Development of Underwater Wireless Power Supply System Using Resonant Energy Transfer

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Abstract

Autonomous Underwater Vehicles (AUV) is one of the key technologies for deep ocean research. However AUV cannot work for long time due to the limitation of battery capacity. To solve this problem, a noncontact wireless power supply is required for AUV to conduct observations for long period. In this study, we developed a resonant energy transfer system, which is mounted into a small AUV "DaryaBird" and the simulations and evaluation tests are carried out in the test tank.

Keywords: AUV, Wireless Power Supply .

1. Introduction

Japan possesses a vast ocean area, seabed resources such as abundant energy resources and minerals have been found in the deep-sea. However, the deep-sea is one of extreme environments that human cannot access directly. Therefore, Underwater robots have attracted attention as useful tools[1-6] to observe deep-sea floor. Especially, Autonomous Underwater Vehicle (AUV) can move wide area freely not having tethered cable with support vessel. However, AUV has the disadvantage of a short operation time. In order to realize long-term operation of the AUV, a wireless battery charging system on the underwater observation station is necessary.

In the conventional electromagnetic induction system for wireless power supply, the transmission distance between power supply and receive coil should be short. Thus, AUVs are required to have highly accurate docking with the underwater stations. Ura[7] et. al developed a wireless power supply system using Electromagnetic induction system, and accomplish 3-days operation.

The purpose of this research is to perform underwater wireless power supply using magnetic resonance method. It is possible to feed in a wide range stronger than the conventional methods even if the large gap of coils and the coil center axis exit. Measurements of the transmission efficiency in the underwater environment using the magnetic field resonance method are carried out, and the changes in the transmission efficiency due to the size and position deviation of the coil are evaluated. Transmission range do the actual experiment using the AUV "DaryaBird". The comparison of electromagnetic induction method and magnetic resonance method is shown in Table 1. The advantage of electromagnetic induction method is high efficiency, however the needs accurate coil setting. The magnetic resonance method can transfer longer distance, and the disadvantage is the difficulty of the design of resonance circuit. The concept of magnetic resonance method is shown in Fig.1.

In this study, we developed a resonant energy transfer system, which is mounted into a small AUV "DaryaBird" and the simulations and evaluation tests are carried out in the test tank.

Table 1. The comparison of wireless supply methods.

	Electromagnetic Induction	Magnetic Resonance
Transfer Distance	~ 10 cm	~ 1 m
Frequency	100 kHz order	~ MHz
Efficiency	70 ~ 90 %	40~ 60 %
Size	~ 3 cm	~ 30 cm

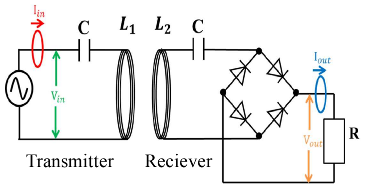


Fig. 1 The concept of magnetic resonance method.

2. Basic Property of Magnetic Resonance

As the performance evaluation experiments in the magnetic field resonance method, transmission efficiency by changing environment (air, pure water and salty water) is compared, and the result is shown in Fig. 2. In all environments, we could not find the distinguish differences.

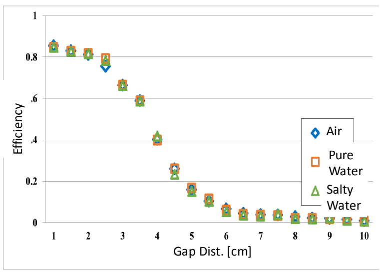


Fig.2 Comparison by Operation Environments

Next, the changes in transmission efficiency caused by winding number of the coil is evaluated. The radius of coils are 30, 40 and 50 mm, respectively (see Fig.2). The specification of each coil is in Table 2.

Table 2. The specifications of coils.

r [mm]	30	40	50
Outer Diameter [mm]	64	83	112
Winding Number	9	13	16
Inductance [μH]	38.3	51.2	78.1

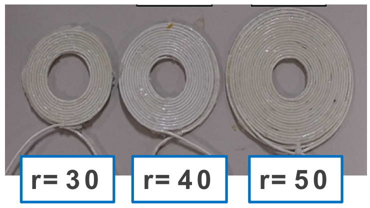
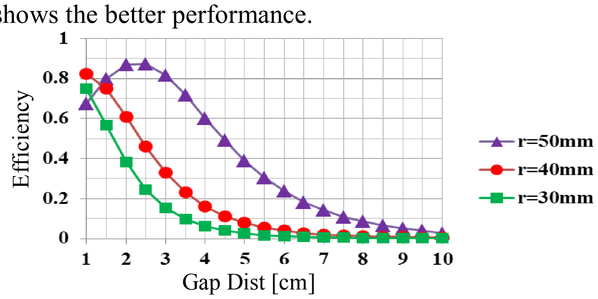
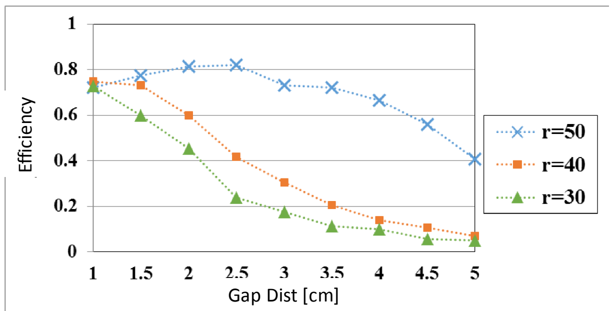


Fig.2 The coils for performance evaluation.

The results are shown in Fig. 3. The bigger coil is more efficient that small one, and small gap distance shows the better performance.



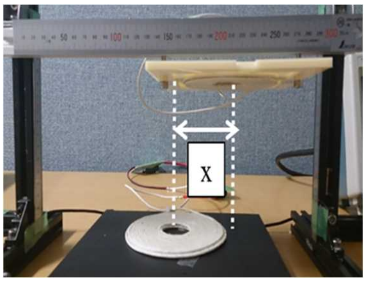
(a) Results of Simulations



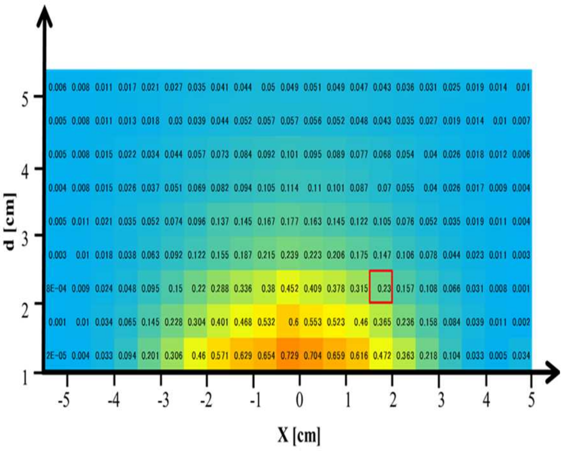
(b) Results of Experiments

Fig. 3 The comparison of efficiency by changing the size of coil and gap distance.

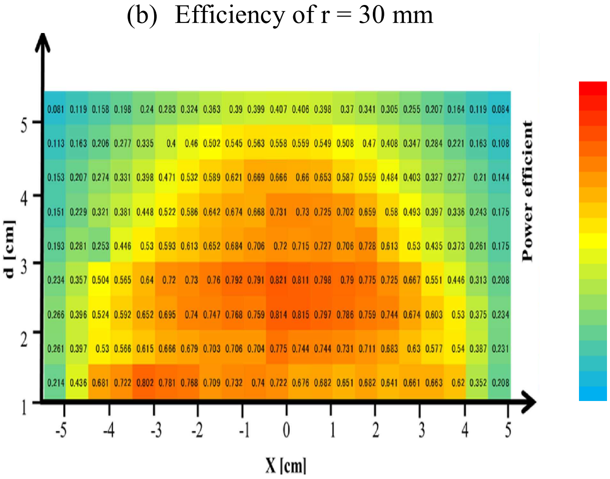
Then, the influence of position alignment of coils centers of transmitters and receivers are evaluated. It is shown that the big diameter coil is more robust than the small coil in center difference.



(a) Experimental setup. X is the gap of two coils.



(b) Efficiency of r = 30 mm



(c) Efficiency of r = 50 mm

Fig.4 The comparison by position alignment of coil centers.

3. Development of Wireless Power Transfer System for AUV

The wireless power supply system is developed under the following conditions from the specification of the target AUV.

(1) mounting position of the receiving coil is with the bottom surface of the AUV to adopt the landing system.
(2) the maximum diameter of the coil as long as it can be installed in AUV considering the axial misalignment between coils.
(3) the optimal position for maximum power transmission efficiency exits, so it is necessary to adjust the gap length between the charging station receiving coil.

Under the above conditions, the wireless power transmission system was developed, whose maximum efficiency was 81% at the time of the gap length 8.5cm. Also regarding positional displacement of the coils has resulted in power can be supplied in a range of -6cm ~ 7.5cm.

The wireless power supply system was mounted for charging experiment to AUV "DaryaBird". Figure 5 shows the block diagram of the system, and Figure 6 shows the arrangement of AUV and charging system. The voltage of the battery is monitored while charging the battery, and when the voltage comes to charging termination voltage, the system cut off the power supply automatically. The experiments were carried out with the positional gaps of coils 0 cm, 3 cm, at 6 cm, and each charging time were 40.8 min., 61 min. and 137.5 min. Figure 7 shows the results at the time of 0cm.

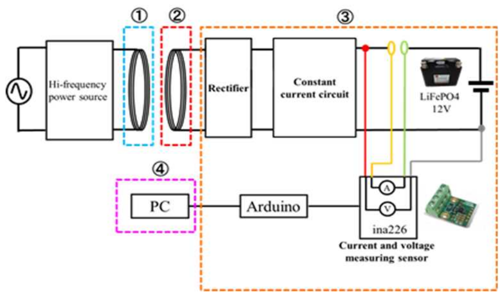


Fig. 5 The Block diagram of wireless power supply system.

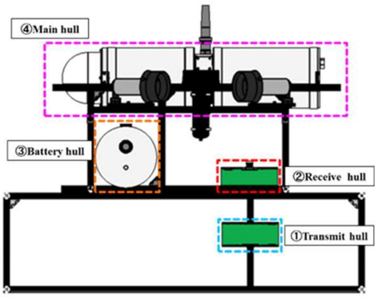


Fig. 6 The arrangement of power transmission system and AUV.

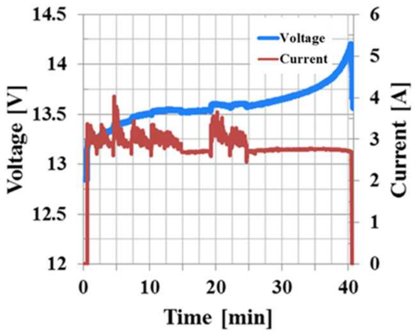


Fig. 7 The results of power supply.

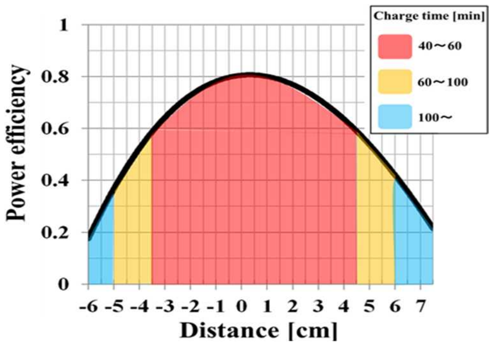


Fig. 8 The relation between charging time and gap of coils' center.

4. Conclusions

In this research, we proposed a wireless power supply system of AUV. The system is evaluated by simulations and experiments using AUV, and the results show good performance and detect the faults. Using magnetic resonance method, the chargeable range and the expected charging time of the battery in the underwater wireless power supply system created are shown in Fig.8. Assuming that the charging efficiency is more than 60% and charging time is 1 hour, the positional gap of 3.5 [cm] to 4.5 [cm] is acceptable.

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