DESIGN AND CONSTRUCTION OF AN ELECTRICAL NERVE STIMULATOR

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Abstract

In previous work, the effect of pulse configuration on the compound muscle action potentials (CMAPs) during magnetic stimulation was examined. It was concluded that an alternative approach, electrical stimulation, was required to re-evaluate and confirm the findings. Accordingly, a special electrical stimulator capable of producing stimuli which resemble those produced by a magnetic stimulator was designed and built. This paper presents general guidelines that cover hardware aspects and components required for designing and fabricating such a device.

Introduction

Transcranial magnetic stimulation (TMS) is a novel non-invasive technology that holds great promise of being an effective clinical tool. However, many of the neurophysiology activities evoked by this technique are not fully understood [1]. This includes: defining precisely the site of stimulation, determining the part of the pulse responsible for initiating the response, and quantifying the effect of different pulse types. With the aim of clarifying some of these issues, our group conducted a study in which magnetic stimulation was applied to ten healthy subjects [2]. The objectives of the study were to define the site of stimulation and to examine the effect of pulse configurations. The findings, specifically those relating to the stimulation site, showed wide variance in defining the position of the virtual cathode, dependence on the pulse type and current direction, and partial disagreement with the results obtained by Nilsson et al.[3]. Consequently, it was decided to re-evaluate the findings by repeating the experiment using electrical stimulation where the cathode site is well defined. Further, to ensure consistency in the protocols of both experiments, it was critical to use an electrical stimulator capable of producing waveforms comparable to that of a magnetic stimulator.

System software and hardware

Electrical stimulators are mainly used in electrodiagnostic examination. A typical electrical stimulator generates square mono-phasic current pulses with a duration ranging between 50 and 1000 Fsec, peak current up to 100 mA, and a repetition rate up to 100 Hz.

Some advanced systems provide two types of pulses (mono-phasic, bi-phasic) along with different options for interfacing and expansions. After examining and assessing some advanced commercial stimulators [4], it was concluded that these systems are costly and produce only square pulses with axis symmetric shapes. These waveforms are different from those produced by magnetic stimulators (damped sine wave).

Accordingly, it was decided to design and construct a new electrical stimulator that can produce the required waveforms. The block diagram in figure (1) shows the stimulator divided into two clusters: software and hardware. Figure (2) displays the front panel of the software section.
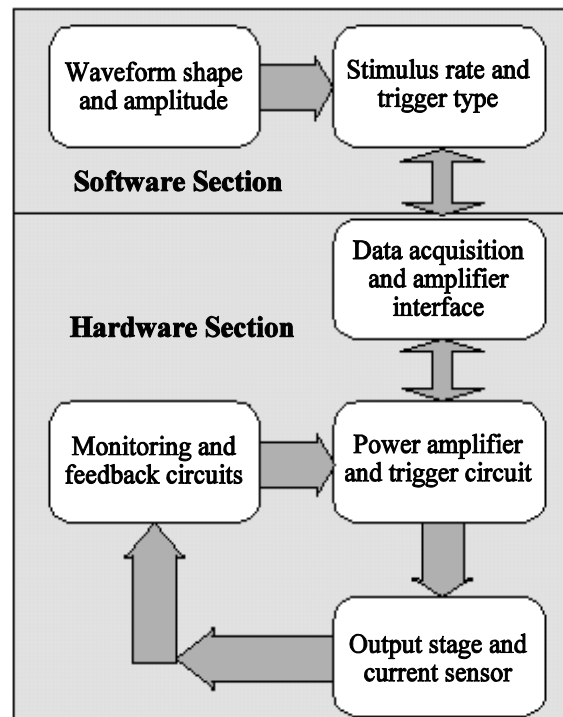

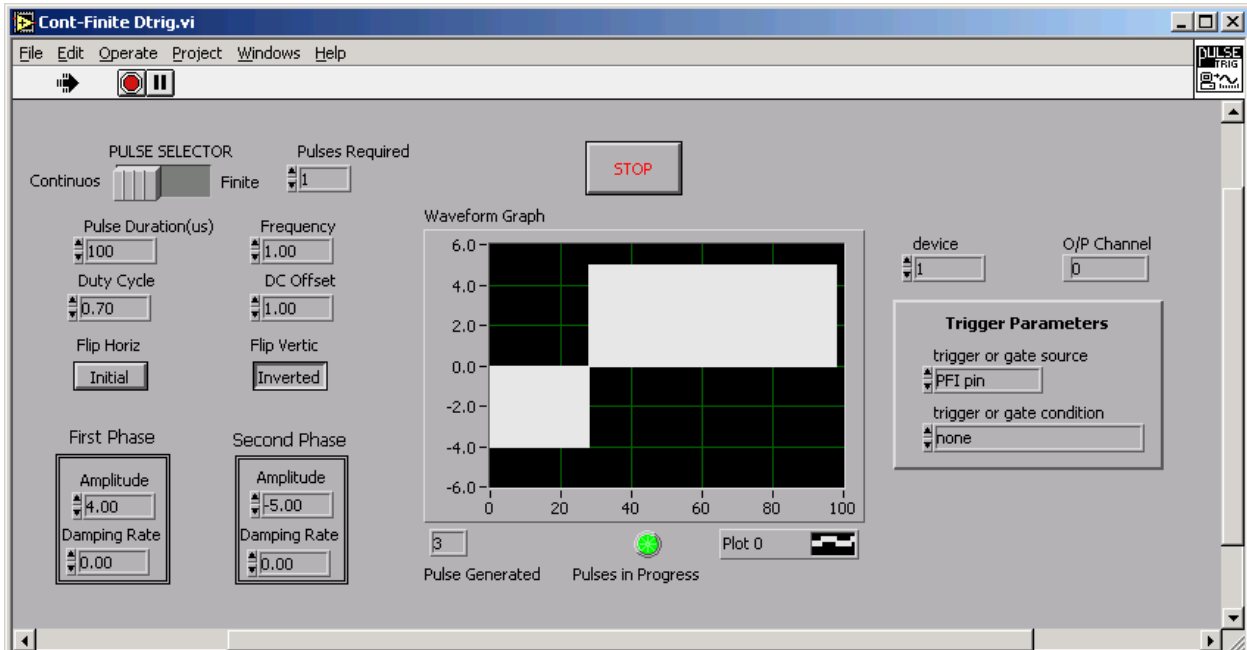Fig. 1: A block diagram of the electrical stimulator

Fig. 2: The front panel of the software.

As shown in figure (1), the two main clusters can be sub-divided into the following sections:

a) Pulse shape and amplitude: The parameters of the generated pulse are defined by this stage. These parameters, which can be independently applied for each pulse phase, may include: pulse amplitude, duration, rate of damping, type (mono-phasic vs bi-phasic), and polarity (hyper-polarization vs de-polarization). Depending on the pulse required, the resultant waveform shape may vary from a square pulse to a damped sine or cosine waveform.

b) Stimulation rate and trigger type: This stage controls the number of pulses, stimulation rate, and the type of trigger required to activate the stimulator. The software allows the user to choose either continuos or limited number of pulses. Further, the software allows the user to choose a stimulation rate that ranges from a single pulse to 100 Hz. Different trigger options (hardware vs software, internal vs external, rising-edge vs falling-edge, and with or without time delay) were included in this stage.

c) Data acquisition card and amplifier interface: The stimulus pulse is supplied to the hardware via a 12-bit data acquisition board (PCI-6024E-National Instruments).This board provides two TTL compatible trigger lines and is guaranteed for 200 kS/sec sampling rate. The output (analog) channel of this board was configured to operate within ±5 volt.

d) Power amplifier and trigger circuit: The amplifier used in this stage was an audio module (STK4040 - Sanyo Co.) with a 70 watt output power and an operating voltage of 35 volts [5]. In addition to meeting the system bandwidth and gain requirements, the module was cost effective and easy to embed in the circuit. A 50 kΩ potentiometer was connected to the amplifier input to control the input voltage and consequently the amplifier output. Further, two rectifiers (connected back to back) were added to the input stage to prevent any saturation.

The trigger circuit implemented for this device is a single pulse hardware-triggered. The trigger pulse is compatible to that of a TTL level and can be used to trigger the hardware and the data acquisition board.

e) Output stage and current sensor: The output stage consists of a step up transformer (1:20) with its secondary connected in series to a 10 kΩ multi-turn potentiometer and a 1 kΩ resistor. The transformer provides complete isolation for the subject while the 10 kΩ pot controls the output current precisely. The 1 kΩ resistor serves two purposes, first to monitor or sense the output current and second to prevent a short circuit across the amplifier in the event that the output leads are shorted by mistake. The peak current of this device was designed not to exceed 60 mA as this value is sufficient to fully stimulate the median nerve and higher values will cause discomfort to the subject [6]. Nevertheless, the output current can easily be increased up to 100 mA by adjusting the operating voltage of the power amplifier.

The output of this stage was connected to two electrodes mounted at the front panel of the device.

f) Monitoring stage and feedback circuit: This stage monitors and displays the input and output voltages using three bar graphs. Each bar graph consists of 20 steps and is linearly proportional to its monitored variable. The first

two bars are used to represent the input pulse (one per phase). The third bar, which is driven by a precision rectifier (National Semiconductor) [7], is an indicator of the output current.

The feedback section is implemented to ensure stimulus voltage compliance with that needed to produce the required current.

g) Power supply and protection stage: The power supply provides the following voltages: ± 35 volt, ± 12 volt, ± 5 volt. These voltages are regulated and protected through fuses. In addition, two sets of fuses, one external and the other internal, were added to the main input.
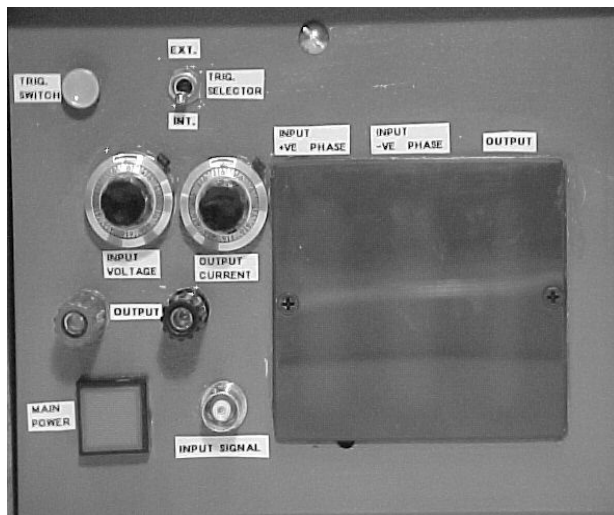
Figure (3) shows the front panel of our stimulator.

Fig. 3: The front panel of the electrical stimulator

Discussion

It has been shown that the current pulse generated by an electrical stimulator must be bounded by the time of nerve depolarization (0.1-0.5 msec for peripheral nerve) and the fundamental law of excitation embodied in the physiological strength-duration relationship (S-D curve [8]). Therefore, the pulse configuration represents a crucial variable in electrical stimulation as it defines the electrical field induced in the excitable tissues.

According to the criteria outlined above, an electrical stimulator was constructed with the objective of producing waveforms comparable to those of a magnetic stimulator. Maccabee et al. [9],used a similar pulse generator, however, it operated on low power (driven by a computer) and was only used for *in vitro* experiments.

The new device was tested successfully. The next step is to repeat the previous study [2] using this stimulator and compare the results of both experiments.

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