코크로프트-윌턴회로와 반파공진인버터를 적용한 경두개 자기자극장치

Transcranial Magnetic Stimulation using Cockroft-Walton Circuit and Half Bridge Resonant Inverter

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요약

기존의 경두개 자극장치는 일정한 자극치료 펄스의 정현파 모양으로 다양한 치료 및 진단을 하는데 한계가 있다. 본 연구에서, 치료 및 진단마다 요구되는 세기, 폭, 펄스모양이 다른 코크로프트-윌턴회로와 반파브리지 공진 인버터를 도입하여 주파수와 전압이 가변되는 새로운 장치를 제안하고자 한다. 기존장치보다 많은 장점을 가진다. 첫째로 고압 변압기를 가지지 않는다. 둘째로 스위칭손실이 적고, 출력에너지를 정밀하게 제어할 수가 있다. 셋째로 자극의 세기, 폭, 펄스모양이 다양하다. 결과적으로 변압기를 사용하지 않는 반파브리지 인버터와 코크로프트-윌턴회로를 적용하여 개선된 특성과 실험을 구하였다.

■ 중심어 : | 과학기술 | (경두개 자기자극장치, 코크로프트-윌턴, 회로) |

Abstract

Though existent a transcranial magnetic stimulation makes various treatment and diagnostic sine waveform of fixed stimulation pulse, there is limitation. In this research, because strength, pulse width, pulse pattern required in treatment and diagnostic introduce other Cockroft-Walton circuit and half bridge inverter frequency and voltage variable become new device propose wish to. Have more advantages than existing device. First, do not have high voltage transformer. Second, switching loss can be less, and control output energy precisely. Three, stimulation strengths, pulse width, pulse pattern are various. As a result, sought special quality and an experiment that is improved applying inverter and cockroft - Walton circuit is half bridge inverter that do not use transformer.

■ keyword : | Science Technology | (Transcranial, Magnetic Stimulation, Cockcroft-Walton, Circuit) |

I. Introduction

Recently magnetic stimulation applications are being widely used in a variety of fields including material processing, industrial instrumentation and

medical equipments. In these applications, the precise power density control of a magnetic pulse has considered to be significant[1]. The conventional magnetic stimulation have been designed for constant voltage or power applications[3][4]. So they can't

perform under the wide range of load voltage condition such as zero to maximum[2]. The capacitors used in these types must be charged by a capacitor-charging power supply. The capacitor voltage is divided into two cycles; charge and discharge[5-7]. During the rapidly discharged by the load, which is inactive in the charge cycle. The discharge cycle is normally much shorter than the charge cycle[8][9]. The capacitor-charging power supply enters the charge cycle with near short-circuit conditions and begins operation in the charging mode. The discharging mode starts as soon as the charging mode is finished, because the output voltage may drift due to capacitor leakage and parasitic resistances[10][11]. Recent magnetic stimulation was composed of high-voltage transformer, rectifier and smoothing capacitor in the transformer secondary. Both capacitor storage energy and laser output energy per pulse can't be varied because the rectified high-voltage DC has the constant energy[12-14].

In this study, we have been proposed the new type of magnetic stimulation adopted a variable voltage capacitor with Cockroft-Walton circuit and constant-frequency current resonant half-bridge inverter. Experiments have been carried out as a function of pulse repetition rate and switching number of charging cycle in order to investigate operational characteristics of this magnetic stimulation[15].

II. The principal of magnetic stimulation

The current density $\vec{J}$ throughout a volume conductor gives rise to a magnetic field given by the following relationship (Stratton, 1941; Jackson, 1975): where r is the distance from an external field point at which $\vec{H}$ is evaluated to an element of volume dv inside the body, $\vec{J}dv$ is a source element, and ∇ is an operator with respect to the source coordinates.

$$4\pi\vec{H} = \int_V \vec{J}X\nabla\left[\frac{1}{r}\right]dv \quad (1)$$

Substituting Equation (1), which is repeated here, into Equation (2) and dividing the inhomogeneous volume conductor into homogeneous regions v_j with conductivity s_j , we obtain.

$$\vec{J} = -\sigma\nabla\phi + \vec{J} \quad (2)$$

If the vector identity $\nabla \times F \vec{A} = F \nabla \times \vec{A} + \nabla F \times \vec{A}$ is used, then the integrand of the last term in Equation can be written $s_j \nabla \times [F \nabla(1/r)] - F \nabla \times \nabla(1/r)$.

$$4\pi\vec{H} = \int_V \vec{J}X\nabla\left[\frac{1}{r}\right]dv - \sum_j \int_{v_j} \sigma_j \nabla\phi X\nabla\left[\frac{1}{r}\right]dv \quad (3)$$

Since $\nabla \times \nabla F = 0$ for any F ,

Fig. 1 Diagram of a transcranial magnetic stimulation

2] is a proposal of a transcranial magnetic stimulation adopted a half bridge converter with Cockcroft-Walton.

2.2 power supply

Also, the power supply is composed of main circuit, pulse forming circuit and trigger starter as shown in [fig. 2] Once coil is triggered by pulse forming starter, then trigger current flow through coil by pulse forming circuit. The Pulse forming circuit creates an ionized spark streamer between electrodes so that the main discharge can occur easily. In order to generate the streamer, the pulse forming current of about 5[kA] is required. It is found that the triggering of the coil reduces the impedance factor of the coil, increases the correct arc diameter, and reduces the peak current density of the coil discharge.

It improves the efficiency of the coil pump source and, hence, the efficiency of the magnetic stimulation also. Main circuit is composed of Cockcroft-Walton circuit, current resonant half bridge inverter and pulse shaping circuit. Inverter output current through L_R is resonant in accordance with sequential switching of half bridge switches S_1 and S_2 and flows into Cockcroft-Walton circuit which is AC to high-voltage DC power conversion and charges C_M .

When charging cycle of energy storage capacitor C_M is completed the trigger signal of SCR S_M is applied, then C_M starts to discharge into the lamp through the pulse shaping inductor L_M . This bursts of energy makes coil of high intensity magnetic field, which is required to magnetic stimulation.

2.3 control circuit

Control circuit is composed of three basic PIC one-chip microprocessors. Namely, PIC ① accepts the input signal from keypad and a timing signal, then generates a displaying and switching control signal.

PIC ② generates a timing signal and PIC ③ generates a displaying signal. Each PIC has to be properly programmed.

[Fig. 3] shows the output waveform of PIC. The waveform 1 is a timing signal comes from PIC ②. Each waveform 2, 3, and 4 is S_1 , S_2 and S_M driving signal comes from PIC ①. As we can see in this picture, the pulse duration of waveform 4 is 16.67[ms]. In other words, this waveform is obtained when the laser system is operating at 60[pps] condition. PIC output signals should be isolated from main circuit safely and amplified in order to drive the switches S_1 , S_2 and S_M properly. Two EXB841(Fuji Co.) are used to generate IGBT(BSM75GB120DN2 : Eupec Co.) driving signal as shown in waveform 1 and 2 as shown in [Fig. 4] Waveform 3 is amplified and isolated SCR(SC30C120 : Sanrex Co.) driving signal. During the charging cycle, [Fig. 4] IGBT driving signals are being applied, then stop to begin discharging cycle. The discharging cycle starts at the instant that SCR driving signal is applied.

Fig. 3 Waveform of a control signal

Fig. 4 Waveform of IGBT and SCR drive

Fig. 5 Waveform of inverter output current and gate

Fig. 6 Waveform of inverter output signal

Fig. 7 Three SCR turn-on signals generated from control circuit with time delay of 150 μ s.

Fig. 8 Experimental waveforms for the collector-to-emitter voltage, current of S1 with their current and bypass current flowing through diode D3.

Fig. 9 Start-up transient process of Cockcroft-Walton circuit.

III. Experimental Result

Fig. 10 Waveform of a up-pulse current

Fig. 11 Waveform of down-pulse voltage

Fig. 12 Waveform of Cockcroft-Walton circuit

Waveform a shows the inverter output current through L_M , each waveform of B and C is driving signal of half-bridge IGBT. S_1 and S_2 , and waveform D is SCR S_M driving signal as shown in [Fig. 5]. The peak value of inverter output current rises and then decreases to some fixed value. Also, the peak value of backward current through body-diode connected in parallel with IGBT, decreases gradually. Because, the energy storage capacitor C_M is being charged step by step.

Fig. 12 Waveform of a coil probe radius $r=20\text{mm}$ Fig. 13 Waveform of a coil probe radius $r=20\text{mm}$

Fig. 14 Coil total B vector

[Fig. 6] shows the enlarged waveform of inverter output current, capacitor C_M charging current and IGBT driving signals at the starting point of charging cycle. Also, it shows that the frequency of IGBT driving signal is constant, and a portion of inverter output current flows to the capacitor C_M . The IGBT switching is occurred at the instant that the current through IGBT is zero. [Fig. 7] Three SCR turn-on signals generated from control circuit with time delay of $150\ \mu\text{s}$. Fig. 8 Experimental waveforms for the collector- to-emitter voltage, current of S_1 with their current and bypass current flowing through diode D_3 . The charging current doesn't flow to the negative reference direction of C_M because of blocking diode D_b , which is between Cockcroft-Walton circuit and C_M . This helps C_M being charged to the desiring voltage just increasingly. The capacitor charging voltage, the charging energy and the single magnetic stimulation output energy are shown in [Fig. 7], which are the parameter of inverter switching times. The capacitor charging voltage is increased rapidly at first, then it increases linearly. Also, the capacitor charging energy and the single magnetic stimulation output energy are increased linearly as the parameter of inverter switching times. In other words, the linear control of the single pulsed magnetic stimulation output energy can be achieved by control of the inverter switching times.

In [Fig. 8], each waveform A, B and C shows the current waveform flow to the coil through pulse-shaping inductor L_M when the inverter switching numbers are 40, 80 and 120. These show that the peak value of current through the coil is increased when the inverter switching numbers are increased. Because, the increased switching number enhance the capacitor charging voltage and the storage energy. This picture shows that FWHM(full width at half maximum) of each current waveform flow to the coil is about 200[us], because the value of capacitor and L_M are remained constant. In [Fig. 9] Start-up transient process of Cockcroft-Walton circuit. It can be noticed that the more pulse repetition rate, the lower value of peak current flows to the coil in this picture. This leads to decrement of single magnetic stimulation output energy. As a result, the slope of magnetic stimulation output power is decreasing gradually when the pulse repetition rate is increased at the same condition of inverter switching numbers.

[Fig. 10] shows the magnetic stimulation waveform of magnetic pulse current as a function of pulse repetition rates and inverter switching numbers. We have known that the magnetic stimulation output power can be increased by two reasons. One is that the increasing pulse repetition rates at the same inverter switching numbers. And the other is the increasing inverter switching numbers at the same pulse repetition rate. Above all, we have known that these two effective factors of magnetic stimulation output power can be controlled simultaneously. [Fig. 11] shows waveform of magnetic pulse voltage. [Fig. 12] shows the magnetic stimulation waveform of a coil probe radius $r=20\text{mm}$. [Fig. 13] shows the magnetic stimulation waveform of a coil probe radius $r=20\text{mm}$. From these results, we could obtain the desired magnetic stimulation output power in this

fashion. [Fig. 14] shows ansoft 3d maxwell simulation Coil total B vector, Fig. 15 YZ plane B vector. The possible obtained range of magnetic stimulation output power is 0 to 210[W].

IV. Conclusion

In this study, we have been proposed the new type of magnetic stimulation adopted a variable voltage capacitor with Cockcroft-Walton circuit and constant-frequency current resonant half-bridge inverter. Experiments have been carried out as a function of pulse repetition rate and switching number of charging cycle simultaneously. We have investigated operational characteristics of this magnetic stimulation system.

From these experiments, we could be obtained the desiring magnetic stimulation by the control of these two effective factors simultaneously. The possible obtaining range of a transcranial magnetic stimulation output power is 0 to 210[W] when the inverter switching number is 0 to 120 and pulse repetition rate is 0 to 100.

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