Fig. 6 Calculation result for large prototype

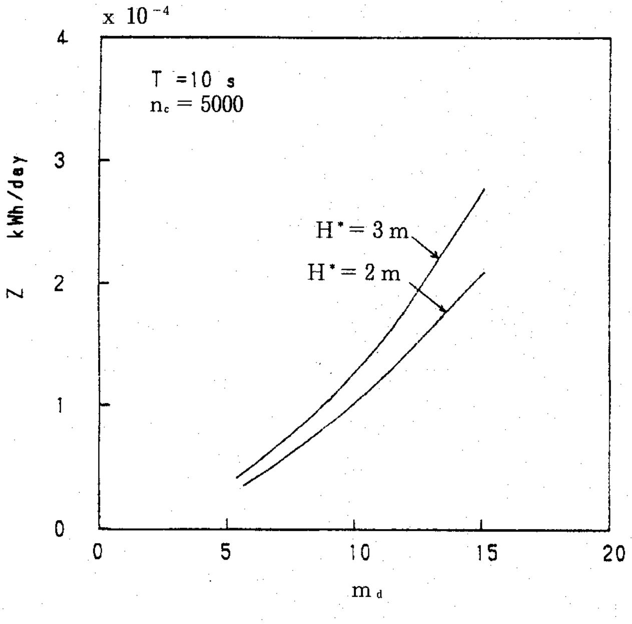

Fig. 7 Power generating capacity Z vs. number of coils m_c

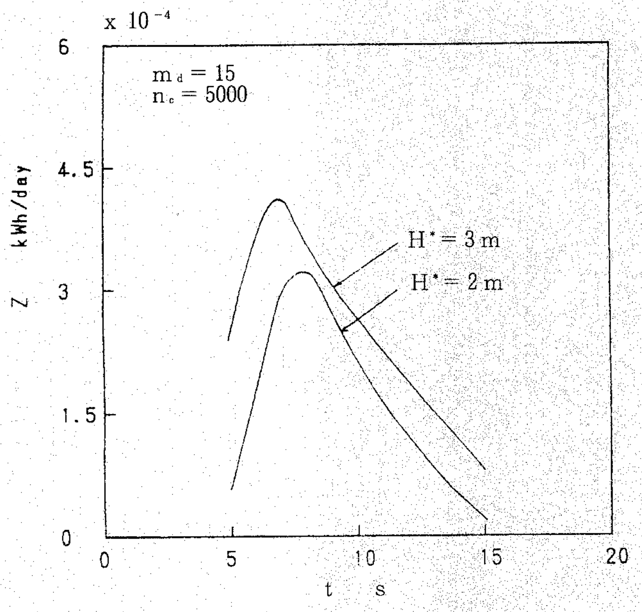

Fig. 8 Power generating capacity Z vs. wave period T

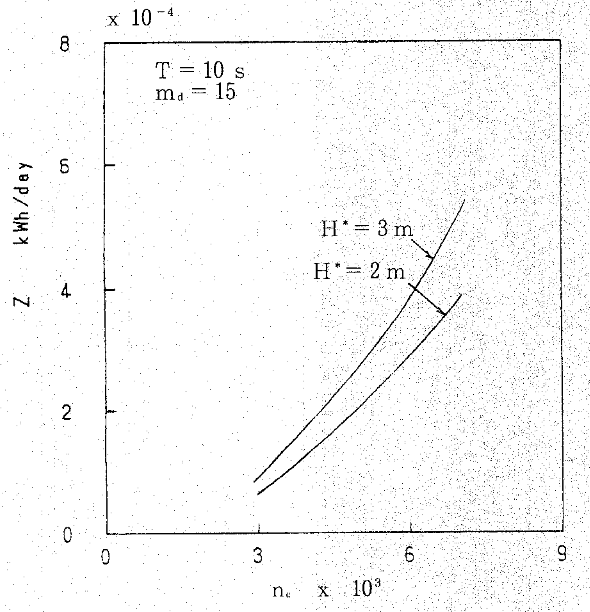

Fig. 9 Power generating capacity Z vs. number of coil turns n_c

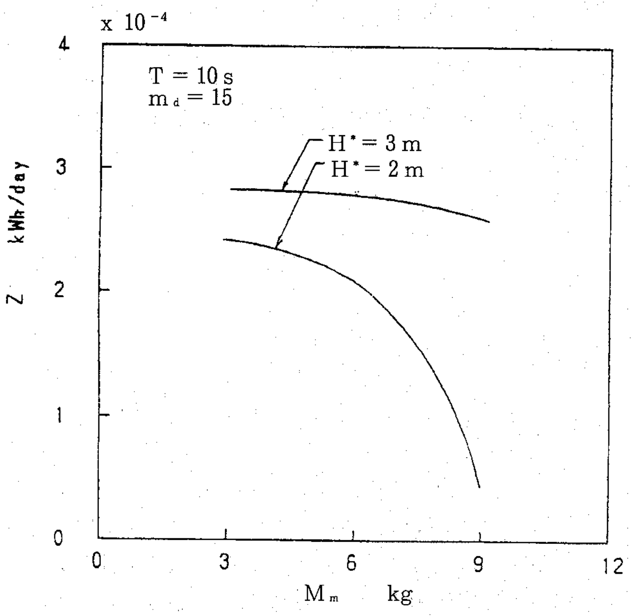

Fig.10 Power generating capacity Z vs. mass of magnet M_m

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U字管内脈動流内の磁石付きカプセルの運動による発電特性

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要　　約

各種自然エネルギーの抽出形態として、往復運動からの利用も多くみられる。ここでは、水スターリングエンジンや海洋波浪のエネルギー変換のための一手段として、それらの発生した脈動流をU字管内に導き、その流体圧で磁石を埋め込んだカプセルを往復運動させる。そのときU字管外に設置したコイルにレンツ則で発生した電力の特性と往復流との関係を検討した。

すなわち、この現象を支配する基礎方程式を誘導し、その妥当性を実験的に確かめた上、実際上のモデルを想定して数値計算でその発電特性を予測した。その結果、実際の巻線抵抗を考慮すると電流は極僅かで比較的大きな電圧が取り出せるものの、ここで取り上げたシステムの他ブースターで増速を図るとか、電圧変化の平滑化を図るとかの他の工夫が必要であろう。

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