경두개 자기자극장치의 치료자극 펄스

Treatment Stimulator's Pulse of Transcranial Magnetic Stimulation

김휘영
동주대학 의료기공학과

Whi-Young Kim(ndyag@dongju.ac.kr)

요약

본 논문에서, 생물계로 자기자극장치를 사용할 경우 잠재적인 사용에 대한 전력소자 응용제어 기술에 대해 언급 하고자 한다. 자기자극장치의 효과는 자기 자극코일에 의해 전달된 전류 펄스파형에 유도한 전계와 기하학 구성에 의존한다. TMS는 두뇌에 있는 전계를 유도하는 전자장의 펄스를 머리의 외부에서 자극하게 된다. TMS는 두뇌의 자극을 통해, 진단 및 치료에 있는 수많은 응용이 가능하다. 이러한 요소들은 코일의 구성과 전원 장치와 크기의 등가적 요구와 특성으로 매우 중요한 기능을 가지게 된다. 제안하고자 하는 해결방법은 입력에 대하여 가변크기와 주기를 가지는 전류펄스 발생을 가진다.

또한, 해결방법은 전원에서 부하로 에너지 전송과 축적의 요소를 기본으로 할 수가 있다. 제안한 방식으로, 전력 회로 매개 변수의 충분한 통제를 통한 기획과 전략으로 단극파형 또는 양극 파형을 얻을 수가 있었다.

■ 중심어 : | 과학기술 | (경두개, 자기, 자극장치, 치료, 자극펄스) |

Abstract

In this study, I presented power control unit with potential use in the magnetic stimulation of biological systems. The effect of the magnetic stimulation depends on the geometry and orientation of the induced electric field as well as on the current pulse waveform delivered by the stimulator coil. TMS is achieved from the outside of the head using pulses of electromagnetic field that induce an electric field in the brain. There are numerous possibities in the applications TMS, such as diagnosis and therapy through the brain stimulation. These factors are very important to define the equipment requirements and characteristics in that the topology of the power supply and the size and geometry of the coil. The proposed solution is the generation of current pulses with variable amplitude and duration, according to a user defined input. Another solution is the topology that uses elements to store and transfer energy from the power source to the load. In addition to proposed topology, an adequate control strategy and right set of the power circuit parameters made possible to obtain unipolar waves and bipolar waves.

■ keyword : | Science Technology | (Transcranial, Magnetic, Stimulator, Treatment, Stimulator' Pulse) |

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I. 서론[INTRODUCTION]

The Stimulation of the exposed human cerebral cortex with electrical currents was first described by Bartholow in 1874 , the currents elicited movements of the opposite side of the body[1]. Electrical brain stimulation is today possible non-invasively using scalp electrodes. However, transcranial electrical stimulation is very painful and hence of limited value[2]. The first experiments with magnetic stimulation were conducted by d'Arsonval in 1896. He reported "phosphenes and vertigo, and in some persons, syncope," when the subject's head was placed inside an induction coil.

Later, many scientists reported the phenomenon of magneto phosphenes, that is, visual sensations caused by the stimulation of the retina due to changing magnetic fields. Magnetic *nerve* stimulation was accomplished only several decades later, first in the frog by Kolin *et al.* in 1959 and then in the human peripheral nerve by Bickford and Fremming in 1965[3][4]. The latter authors used an oscillatory magnetic field that lasted 40 ms. The resulting long-lasting activation interval made it impossible to record nerve or muscle action potentials, and the work was not pursued further[5].

In the following years, the technique was investigated only occasionally current sent through a coil produces a magnetic field that, in turn, induces electric field in the brain, which can cause neurons to fire[6]. Available MS devices induce damped cosine electric field pulses. The pulse forming technology can be adjusted over a wide range, whereas control over the pulse width is nonexistent or very limited. Strength-duty curves linking pulse forming technology to electric field strength E and coil energy W for threshold stimulation of neuron with membrane time constant of = 150 s. Curves are normalized to one at PW = 100 s. [그림 1] diagram of a Transcranial Magnetic Stimulation pulse forming technology adjustment, the pulse shape reduces power consumption and coil heating[7][8].

Thus, MS can expand the functionality and improve the efficiency of MS as a clinical and research tool. Pulse forming technology control of the MS stimulus enables response characterization of different neuronal populations and optimization of the pulse forming technology for various research and clinical applications[9]. For example, the strength-duty curve relates the pulse amplitude or energy for threshold stimulation with the pulse forming technology.

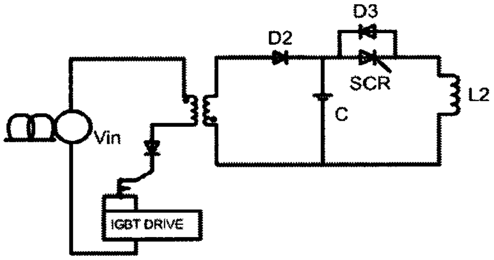

그림1. Diagram of Transcranial Magnetic Stimulation

MS with adjustable pulse forming technology could also be used to study and selectively target distinct neuronal populations that overlap in space. Therefore, using briefer pulses could improve the tolerability of MS by reducing unpleasant scalp sensations.

Finally, within a cortical region, MS might be able to selectively activate distinct neuronal population possessing different strength-duration characteristics, thereby improving the effective spatial and functional resolution of MS through selective targeting[6]. The switching characteristic of SCRs does not allow them to be turned off at an arbitrary point in time. In particular, once an SCR is turned on by applying a current pulse to the gate terminal, it can be turned off only when the anode current reaches zero. Thus, the SCR switch can only initiate the pulse but cannot control its pulse forming technology[5]. In this case, the pulse forming technology is determined by the resonant period of the capacitor and the coil. This approach still provides only discrete pulse-width adjustment, and requires powering down the system to manually insert connectors configuring the capacitors. Further, implementing this system with electronically controlled switches would be impractical since it would require the use of seven high-power semiconductor devices and/or relays, with up to three switches connected in series in some capacitor configurations. They pointed out that enlarging the inductance increases the pulse forming technology, but decreases the amplitude of the induced current.

II. 회로설계[CIRCUIT DESIGN]

A circular 90mm mean diameter coil is supplied as standard with single pulse systems. This coil is most effective in stimulating the human motor cortex and spinal nerve roots. A more recent development is the remote control coil which allows the user to operate the stimulator from control buttons situated on the coil handle. To date, circular coils with a mean diameter of 80-100mm have remained the most widely used in magnetic stimulation. The pulse forming technology is limited to a quarter resonant period, which corresponds to complete discharge. For brief pulse forming technology's, the coil current rise is approximately linear and the induced electric field pulse is near. Thus, by choosing an appropriately large capacitance, a wide range of pulse forming technology control and initial phase of the induced pulses can be effected. Therefore, after is turned off the coil current decays exponentially, inducing a negative electric field. Through the device controller, the user specifies the voltage of capacitor which determines the amplitude of the induced electric field, and the on-time of switch which sets the pulse forming technology of the positive phase of the induced pulse. Mathematically, the initial positive phase of the MS coil current is an under damped oscillatory response, and the subsequent negative phase is an exponentially decaying response. The induced electric field in the brain is proportional to the rate of change of the coil current. The electric field as a function of time is given in , found at the bottom of the page, where is a proportionality coefficient which depends on the number of turns and geometry of the coil, and the electric conductivity profile of the brain. In the limit of small parasitic resistance and large capacitor or brief pulse, the positive phase of the pulse approaches a rectangle, it can be seen that the amplitude and rate of decay of the negative electric field phase depend on the value of the dissipation resistor. The use of the correct coil side is particularly important in cortical stimulation as the human motor cortex is more sensitive when the induced current is flowing from posterior to anterior. While the basic circuit topology

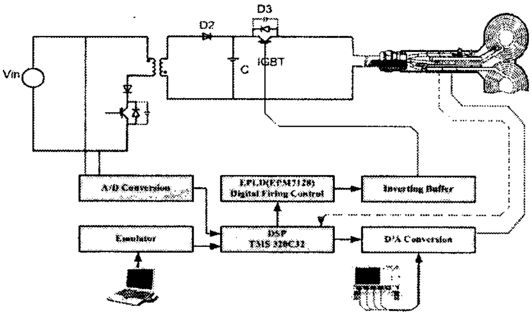

그림 2. Proposal of Transcranial Magnetic Stimulation

of MS devices is simple, the circuit implementation requires careful component selection, layout, thermal management, and transient suppression, due to the very high operating voltages and peak currents. For the pulse parameters typical in MS, suitable switch choices are IGBTs, gate-controlled thyristors, and GTO-derived devices such as integrated gate-commutated thyristors. [그림 2] Proposal of a Transcranial Magnetic Stimulation, Implementation schematic of MS device. Snubber circuits in parallel with capacitor bank C and switch Q suppress voltage spikes associated with Q turn off and reduce power dissipation in Q. The voltage rating was chosen to be safely above the peak IGBT collector-emitter voltage appearing during switching transients. A custom-made controller sent triggering pulses to the gate drive via an optic cable, with pulse forming technology set by the user. Free-wheeling diode was implemented with two series-connected fast 1800 V /105 A diodes. The maximum capacitor voltage should be chosen to allow supra threshold stimulation of the targeted neuronal population at the shortest desired pulse forming technology. The capacitance value should be chosen based on the upper limit of the desired pulse forming technology range. However, using excessively large capacitance would require large physical dimension of the machine, and will pose safety risks due to the increased energy storage.

III. 하드웨어 구현

[HARDWARE IMPLEMENTATION]

The flyback converter in this circuit is designed to operate in discontinuous operation. To ensure this, the primary inductance Lp needs to be limited to a maximum value. Therefore, the maximum primary inductance for discontinuous conduction at maximum load needs to be determined. The input power is defined as

$$P_{IN} = \frac{P_{OUT}}{\eta} \tag{1}$$

where η is the efficiency of the inductor. The input power can also be defined as the product of the stored energy E in the magnetic field and the switching frequency fs:

$$P_{IN} = Ef_s = \frac{L_p I^2_{pk} f_s}{2} \tag{2}$$

This allows the required primary inductance to be determined, but it is also necessary to know the peak current *Ipk* to be able to calculate this. The peak current is defined by (1).

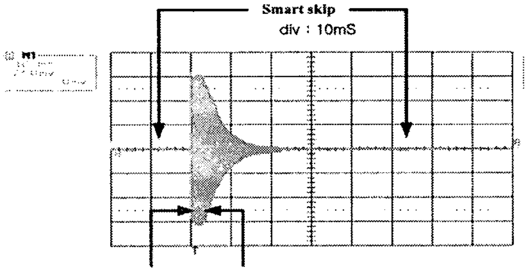

그림 3. Waveform of pulse(sense, power pulses) generator

$$L_{p(\max)} = \frac{V^{2}{}_{\in(\max)} \delta^{2}{}_{\max} T_s}{2P_{\in(\max)}} \tag{3}$$

where Vin(min) is the minimum supply voltage and ton(max) is the maximum on-time of the switch.

Therefore, to limit the primary inductance to ensure discontinuous operation, the maximum inductance is determined, where δmax is the maximum duty cycle and Ts is the PWM switching period. By combining equations (2) and (4) it is possible to determine the maximum primary inductance

$$I_{pk} = \frac{V_{\in(\min)} t_{O.V(\max)}}{L_p} \tag{4}$$

$$L_{p(\max)} \leq \frac{V_{\in(\min)} t_{O.V(\max)}}{I_{pk}} = \frac{V_{\in(\max)}}{I_{pk}} \delta_{\max} T_s$$

prototype in [그림 3], the energy storage capacitor was implemented with pulse(sense, power pulses) generator in parallel. The MS device can be used with most available MS coils (typical inductance range 10 --35 H). Therefore, the wiring and component placement in the MS device were arranged so as to minimize the stray inductance. Still, stray inductance cannot be completely eliminated. [그림 4] waveform of smart skip analysis, [그림 5] waveform of discharge capacitor and [그림 6] Waveform of discharge coil current.

Therefore, snubber components were installed in parallel with the energy-storage capacitor bank and the switch to handle the turn-off transient. diode consists of three series-connected fast-recovery 1200 V/60 A diodes Snubber capacitors utilize high-voltage, high-current polypropylene, and paper film/foil capacitors. These capacitors have to be large enough to hold the peak switch voltage below its rated limit. On the other hand, too large capacitance would increase switching losses.

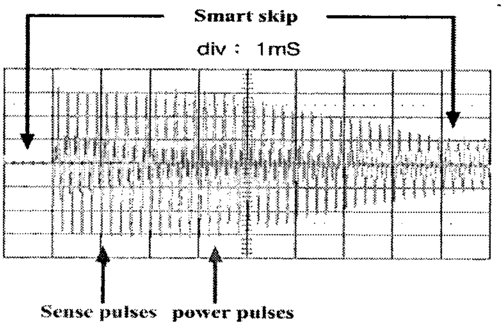

그림 4. Waveform of smart skip analysis

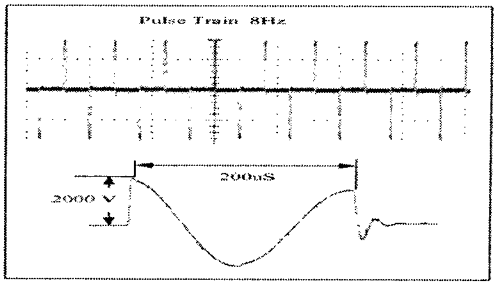

그림 5. Waveform of discharge capacitor voltage

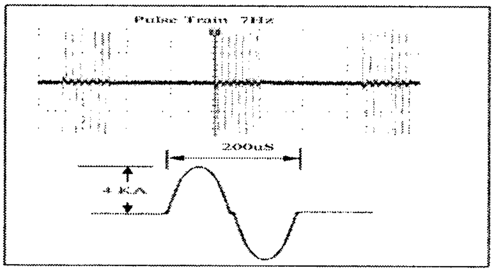

그림 6. Waveform of discharge coil current

IV. 실험결과[EXPERIMENTAL RESULTS]

The MS device was tested with capacitor voltages up to 1.65 kV and peak coil currents up to 6 kA. The pulse forming technology range of the initial electric field phase was 5 to 160 s. The experimental measurements of key MS switching waveforms are given in [그림 7][그림 8]. Measured MS waveforms for pulse forming technology of t = 20, 40, 60, 80, 100, and 120 s in [그림 9] . The waveforms associated with pulse forming technology of 20, 40, 60, 80, 100, and 120 s are overlaid for comparison. As expected,

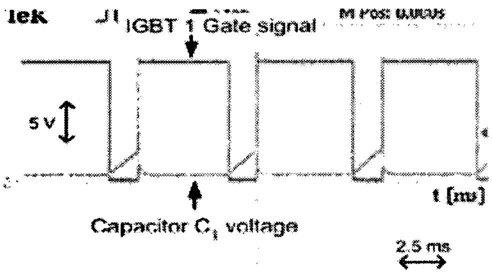

그림 7. Proposal of a controllable IGBT gate signal

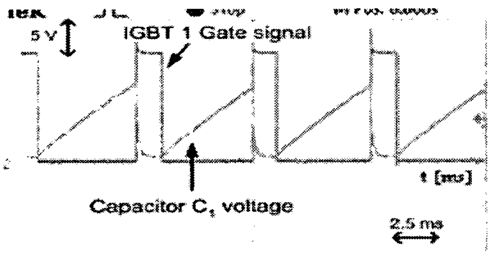

그림 8. Proposal of a controllable capacitor voltage

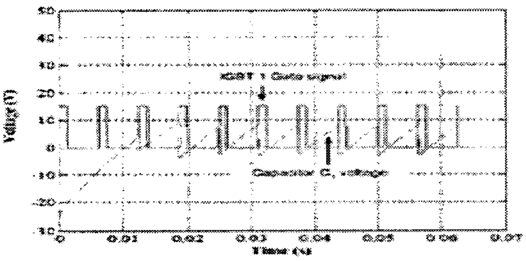

그림 9. Proposal of a controllable treatment pulse(IGBT)

the positive phase of the induced pulse comprises a portion of a cosine wave, which is close to rectangular for brief pulse forming technology. [그림10] Proposal of a controllable treatment pulse. Finally, from the emulated neuronal membrane potential it can be seen that longer pulse forming technology. produce more membrane depolarization. [그림 11] Proposal of a controllable treatment pulse(high load),

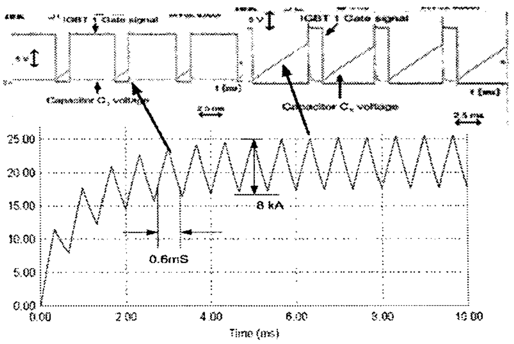

그림 10. Proposal of a controllable treatment pulse

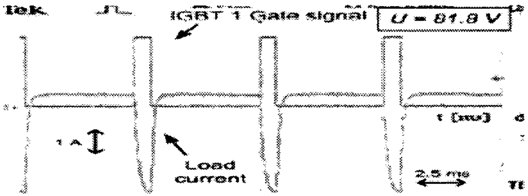

그림 11 Proposal of a controllable treatment pulse(high load)

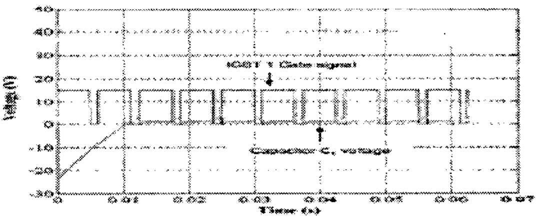

그림 12. Proposal of a controllable treatment pulse(Capacitor)

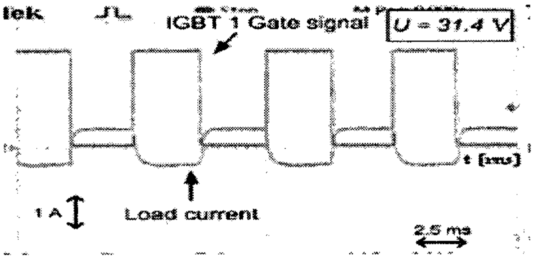

Fig. 13 Proposal of a controllable treatment pulse(lowLoad)

[그림 12] Proposal of a controllable treatment pulse(Capacitor),[그림 13] Proposal of a controllable treatment pulse(lowLoad). The amplitude of the spike is successfully limited by the snubber capacitors, and does not exceed 10% of the initial voltage. The energy per pulse can be measured by subtracting the energy on all capacitors in the power circuit before and after the pulse. In expression, it is assumed that the capacitor charger is turned off or contributes a negligible amount of charge during the pulse. [그림 14] Experimental tool setting. The contribution of the negative pulse phase is not included since it depends on the value of the dissipation resistor, which can be chosen arbitrarily. As with the cosine pulses, the coil heating was quantified with the load integral over the positive pulse phase. It should be noted that the charger was not disconnected during the pulse measurements since it contributed charge of less than 0.1% of the initial charge during the positive pulse.

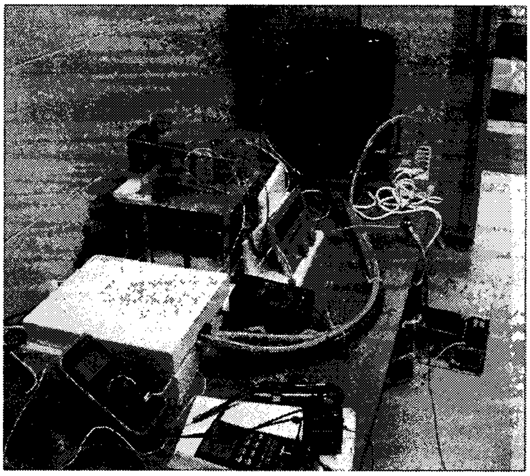

그림 14. Experimental tool setting

Finally, the capacitor charger efficiency is not included in the power consumption estimate for either configuration. However, it is reasonable to expect that a properly designed charger supplying a more narrow output voltage range close to the peak voltage, as is the case in MS, will have better efficiency than that of a conventional monophasic MS device where the capacitor is charged up from zero after every pulse.

V. 결론[CONCLUSION]

Brain stimulation with MS is achieved from the out side of the head using pulses of electromagnetic field that induce an electric field in the brain. MS has num erous applications in the study, diagnosis and therapy of the brain. The proposed solution is able to generate current pulses with variable amplitude and duration, according to a user defined input. The proposed solution is based on a topology that uses elements to store and transfer energy from the power source to the load. The design could be further optimized to reduce the turn-off voltage overshoots and ringing, while keeping the snubber capacitors in parallel with the IGBT and the switching losses, reasonably small.

Consequently, the MS electric field remains at near-peak value during the positive pulse phase. We have successfully developed the first TMS device capable of inducing near-rectangular pulses with PW adjustable from 5 to over 100 s. Coil currents up to 6 kA were force-commutated by an IGBT switch with appropriate snubbers, while the resulting transient voltage spikes did not exceed power-train component ratings.

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저자소개

김 휘 영(Whi-Young Kim) **정회원**

- 2001년 2월 : 부산대학교 전기공학과(공학박사)
- 2000년 3월 ~ 현재 : 동주대학 의료기공학과 부교수

<관심분야>: 의료치료기기, 진단기기