Research on Ultrasound Coupled Wireless Energy Transmission in Marine Environment

Junchen Lu *, Xiyou Chen

Dalian University of Technology, Dalian 116024, China

* Correspondence author email: lujunchenx@foxmail.com

Abstract: In recent years, the wireless transmission of electric energy and its application have been successful, and the research of using ultrasonic coupling to transfer electric energy has become possible in theory and practice. Most of the above research is based on the application of ultrasonic and electromagnetic wave in the air to transmit electric energy. Compared with mature solids and gas transmission media, the situation of liquid transmission and conversion media is more complex and relatively difficult. In this paper, the underwater ultrasonic coupled power transmission in ocean environment is studied, and the attenuation of the underwater acoustic coupled power transmission is simulated.

Key words: ultrasonic coupling; wireless energy transmission; energy attenuation process.

1. Introduction

Overview: Since Marin Soljac of MIT successfully lit a 60W lamp 2.13M away from the transmitter in 2007, there has been a worldwide upsurge in the research of wireless power transmission. The methods of wireless power transmission mainly include electromagnetic induction, electromagnetic resonance induction, laser and microwave.

However, most of these studies are based on electromagnetic waveform to characterize the charging performance. There are relatively few studies on ultrasound as a power transmission medium. Toshihiko Ishiyama, a Japanese scholar, has discussed the method of wireless charging low-power mobile devices by ultrasound. The above research is based on ultrasonic waveform, which has no electromagnetic shielding phenomenon, although it will attenuate, but there are no restrictions such as encapsulation and transmission isolation, so it is more suitable for use in complex electromagnetic environment.

Ultrasound refers to the sound wave whose frequency is more than 20 kHz that can not be heard by human bare ear. Nowadays, there are many methods to produce ultrasound, such as hydrodynamic method, piezoelectric effect method and magnetostrictive effect method. The piezoelectric properties of piezoelectric materials can be used as the medium for generating and receiving ultrasonic waves, and as the converter of acoustic and electromagnetic waves. Because the medium parameters in water are different from those in air, the corresponding frequencies of ultrasonic energy are also different. Correspondingly, the noise associated with the more complex marine environment is likely to cause unnecessary crosstalk and resonance, thus affecting the load and transmission characteristics of ultrasound. Therefore, it is very important to effectively carry out spectrum analysis and dynamic
monitoring of coherent noise in the marine environment so as to select carrier frequency and conversion ratio properly.

2. Design of Ultrasound Coupled Wireless Power Transmission System

The whole system is divided into two parts: the transmitting module and the receiving module. The transmitting module includes the main circuit and the control circuit, and the main circuit includes the matching circuit, the rectifying circuit and the inverting circuit. The matching circuit plays the role of impedance conversion to improve the output power and efficiency of the circuit; the rectifier and inverter circuit can convert the power frequency into other frequencies; the control circuit can control the switching frequency of the power tube gate of the main circuit through closed-loop feedback, so as to realize the electromechanical resonance between the main circuit and the piezoelectric transducer. The piezoelectric transducer of the receiving module receives the high-frequency electricity from the inverse piezoelectric effect by receiving the ultrasonic wave, and then rectifies it to supply some direct-current electrical equipment for direct use.

It is difficult to study the mechanical vibration of particle in the process of ultrasonic energy transmission. In order to facilitate the study of energy transmission process, the system can be equivalent to a circuit form by electromechanical equivalent method. When alternating voltage is applied to piezoelectric ceramic crystals, the transducer will produce longitudinal vibration. When the frequency of alternating voltage equals the resonant frequency of the transducer, the vibration is the strongest. The equivalent circuit of the piezoelectric transducer near the resonant frequency is shown in Figure 1. The total reactance of the vibration system near the resonant frequency FS of the transducer in series can be zero by adding appropriate tuning inductance.

![Figure 1. Equivalent circuit of piezoelectric power converter](image_url)

In the figure, C0 is the static capacitance of the piezoelectric transducer, R0 is the dielectric loss resistance, Cm, Lm and Rm are the dynamic equivalent capacitance, equivalent inductance and equivalent resistance of the piezoelectric transducer respectively.

However, when ultrasonic wave propagates in water, the influence between the receiver and the transducer is very complex because of the existence of physical phenomena such as elastic friction absorption, viscous and heat conduction of the medium, and the influence of the directivity of the ultrasonic transducer.

3. Ultrasound Propagation and Frequency Coupling in Seawater

Due to the influence of solar radiation heating and wind stirring, the vertical distribution of sea water temperature is generally stratified structure, and the influence of pressure makes the sound velocity in the ocean vertical distribution. Sound waves emitted from the place with the lowest sound velocity refract due to the difference of sound velocity between upper and lower layers. The sound rays reflecting
the sound propagation path always bend to the place with the lowest sound velocity. Most sound waves pass through such a reciprocating bending refraction in the sea water, but do not contact with the sea surface and the seabed, so the energy loss is very small. This phenomenon is called the vocal channel phenomenon, and the place with the lowest sound velocity is called the vocal channel axis.

Low-frequency sound waves can travel far in the channel, such as the explosion of a kilogram of TNT explosives, which can transmit more than 10,000 kilometers in the channel. Therefore, this characteristic of the channel can be used to transmit the rescue signals of the wrecked aircraft and ships, to monitor underwater earthquakes, volcanic eruptions and tsunamis, and also to transmit high-frequency sound. Frequency ultrasound is used to transmit wireless energy.

The stirring of wind and waves makes the surface sea water form an isothermal layer. The static pressure makes the sound velocity increase slightly with the increase of depth. Sound rays originating from sound sources in the isotherm always bend upward and propagate forward by reflection from the sea surface. They can also propagate to distant places, known as surface channels.

In the absence of wind and wave stirring, when the surface seawater is exposed to sunlight, the temperature and sound velocity of the upper layer are higher than those of the lower layer, which results in a vertical distribution of negative gradient of sound velocity. In this case, the curve of sound wave propagation always bends downward, producing sound and shadow areas where the sound energy can not reach. In addition, if the sea is shallow, the sound line will touch the bottom of the sea. Because of the great loss of reflection from the seabed and the great attenuation of sound energy, it can not spread far.

The seabed has a great influence on the propagation of sound waves, so the propagation characteristics of sound in shallow water mainly depend on the reflection ability of the seabed. The reflection loss of seabed to sound wave is related to the density of seabed material, sound velocity and incident angle of sound wave. Generally speaking, the higher the density of the seabed, the higher the speed of sound, the smaller the reflection loss; the higher the frequency of sound wave, the greater the reflection loss of the seabed.

When sound waves propagate in sea water, some sound energy is absorbed and converted into heat energy due to the heat conduction and viscosity of the medium. Under the action of sound wave, the structure of water molecules has a relaxation process from loose to tight, which increases the absorption of sound by sea water. For acoustic waves with lower frequencies, the attenuation of sound energy is due to the scattering of sound caused by turbulence. Bubbles, marine organisms and suspended matter in the sea scatter and reflect sound waves.

The noise of 500-5000Hz produced by waves is related to the wind level and sea conditions on the sea surface. The wind level and sea condition can be monitored by using the noise of this frequency. The underwater noise generated by tsunami can be used to predict tsunami. The sounds of marine organisms are related to their species and living conditions. The characteristics of this sound can be monitored in order to distinguish the species of organisms, grasp their living rules and provide information for the study of fishery resources. In addition, it is possible to use acoustic signals to control the activities of marine organisms to meet human needs. At the same time, the main interference noise can be studied by spectrum analysis based on Fourier transform, and the interference caused by overlapping carrier bands can be avoided.

Sound wave, electromagnetic wave and other forms of energy in its transmission and transmission process, regardless of the form of medium exists, energy dissipation is inevitable. Generally speaking, the loss of acoustic energy is the decrease of amplitude, but the random oscillation of amplitude is also considered as the attenuation of signal energy.
We use MATLAB software to study the energy and amplitude attenuation of ultrasound in the marine environment, and make the attenuation simulation.

![Ultrasound transducer](image)

**Figure 2.** Ultrasound transducer

**Figure 3.** The effect of frequency and temperature on attenuation

### 4. Conclusion

Ultrasound can transmit for a long distance in the ocean environment, but because of the complexity of the ocean environment and the influence of tidal waves, there will be a large range of band noise interference, and the sea water is viscous. Therefore, it is very important to select the frequency and phase of the transmission of ultrasound reasonably, based on different times and different phases. The electromagnetic waves coupled with the external environment of the cycle also need to change with each other to achieve a reasonable coordination. Through the study of the attenuation of ultrasound in the marine environment, the most effective transmission length and the most efficient conversion frequency can be determined through different bands.

### References

[1] Zhou Fengdao, Guo Xin, Tang Hongzhong, et al. Design of ultrasonic positioning system for ocean exploration equipment [J]. Laboratory Research and Exploration, 2013, 32 (11): 85-88.

[2] Wang Meng, Huang Rui and Yang Jie. Principle and technical analysis of magnetic coupled resonant wireless power transmission system [J]. Electronic technology and software engineering, 2015 (4): 146-147.

[3] Zhao Yucheng. Research on Inductively Coupled Wireless Ultrasound Sensors [D]. University of Electronic Science and Technology, 2018.

[4] Liu Danning,.Research on Ultrasonic Based Wireless Power Transfer Through Metallic Media: CN104734204A [P]. 2015.

[5] Li Lu. Study on Power Transmission Characteristics and Power Upgrading Method of Ultrasound Wireless Power Transmission [D]. Chongqing University, 2017.
[6] Chen Xiyou, Xu Kang, Mou Xianmin, et al. [J] Comparisons of inductive coupling and ultrasonic coupling wireless power transfer under seawater [J]. Journal of Electrical Machinery and Control, 2018, 22 (3): 9-16.

[7] Xu Kang, Chen Xiyou, Liu Danning. Electrical Impedance Transformation Techniques for an Ultrasonic Coupling

[8] Electrical Impedance Transformation Techniques for an Ultrasonic Coupling Wireless Power Transfer System Under Sea Water [J]. Chinese Journal of Electrical Engineering, 2015, 35 (17): 4461-4467.

[9] Wu Hongxia. The Research on Steady Voltage and Current Technologies of Capacitively Coupled Contactless Supply [D]. Dalian University of Technology, 2015.