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The Transcutaneous Charger for Implanted Nerve Stimulation Device

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Abstract: Implanted nerve stimulation offers many advantages to improve the QOL (quality of life) of the patients suffering from nervous system diseases such as Parkinson's disease and epilepsy. Secondary battery begins to be used instead of primary secondary, service life of the implanted device is extended and the device becomes smaller and lighter. For charging the secondary battery fit in the body, a transcutaneous charger is designed. Two coupling coils designed specially are used to transmit and receive energy. With the mentioned coupling coils, the charger attains 15mA charge current and the charge requirement is satisfied.

Key words: implanted nerve stimulation device, electromagnetic coupling, recharge

I. INTRODUCTION

With the development of modern iatrology, implanted nerve stimulation is playing a more and more important role in curing nervous system diseases such as Parkinson's disease, epilepsy and continuity headache for its less minus effect and complication than surgery and clinical medicine that commonly used. At present, a majority of the implanted nerve stimulation devices are produced by three USA companies, Medtronic, Cyberonics and Advanced Neuromodulation Systems.

Now, most medical devices that have been implanted inside the human bodies are powered by primary batteries, and many disadvantages exist. Although high energy density lithium batteries are used to reduce the size of the batteries, they still occupy approximately 25-60% of the volume of implanted devices. [1] For typical nerve stimulation devices, the batteries will take a half of the volume and weight. Because of the huge battery, the minimizing of size and weight of the device is restricted. This will increase the unnecessary influence of the device to the body, and decrease the advancements of QOL of the recipients as well. Beside this, the application of the device for children is limited. Even though, for most implanted devices, the energy of battery will be exhausted in 5 years. Then, the recipients have to receive a second operation to change their nerve stimulation devices.

For solving these problems, secondary battery begins to be used to replace the primary battery. At present, most secondary batteries used in implant technology are lithium-ion batteries. Although its capacity and energy density is lower than the lithium primary battery, the secondary battery can have smaller size and hundreds of recharge cycles.

In order to recharge the implanted device including a secondary battery, transcutaneous charger must be used. The charger includes two coupling coils, which are widely used to transfer data/power into recipients' bodies in implanted medical devices.

In the current studies, symmetric and coaxial coupling coils are used to transfer power into the medical devices such as Artificial Heart (AH). [2] The efficiency of transmission is high, may be up to 60% in the mock test, however, a 50mm-diameter coil is too big to fit into the nerve stimulation device.

In this paper, a transcutaneous charger, including a specially designed mini inner coil and a secondary battery, is designed.

II. PROPOSED TRANSCUTANEOUS CHARGER

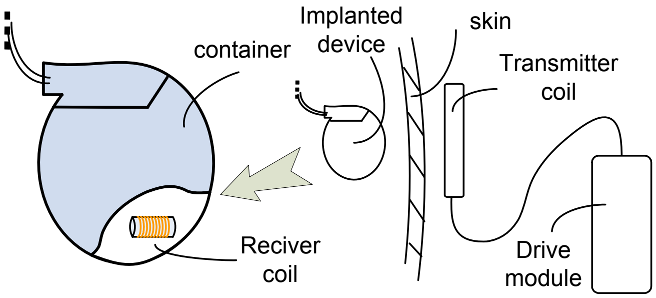

Figure 1. Schematic of the transcutaneous charger

As shown in Figure 1, the transcutaneous charger consists of four parts. The receiver coil and charge module are encapsulated inside the nerve stimulation device and implanted in the body. The transmitter coil and its drive module are placed outside the body. The nerve stimulation device is packed into a container, which prevents the tissue fluid filter in to erode the circuit. The container is usually made of titanium.

A. Basic principle of Transcutaneous Charger.

Energy is transmitted from outside into the body with transmitter coil and receiver coil in the transcutaneous charger. It is based on the theory of electromagnetic coupling. When the current, supplied by the drive module, flows at the transmitter coil, magnetic flux is generated. Voltage is induced at the receiver coil placed in the magnetic filed, and energy is transmitted into body. The voltage supplies the charge module and the secondary battery is recharged.

B. Construction of Transcutaneous Charger.

Figure 2 shows the block diagram of the designed transcutaneous charger.

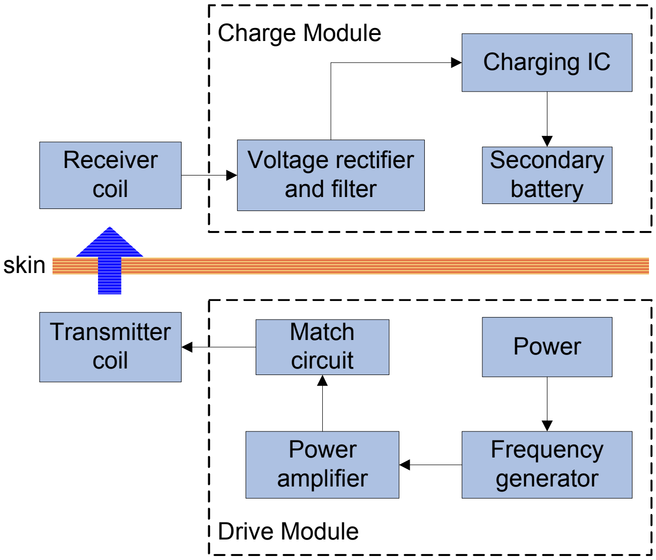

Figure 2. Block diagram of the designed transcutaneous charger

Frequency generator and power amplifier are the main parts of the drive module. In the frequency generator, direct digital synthesis (DDS) is used to generate accurate high frequency waveforms. A power MOSFET is used in the power amplifier. Transmission frequency is about tens of kHz, and it can be changed by an AT89C51 MCU.

The charge module consists of rectifier and filter circuit, charging IC and a lithium-ion secondary battery. Induced voltage of receiver coil passes though a bridge rectifier and a capacitive filter, then direct voltage is acquired. The direct voltage drives the high accuracy charging IC (BQ24202, Texas Instruments) for the secondary battery.

Figure 3 shows R10499 cell lithium-ion secondary battery produced by Wilson Greatbatch Technologies, Inc, one of the best implanted battery suppliers in USA. Its capacity is 35mAh and cycle life is about 1000. The battery is only 1.75g and its volume is 1 cm3.[3]

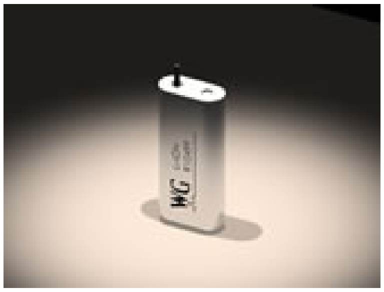

Figure 3. R10499 cell, Lithium secondary battery

C. Performance requirement of Transcutaneous Charger.

For the nerve stimulation device, the average current is about 30μA and the typical power requirement is about 100μW, when it works in normal conditions.

The performance of the transcutaneous charger is the recharged current is 15mA. So, the battery will be fully recharged in 3 hours and can supply the implanted nerve stimulation device for more than one month.

III. DESIGN OF COUPLING COILS

As shown in figure 4, coupling coils in the charger are specially designed.

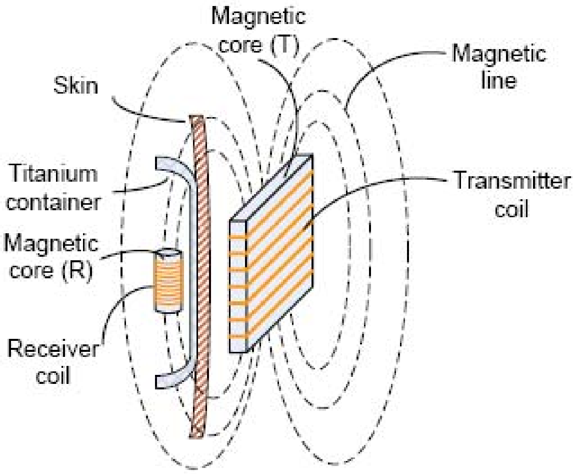

Figure 4. Schematic of coils coupling

The receiver coil fit in body is small and columned.

Because the receiver coil is encapsulated in a titanium container and implanted under skin, it is hard to be located accurately.

If the symmetrical coil is used outside, the radial displacement occurs easily and the drop of efficiency causes. In order to improve the stability of the recharge, the transmitter coil is designed much bigger and its shape is flat. The two coils' axes are parallel.

The bigger, flat transmitter coil generates a uniform magnetic field in a bigger area. When the receiver coil shifts in this area, the coupling conditions charge slightly, however, the stability of the recharge is improved.

Magnetic cores are used in both two coils to increase the effectiveness of coupling and ferrite for high frequency devices is selected for core.

IV. EXPERIMENTS AND RESULTS

With the transcutaneous charger, experiments were carried out and charging current and efficiency were measured.

The design parameters of the transmitter coil and receiver coils used in the experiments are shown in Table. 1.

TABLE 1

PARAMETER OF COILS

parameter	**Transmitter coil**	**Receiver coil**
Wire diameter	0.25mm	0.1mm
Turns	17	300
Core size	50×48×8 mm	Φ5×15mm
Inductance	34.6μH	1.61mH
Weight	106g	1.44g

In the experiments, rechargeable lithium battery Lir2302 (PowerStream Inc.) was used.

Charging efficiency η is calculated by equation (1).

$$\eta = \frac{U_{charge} \times I_{charge}}{W_{power} - W_{circuit}} \times 100\% \qquad (1)$$

where

U_{charge}: Voltage of the rechargeable battery, (V)

I_{charge}: Charge current, (A)

W_{power}: Output power of the power source, (W)

$W_{circuit}$: Power consumption of the circuit, (W)

Charge current is an important parameter of the charger. As table.2 shown, when the charging frequency f=40 kHz and charging distance d=5mm, the charge current is 16.4mA.

TABLE 2

CHARGING EFFECT

Parameter	**value**
Distance	5 mm
frequency	40 kHz
Battery voltage	3.91 V
Charge current	16.4 mA

Energy is transmitted into the patient's body by way of electromagnetic coupling. Energy is transmitted by the coil outside the body, and received by the coil inside. In inductively powered system, the two coils are fairly weakly coupled, and the typical values the proportion of energy capture by the receiver coil are between 0.01 and 0.1.[4]

As titanium is a fine conduction and paramagnetic, the container could be quite electric shielding and magnetic shielding. When the magnetic flux passes though the titanium container, the eddy current is induced. The container is heated by the effect of the eddy current and the heating power is calculated by equation (2).[5]

$$P_e = \frac{\sqrt{2}}{4}\sqrt{\frac{\gamma\omega^3}{\mu}}\,aB_{zav}^2V \qquad (2)$$

where $\omega = 2\pi f$.

From the equation (2), the lower of charging frequency, the less heat waste occurs. The change of the charging frequency can also affect the condition of the coupling. Figure.5 shows the change of the charging efficiency according the variation of charging frequency. From figure.5, the maximum efficiency is obtained at f=60 kHz.

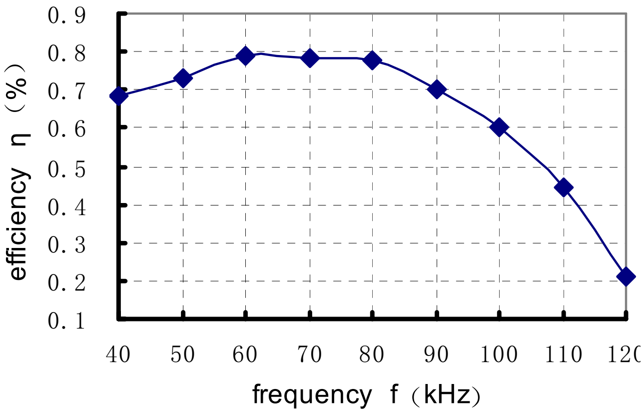

Figure 5. Charging efficiency according to variation of charging frequency.(charging distance d=5mm)

Experiment was also carried out to find out the influence of the container shielding to the charging efficiency. The result is shown as figure.6. From the figure.6, the charging efficiency decreases with the rise of the charging distance. As the charging distance d=1mm, the efficiency with the container shielding is only about 30% of it without container shielding.

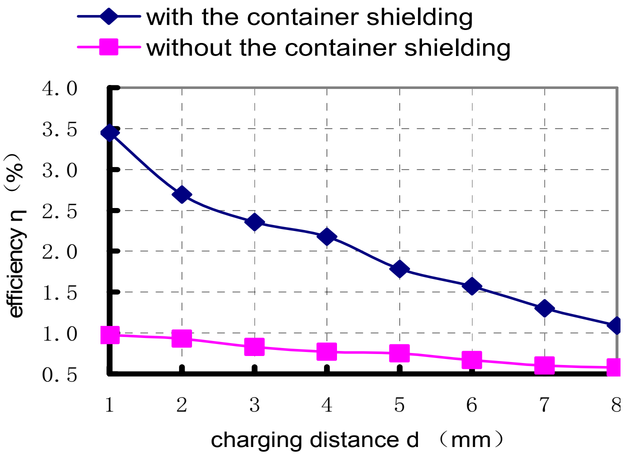

Figure 6. Charging efficiency according to variation of charging distance

V. CONCLUSION

This paper mentions the design of a transcutaneous charger for implanted nerve stimulation device. In order to reduce the volume and weight of the whole implanted device, a columnar receiver coil whose size is only Φ6mm×15mm. A flat transmitter coil is used to generate a uniform magnetic field in a bigger area. So, the statue of the recharge becomes more stable and convenient. In the proposed charger, the receiver coil, charge circuit and the rechargeable battery are smaller and lighter, and more suitable for the implanted nerve stimulation device. The designed charger can offer more than 15mA charge current within about 5 mm distance. So, the charge requirement is satisfied. Using the appropriate charging parameter, the heating value should be limited strictly and the temperature of container will be acceptable for human body.

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