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Research and Development of Multi-Mode Head-Mounted Transcranial Magnetic Stimulation Equipment

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Abstract: Transcranial magnetic stimulation (TMS) has shown its therapeutic value in clinical practice as a non-invasive treatment device that can achieve multiple functions. In this paper, a multi-mode head-mounted transcranial magnetic stimulation device was developed by combining transcranial electrical stimulation and physical stimulation with altitude insomnia as the treatment target. The device has a variety of treatment modes, and the threshold of use is lower, the audience is wider, and has a good market value.

1. Introduction

The world's first transcranial magnetic stimulation device was formed in 1985. Professor Barker and his research team from the University of Sheffield successfully generated motor evoked potential in the stimulation coil through alternating current, which was also the symbol of the birth of transcranial magnetic stimulation technology[1]. Since then, various kinds of transcranial magnetic stimulation devices have emerged, such as the 200 series, BiStim series and Rapid series of the British Magsim Company, and the series of devices produced by the American Medtronic Company[2].

The first TMS device in China was formed in 1988 and developed by Liao Jiahua, director of Tongji Hospital. Due to technical limitations, the TMS device could not be formally put into clinical application due to problems such as slow charging speed and easy heating of coils during long-term use, but it still provided valuable experience for the subsequent research and development of TMS devices in China[3]. In 2005, Huazhong Yijie cooperated with Tongji Medical College to develop China's first repetitive transcranial magnetic stimulation device. In 2008, Wuhan IREAD Company developed China's first inert liquid internal circulation cooling system transcranial magnetic stimulator with independent intellectual property rights (IREAD CCY- ⅰ machine)[4]. Since then, China's transcranial magnetic stimulation equipment has entered the era of commercial development.

At present, most of the transcranial magnetic stimulation devices on the market are single-function devices, that is, they can only treat the patient by magnetic stimulation. In addition, most of the TMS equipment on the market need to be operated by a special person, which is difficult to achieve home use, and the threshold of use is high. In this paper, a set of multi-mode head-mounted TMS equipment is designed for patients with plateau insomnia, which integrates TMS, TMS and scalp physical stimulation. The equipment can make up for the above shortcomings of TMS equipment in the market.

In this paper, the multi-mode head-mounted TMS device can achieve TMS, TMS and scalp acupoint physical stimulation, and the three treatment modes can be performed alone or in parallel. The device comes in the form of a head-mounted helmet that minimizes the difficulty of its use.

2. The structure design

The TMS area is usually different depending on the treatment goal; For example, in the treatment of Alzheimer's disease, the Dorsolateral Prefrontal Cortex (DLPFC) and the Left Lateral Temporal Lobe (LTL) are usually stimulated[5], the Left-Dorsolateral Prefrontal Cortex is usually stimulated in the treatment of major depression. L-DLPFC or Right Dorsolateral Prefrontal Cortex (R-DLPFC)[6], the occipital area is usually stimulated in the treatment of abortion, and the contralateral (right) subfrontal gyrus area near the Broca area is usually stimulated in the treatment of aphasia[7]. In the treatment of insomnia, the stimulation area is usually selected in the right dorsolateral prefrontal F4 region and the right parietal P4 region in the 10-10 international standard lead system, as shown in Figure 1. Considering that there are a large number of preset scalp physical stimulation stimulation sites near the F4 region of the right dorsolateral prefrontal lobe, in order to ensure the rationality of the structure, the equipment in this paper selected the P4 region of the right top as the magnetic stimulation treatment area.

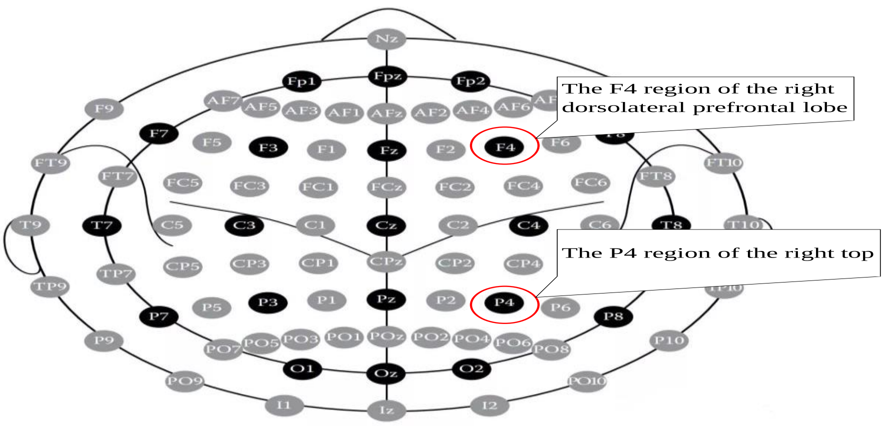

Figure 1. Region F4 and P4 in 10-10 international standard lead system

A large number of components are integrated into the helmet, so the design needs to consider the weight of the human neck. Military helmets are designed to exert a maximum pressure on the human head of no more than 49kg, that is, the helmet weight should not exceed 5kg[8]. The Chinese national standard GB-811-2022 "Motorcycle and electric bicycle Occupant helmet" stipulates that the maximum weight limit of the helmet is 2kg. Considering the difference between the object of use of military helmet and the object of use of the helmet treated in this paper and the effect of Gz acceleration on the neck of riding helmet, the weight of the helmet treated in this paper should not exceed 2kg. Since the magnetic stimulation coil itself has a certain weight, and the multi-mode head-worn TMS device has a variety of working modes, including the working mode without magnetic stimulation, such as physical stimulation alone or electrical stimulation alone, in these modes, the magnetic stimulation coil does not play a role. In order to minimize the load bearing of the human neck on the treatment device, In this paper, the magnetic stimulation coil is designed as a detachable coil, as shown in Figure 2. During TMS treatment, the coil can be placed in the card slot of the corresponding treatment area of the helmet, and the coil can be removed at the end of the treatment without affecting the realization of physical stimulation or TMS function.

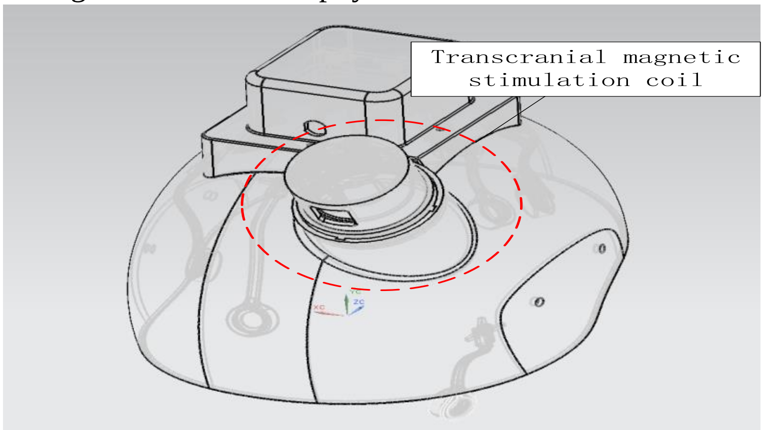

Figure 2. Arrangement of magnetic stimulation coil

The electrical stimulation involved in this paper takes the form of an electrode patch, and the electrodes appear in a positive and negative form, so at least one pair or two electrode patches are required. According to the clinical study of bionic electrical stimulation in the cerebellar apex nucleus, there may be an inherent neural pathway through the cerebellar apex nucleus and cerebral cortex. After stimulating the cerebellar apex nucleus, cerebral cortex vasodilates the center, expands cerebral vessels, increases cerebral blood flow, thereby improving cortical blood flow, promoting nerve cell metabolism, and thus improving function. To stimulate this neural pathway, extracranial stimulation at the mastoid point behind the ear was used[9]. To sum up, the arrangement of electrical stimulation is to use one positive and one negative electrode patch respectively affixed to the mastoid point behind the ear.

Physical stimulation According to the standard scalp needle and thread and clinical insomnia treatment experience, select appropriate scalp acupuncture points for stimulation. There are 14 standardized head stitches, which are located in the frontal area, parietal area, temporal area and occipital area. In clinical studies, midfrontal line, parafrontal line, parafrontal line, parafrontal line, parafrontal line and parietotemporal oblique line were used to treat insomnia. Finally, the physical stimulation points selected in this paper are Sishencong, midfrontal line, posttemporal line, Fang's: Fuxiang head, Fang's: thinking, Fang's: signal, Fang's: Fuzang upper Jiao, Fang's: Pour Zang upper Jiao, Jiao's: Shenmen, Shenting point, parietal line, parietal line, parietal line 3, parietal line 2, Anmian point.

In order to achieve the physical stimulation of the above points, this paper uses a small vibration motor motor. Vibration motors are dispersed and fixed in the inner layer of the helmet in the form of tentacles, as shown in Figure 3. The tentacles are curved and need to have a certain degree of toughness to facilitate the application of force to the scalp. In terms of material selection, this paper considers three kinds of materials: nylon, toughness resin and TPU (as shown in Figure 4), and the bending characteristics of the materials are shown in Table 1. In the actual application process, it was found that the hardness of the ductile resin was high but the toughness was slightly insufficient, and the TPU material could not provide enough force feedback. After considering the bending strength, bending modulus and actual feeling of the material, nylon was selected as the tentacle material.

Table 1 Comparison of bending properties of nylon material, toughness resin material and TPU material

Material	The bending strength	The bending modulus
nylon material	47MPa	1700MPa
toughness resin material	112MPa	2732MPa
TPU **material**	2-3MPa	80-100MPa

Figure 3. Arrangement of motors

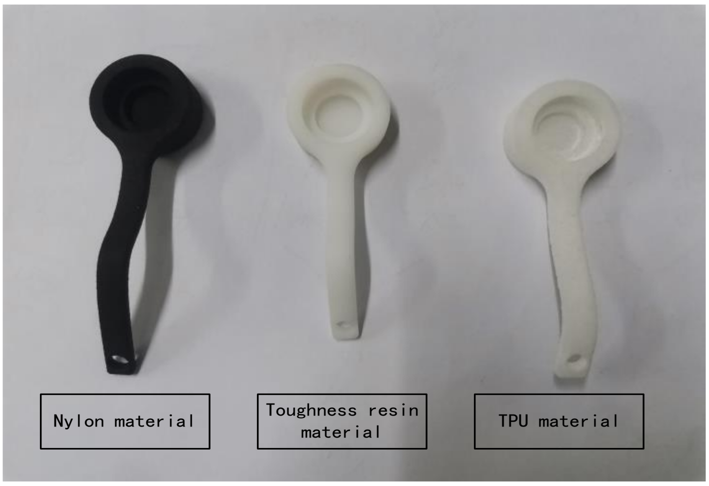

Figure 4. Nylon material, toughness resin material, TPU material

3. The circuit design

Related to the circuit design of the equipment, its process includes: scheme design, schematic design (including component selection, the principle can be written software), PCB layout design, PCB component welding, circuit debugging, program software debugging, system comprehensive testing, complete design. This paper will describe the circuit design of the device according to the realization of different functions.

The hardware of the circuit system in this paper is divided into four circuit boards (as shown in Figure 5) : 1. Main control board + motor driver + other signal interfaces; 2, electric stimulation drive board, including 0 to 120V, the maximum 2mA drive board + control and signal interface; 3. Magnetic stimulation drive board +36V/30A sine inverter + signal interface + power interface (as shown in Figure 6); 4, power conversion board: AC 220V to DC 36V/30A 1500W ACDC converter + AC 220 to DC 15V 30W AC/DC converter. Among them, the power conversion board can be replaced by the power supply on the market, this paper chooses the MS-1500-36 model power supply of Shenzhen Mingwei Company.

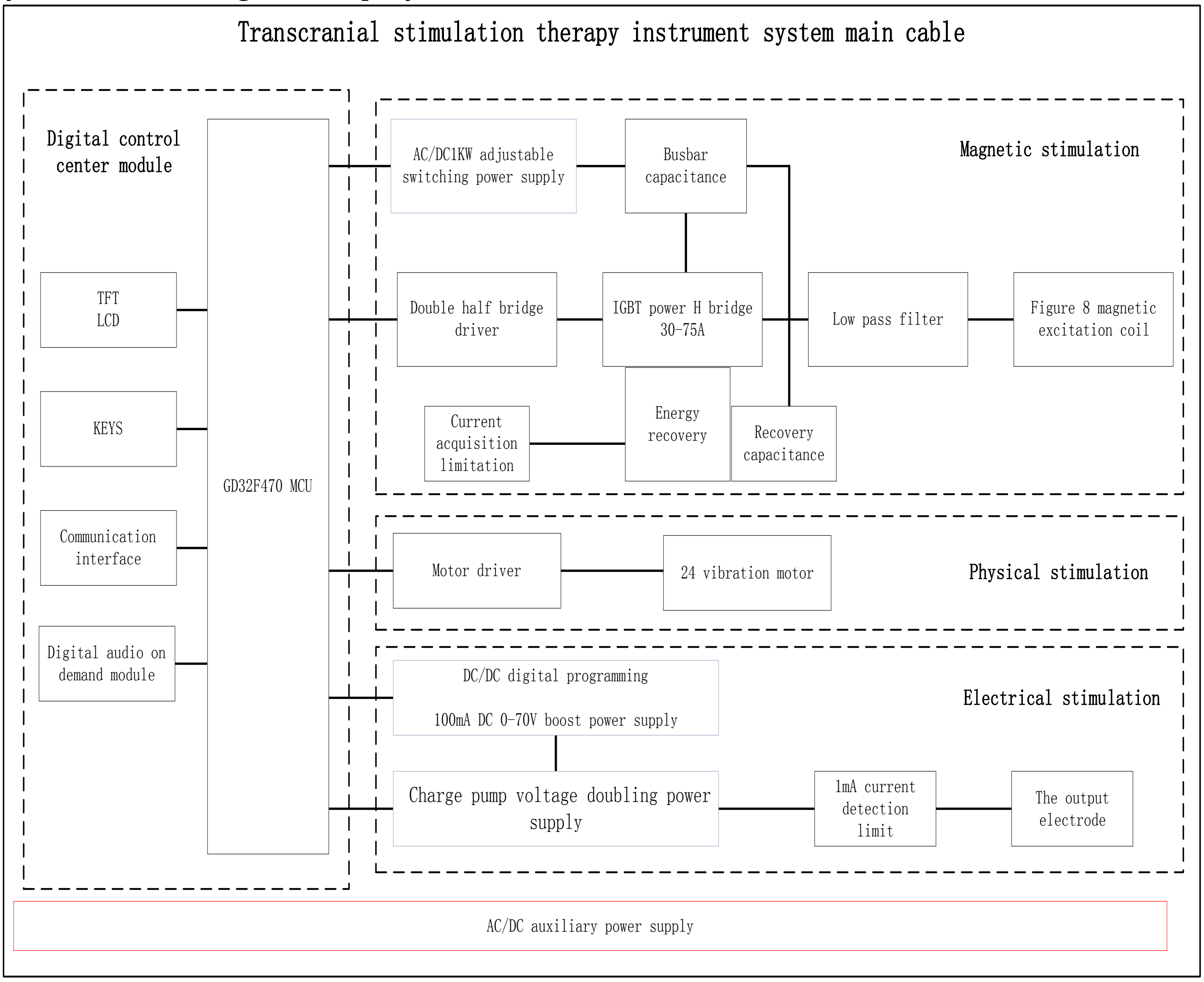

Figure 5. Overview of equipment circuit system

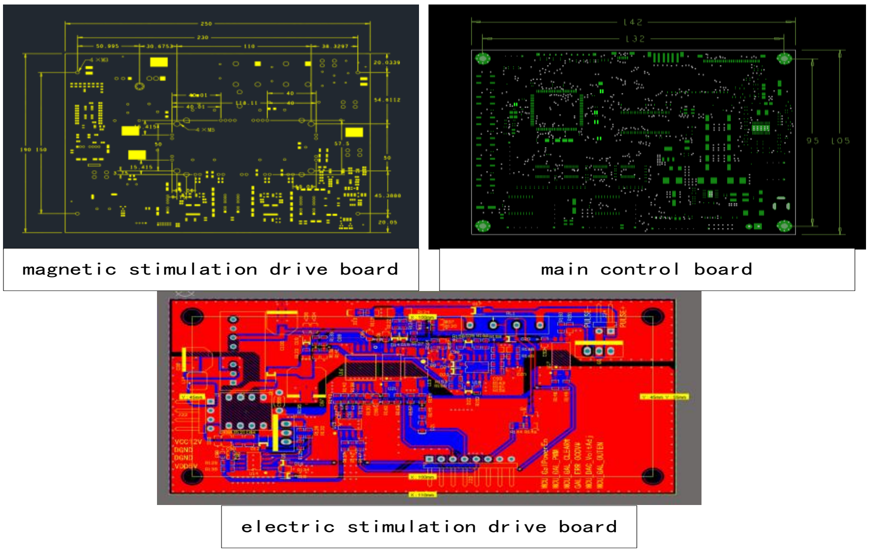

Figure 6. Design of magnetic stimulation drive board, main control board, electric stimulation drive board

Resources to be controlled by the software system: 1. TFT-LCD with TLI interface, 800X480, using SDRAM as video memory; 2. 2, 16 GPIO motor control interface, 5V power supply, single current is not more than 500mA; 3, electrical stimulation control interface, need resources, timer and PWM,DAC voltage regulation, boost system overcurrent and overcurrent detection, output voltage range 8-120V maximum current full voltage range is not more than 2.5mA, electrical excitation strength is adjustable; 4, magnetic stimulation, excitation voltage is expected to be 36V, current 35A, full bridge to achieve SPWM modulation output sine wave, automatic energy feedback, automatic overcurrent protection, timer 4 channel PWM; 5, configure the capacitive touch screen corresponding to the screen size, need to customize the driver based on I2C bus communication; 6, six system functions operate physical buttons, based on hardware GPIO mode, software can be achieved through IO interrupt mode. The GD32F470ZIT6 chip is used to achieve the above functions, as shown in Figure 7.

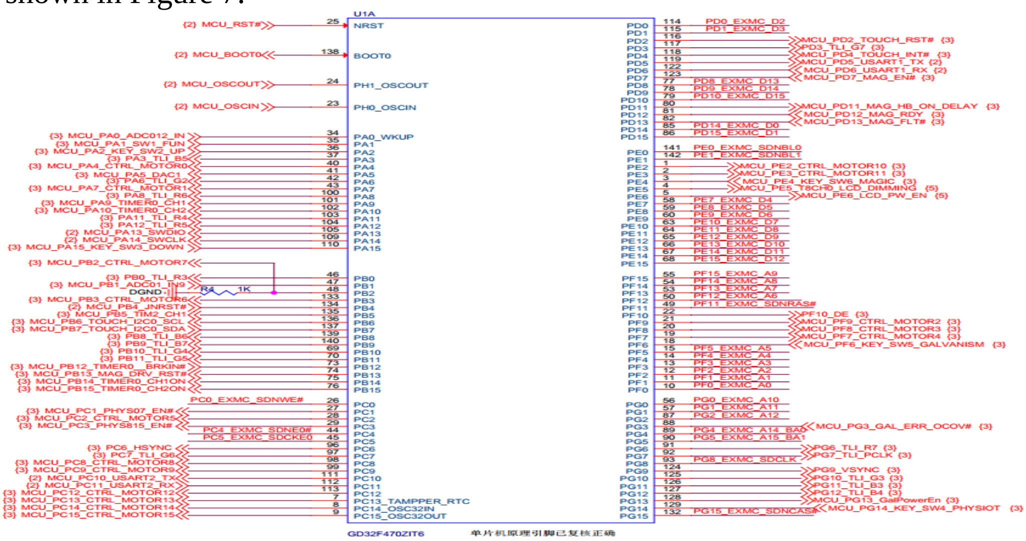

Figure 7. GD32F470ZIT6 chip 144 pin function distribution diagram

In order to realize the transcranial magnetic stimulation function, it is necessary to define the magnetic stimulation coil parameters, which will determine how the circuit implements the modulation and drive of the output. If the voltage is not high, the current is not large, it can be driven by modulation and amplification; If the voltage is high and the current is large, the appropriate device needs to be found, and the technical means of DC/AC inverter need to be used to achieve it.

Magnetic stimulation coil is divided into cored coil and non-cored coil, if the cored coil, the inductance is low, if the number of coils is less, the DC resistance will be reduced, the current rise time is short when the power supply is equivalent to a short circuit, the control system must turn off the output when the current rises to the maximum allowed, otherwise there is a risk of failure at the power supply end. With core coils, it is necessary to consider the iron core material. The saturation magnetic induction intensity of ferrite is about 500mT, and it is easy to reach saturation in the process of transcranial magnetic stimulation, resulting in a sharp decline in permeability. Therefore, ferrite is usually not selected as the coil core material. The saturation magnetic induction strength of pure iron or silicon steel sheet is about 1500mT, which is not easy to reach saturation state in the process of transcranial magnetic stimulation. Therefore, pure iron is chosen as the core material in this paper.

Magnetic stimulation coil selected copper enameled wire, for safety considerations, the maximum current per square millimeter of copper wire should not exceed 4A, because the maximum current through the coil can reach 35A, so the copper wire cross-sectional area should not be less than 8.75 square millimeters, otherwise there are serious security risks.

The magnetic stimulation hardware circuit board includes signal interface, 36V/50A full-bridge inverter, power filter, quasi-resonant energy feed circuit, over-current and over-current protection, etc. In addition, due to the energy loss of high-voltage and high-current drive, heat dissipation should also be considered. In this paper, aluminum heat sink is used to heat the magnetic stimulation hardware circuit board.

4. Summary and prospect

With the development of productivity and the improvement of people's living standards, Chinese residents pay more and more attention to their own health. Under this background, non-invasive therapeutic instruments represented by transcranial magnetic stimulation equipment are also developing rapidly. Focusing on the specific symptom of plateau insomnia, this paper proposed the development process of multi-mode head-worn TMS equipment with TMS as the main function, and provided certain experience guidance for the subsequent development of TMS equipment.

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