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Design of functional electrical stimulator for foot drop rehabilitation

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Abstract: This paper designed a functional electrical stimulator controlled by STM32F103 microprocessor for the rehabilitation of foot drop patients. The frequency, pulse width, period and other parameters of the electrical stimulator are set by the upper computer and transmitted to the remote controller. The remote controller then controls the lower computer to adjust the stimulus intensity through Bluetooth for electrical stimulation treatment. The electric stimulator outputs the stimulus current through the boost control circuit and the constant current output circuit. The results show that the functional electrical stimulator can adjust the therapeutic pulse in the range of 0-100mA current intensity, 17-40Hz frequency and 100-300μs pulse width. The design is easy to use, high degree of automation, easy to use in the home and hospital.

1. INTRODUCTION:

Functional electrical stimulation (FES) is a treatment commonly used to treat foot droop. Patients with foot droop have two lower limbs that hang naturally and are completely incapable of active dorsiflexion and roll-over. This therapy can make the disaffected nerve center efferent nerve excited again through safe and reliable electrical stimulation pulse when the patient cannot lift normally during the exercise process, so that the muscle function can be restored. Functional electrical stimulation belongs to the category of physical factor therapy in rehabilitation therapy. [1] A large number of studies have proved that it can also enhance the muscle strength of stroke patients, improve the muscle tone and the limb function of hemiplegia.

The stimulation pulse in the design of electrical stimulator is an important research focus of this design. Human skin impedance is about 1 k Ω, unidirectional current stimulation can cause charge accumulation causes tingling, damage to the electrode, and other issues. [2] In order to solve these problems, this paper proposes a kind of stimulus pulse with bipolar output ability. This pulse requires the BOOST circuit to ensure the stimulation ability and the constant current output to ensure the stability of the stimulus level.

This design uses STM32F103 chip as the control chip, which has the advantages of low cost and high efficiency. The BOOST circuit is adopted, and the constant current circuit outputs the stimulus pulse. The MPU6050 sensor detects the position and collects the Angle signal, which is connected to the remote control through the Bluetooth module. The hardware circuit of electrical stimulator and remote controller was designed, the hardware operating system was built, the software programming and debugging were realized, and human experiments were carried out.

2. WORKING PRINCIPLE OF FUNCTIONAL ELECTRICAL STIMULATOR

Through the study of biological cytology, it is found that there is an electric potential difference between inside and outside the cell membrane, and the electric potential outside the cell membrane is higher than

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that inside the cell membrane under normal conditions. All cells in the human body generally have the ability to cause excitement after being stimulated. Studies have found that neurons in the human body have low thresholds and are prone to firing when stimulated. [3] At rest, the neuron's potential difference is about -70 mV. After the use of a certain intensity current stimulate cell membranes, ion permeability will immediately change, the distribution of ions will also change, but as time goes by, ion will return to its original state, and once the cell membrane from the external stimulation, inside and outside of the cell membrane potential changes quickly, and be reflected and reduction, therefore produce an action potential, they will receive the stimulating signals sent to the corresponding target groups, eventually the body will be able to feel the stimulation, the muscle will produce contraction. For the patient with the paralysis of the organization such as foot ptosis, the nerve cells of the sick organization lost the ability to cause excitement, and the electrical stimulator is to stimulate through electric current, cause the potential difference of the cell inside and outside, produce nerve impulse, assist in completing muscle contraction. Figure 1 shows the mechanism of electrical stimulation.

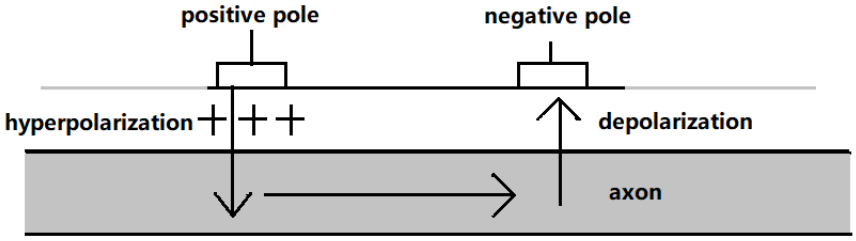

Figure 1 shows the mechanism of electrical stimulation

3. HARDWARE DESIGN OF FUNCTIONAL ELECTRICAL STIMULATOR

The main machine of the electric stimulator mainly includes a booster module, a stimulus constant voltage source, a pulse generating circuit and a serial communication module. Through two PWM output channels, one way controls the switch of the booster module, the other way controls the constant current output circuit. [4] This host is a wearable device. The whole device is powered by lithium battery. The lithium battery is charged by USB cable to ensure the normal operation of each module. The host communicates with the remote controller through Bluetooth module, and the remote controller and the computer obtain instructions from the upper computer through USB connection, including the sending and receiving of parameters such as stimulus mode, stimulus frequency, stimulus pulse width, rise time, fall time, duration and so on.A group of stimulus parameters are temporarily stored in the remote control to adjust the stimulus range of the host machine in real time. [5] The host of the electric stimulator is treated by contact discharge with the human body through two electrodes. An alarm is generated when the electrode patch comes off. The voltage booster module is to boost the voltage of the lithium battery, and generate the stimulus voltage of the constant voltage source corresponding to the specified current amplitude through the voltage control constant current source. The microcontroller controls the constant-current output module to generate bipolar stimulus pulse and output constant current, so as to realize the output of electric stimulus pulse whose stimulus intensity can be adjusted in real time. The system block diagram of the electrical stimulation output device that can be adjusted in real time is shown in Fig. 2.

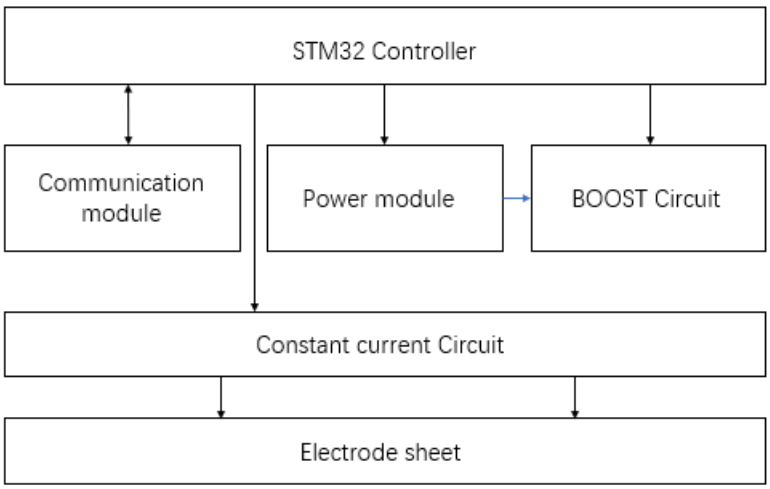

Figure 2 System block diagram

3.1. STM32 controller

The lower computer chooses STM32F103 as the main control chip, which adopts 32-bit ARM Cortex-M3 core chip. Compared with other chips, the chip has the advantages of real-time, digital signal processing, low voltage, low power consumption, high performance, high integration and easy development, etc. It is embedded in the embedded system to ensure the orderly progress of each function. For stimulation pulse generation, the PWM of STM32 controller is powerful.

3.2. Booster circuit:

Boost or Step-Up Converter is a common switched DC booster circuit, which controls the energy storage and release of the inductor through switching on and off of the switch tube, so that the output voltage is higher than the input voltage. Figure 3 below is the Boost booster circuit used in this design.TP1 is connected to the battery power supply. The switching power supply is controlled by Pulse Width Modulation (PWM) TP4. The BOOST circuit is mainly composed of inductor L2, switch Q5 and diode D12.

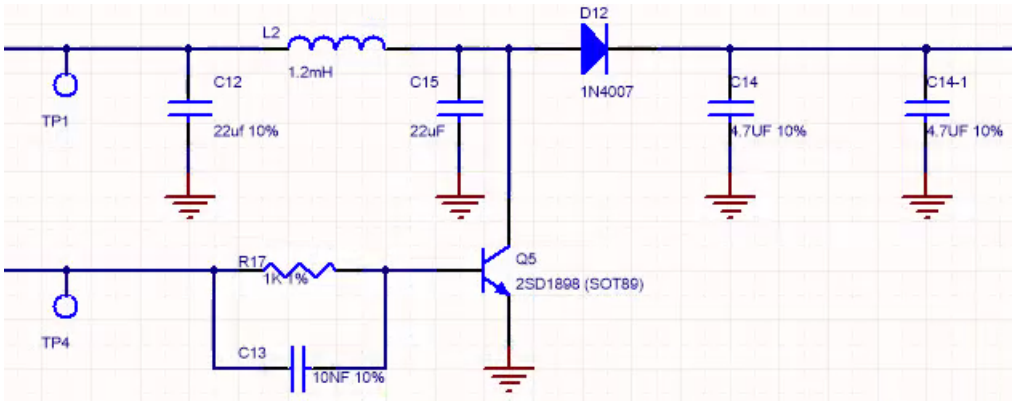

Figure 3 BOOST circuit

3.3. constant current circuit analysis

Constant current source is a wide spectrum, high precision AC steady current power supply, has the advantages of fast response speed, high accuracy of constant current, long-term stable work, suitable for loads of various properties, etc. In order to meet the constant current source module with zero output impedance, it is mainly composed of operational amplifier. The constant current source circuit is shown in Fig. 4.

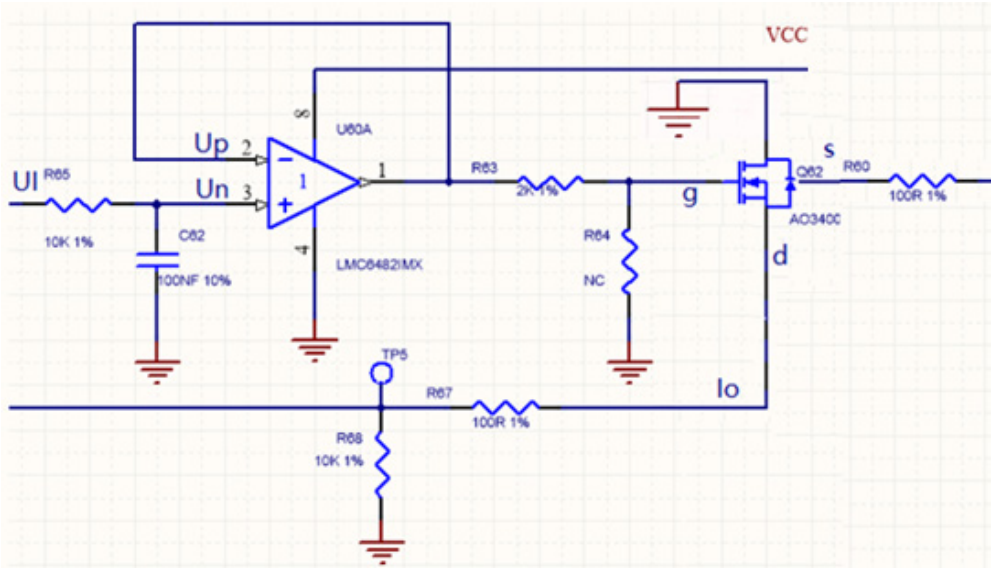

Figure 4 Constant current source circuit

The voltage controlled constant current source is an important part of the constant current circuit, its function is to use the voltage to control the change of current, because the output current size and precision of the requirements are relatively high, so it is particularly important to choose the voltage controlled constant current source circuit.The constant current source circuit is composed of operational amplifier, high power field effect tube (FET) Q62, load resistor R67, etc. The adjusting tube in the circuit adopts high power field effect tube AO3400. Using the field effect tube, it is easier to realize the voltage linear control of the current, which can not only meet the requirements of the maximum output current of 100mA, but also better realize the voltage approximately linear control of the current. Because the leakage current Id is approximate to the voltage Ugs controlled current when the field effector tube is operating in the saturated region. As long as Ugs doesn't change, ID doesn't change. The LMC6482IMX is used as the voltage follower

$$UI=Up=Un$$
$$Id=Is$$

so

$$Io=Is=Un/R60=UI/R60$$

It is because

$$Io=UI/R60$$

The circuit input voltage UI controls the current Io, that is, Io does not change with the change of R67, so as to achieve voltage control constant current.

4. SOFTWARE DESIGN

The lower computer software adopts Keil5 to write stimulus host and remote control programs respectively, which is implanted into the embedded system of RT-Thread China to realize man-machine interaction, remote control of host, functional electrical stimulation, parameter setting and acquisition, and other functions. Figure 5 is the flow chart of the electrical stimulator software.

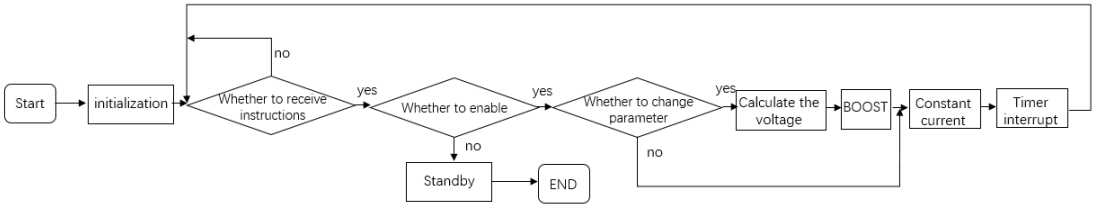

Figure 5 Software flow chart of electrical stimulator

4.1. Stimulus pulse parameter adjustment program

To change the frequency and duty cycle of the stimulation pulse, the parameter values in the PWM output need to be recalculation, because the selected STM32F103 set the main frequency as 72M, where ARR is the automatic reloading value of timer counter, PSC is the pre-frequency divider, and CCR is the value of the capture and comparison register.

$$\text{Frequency} = 72M/((ARR+1)*(PSC+1))(\text{Unit: Hz})$$

$$\text{Duty Ratio} = CCR/ARR\ (\text{Unit: \%})$$

Test using Tektronix TBS1102C oscilloscope with 100M broadband and 20K storage. Figure 6 shows the output pulses of 20% duty cycle and 10% duty cycle.

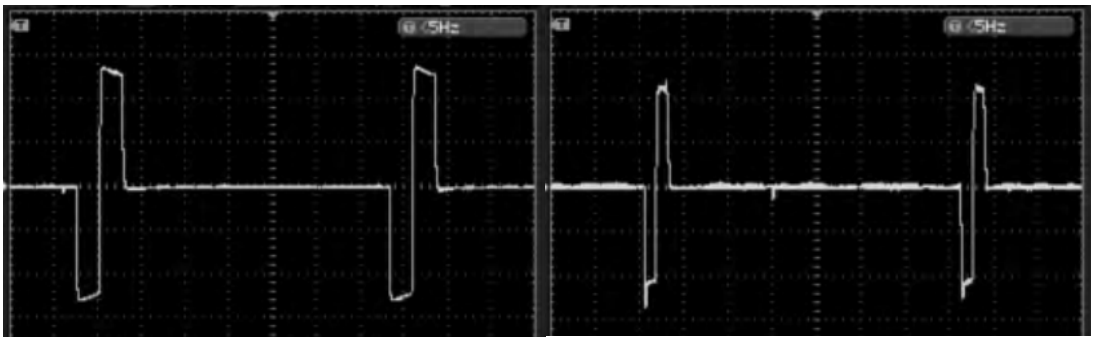

Figure 6 Output pulses of 20% duty cycle and 10% duty cycle

5. EXPERIMENTAL RESULTS

The upper computer is connected to the remote controller through the USB cable, and the remote controller is connected to the host computer of the stimulator through Bluetooth to send and receive each parameter of the host computer of the stimulator. Meanwhile, the wearing stimulator can also upload the real-time Angle of the patient's walking gait to the upper computer. The commonly used stimulus waveform of the functional electrical stimulator is a bipolar symmetrical wave, the stimulus frequency is 17-40Hz, and the pulse width is 100-300μs. [6] According to the patient's condition, the stimulus part and other factors are adjusted. The current amplitude can also be adjusted.

6. CONCLUSION

Aiming at the treatment of foot drop disease, this paper designs a functional electrical stimulator that can be adjusted in real time, and demonstrates the hardware system and software system for stimulating pulse generation. Finally, the experimental verification is carried out. Through the bipolar pulse, and realize the constant current output, prevent the patient's muscle fatigue and unstable stimulation problems caused by long-term treatment. The design is wearable and can be controlled by a remote control, which is convenient for patients. The results show that under the condition of stimulating different people and different parts, adjusting different current amplitude, frequency, pulse width and other parameters can achieve the purpose of rehabilitation.

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