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A Low Cost Electrical Muscle Stimulation Device For Biomedical Applications

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Abstract— **In this work a low cost electrical muscle stimulator (EMS) is designed and realized. This instrument is dedicated to stimulate muscles and acquire the electromyography (EMG) response. Two electrical circuits are realized, the first based on a power stage delivering impulses for the electrical stimulation muscle, the second based on data acquisition system of the EMG signal to measure the response time between the excitation impulses. A graphical interface is developed to display information about the patient, the signal acquisition and the results of the diagnosis. Our application is focused to quantify the degree of muscular fatigue, for this, we chose one of the parameters that define a muscle shock which is the latency. The preliminary experiment is done on the biceps muscle, because the force developed by the motor unit is high.**

Keywords— **EMS, EMG, Stimulation, Muscular fatigue**

I. INTRODUCTION

The Electrical Muscle Stimulation (EMS) has been heavily explored in the last decades. It was demonstrated that we can get muscle contractions with electrical pulses generated by the human nerves allow him to control his motor actions. The signals from muscle contractions are biological representing the manifestation of neuromuscular electrical activity, this electrical event can provide important information on the state of a muscle in the body. The work presented in this paper is a part of research represented by the implementation of a device with an EMS and electromyography (EMG) in order to quantify the degree of fatigue. The EMS comprises different choices of parameters to use its in several areas: sports, therapeutic, medical, [1], [2], [3], [4]. The acquired signal from the stimulated muscles allows us to provide information that can be used by a doctor to provide diagnosis or the most appropriate response [5]. As an application, the quantification of the fatigue degree is experienced on a biceps muscle.

II. MATERIAL

The device has been conceived to deliver constant current stimulation impulses. It allows also acquiring EMG with the difference between two muscular EMG electrodes and a reference erasing with one electrode laid on a bony point. The EMG measures the electrical activity of a muscle when was relaxed or contracted. This activity generates a signal by the muscle fibers in same time of muscle force production; this signal can be measured by applying a conductive element [6]. The EMS, reproduces the process of voluntary muscle contraction via sending pulses, the intensity of these pulses released by device focuses at the electrodes and is delivered in small landfills in the body; witch allow to excite the muscle and promote contraction [7]. If we observe the EMG signal, the amplitude varies from 10µV to 3mV. However, for the frequency, we can see that the frequency band that is present in the signal obtained by the muscles and nerves is wide about 3KHz. An explanation that can be given is that the frequency changes a lot depending on the muscle that we want study. The bidirectional current used in stimulation is depolarized, the negative pole and the positive pole is reversed at each pulse, symmetric or asymmetric with zero average, it does not present electrolytic property, so does not produce chemical burn, it can be applied to patient carrying metal parts, which provide an expanding field application [8]. The duration of the electrical stimulus is another determining factor in relation to the effectiveness of stimulation, for very short durations of stimulus that are less than 0.1ms, the current required increases strongly. Stimulus duration between 0.2ms and 1ms is usually chosen; therefore, the selection of the pulse width depends on the desired penetration depth. Most of the time, it is desirable to work with a relax time longer as working time if the chosen frequency is important and create a tetanic contraction [9]. To achieve a maximum potential strength, we must stimulate muscle repeatedly to trigger a tetanic contraction. The frequency of stimulation needed to achieve this will be somewhat different [10].

A. *EMS Systems*

The principle of EMS consist to send to the muscle or nerve current with a specific form, the bidirectional current is the most used and most fit, the flowing block diagram (Fig.1) gives us an overview of the electrical stimulator operations. We chose the 18F2550 microcontroller equipped with an HID protocol and an enough storage space for our device, it is the processing and control unit. One of its functions is to generate two shifted pulses with a frequency and pulse width selected using two selectors [11]. In order to widen the use of our muscle stimulator we integrated a several frequencies that exist in the ranges of frequency selection. Same for a pulse width, we put the most used in electrical stimulation for use throughout the body. Once the two pulses was generated, both MOSFETs will the saturated one after another, knowing that the MOSFETs are high-speed switches, it's choice turn around switching time and load current. The MOSFET used

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have a relatively fast switching time 60ns, which is amply sufficient, because the minimum pulse width is 80µs. The drains of the MOSFETs are connected to a central transformer having a 2x12V used as elevator, the output of the transformer produce a biphasic waveform flowing by a power stage [12]. The output of the transformer is connected to a differential stage limiting the output current with a voltage regulation. The two transistors used works with high voltages accepting a voltage of 300V between the emitter and the collector, the zener diode clip the signal at a voltage of 5.1V, a diode placed directly imposes a positive voltage to the transistor NPN type and the reverse diode requires a negative voltage to the complement thereof. For current limitation, we used a potentiometer connected to the output. Fig. 2 shows the electrical EMS circuit.

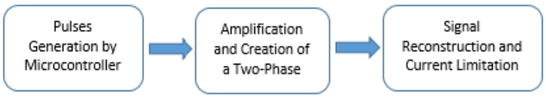

Fig.1 EMS diagram block

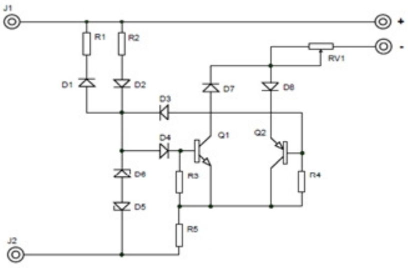

Fig. 2 Electrical EMS circuit

B. EMG hardware design

The EMG signal is picked-up on the skin surface with three gelled Ag/AgCl commercial electrodes set configuration shown in Fig.3. The input signal is preamplifier by an instrumentation amplifier AD622 from Analog Devices with a gain up to 1000. After amplification, the signal is filtered with an analog band-pass filter. The filter stage contains a 2nd order Butterworth high-pass filter with cut-off frequency of 0.05Hz to remove the DC artifact and a 4th order Butterworth low-pass filter with cut-off frequency of 500Hz. The filters have unity gain and are built around the operational amplifier OP07. The analog circuit (instrumentation amplifier and analog filter) were enclosed in a metallic box to ensure more interference rejection. The metallic box was connected to the analog ground as additional noise reduction technique.

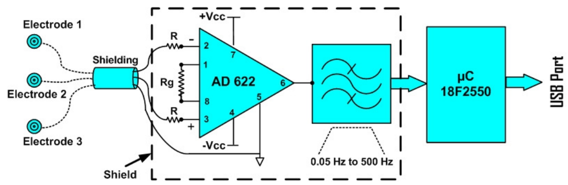

Fig. 3 EMG conditioning signal

The preamplifier stage is the most critical module in the design of the measurement signal chain. Its main goal is to eliminate the selective amplification and strongly attenuates any signals contains nose. Secondly, it amplifies the voltage between two measure electrodes while rejecting the common mode signal. According to the compromise between performance and cost, our choice fell on the AD622. The role of the latter is simply to amplify the potential difference between two electrodes relative to a third. In addition, we inserted a negative feedback circuit additional to a preamplifier stage, which aim to reverse the common mode interference caused by the coupling electrodes between the patient and the power (Fig.4).

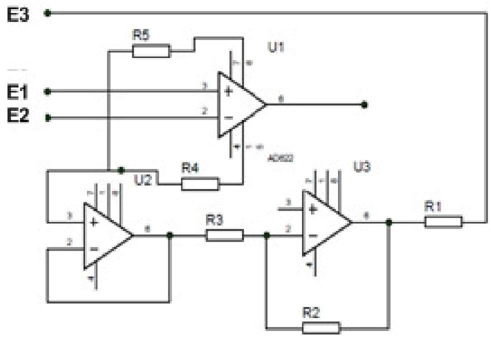

Fig. 4 Preamplifier and a negative feedback circuit

To make the device more secure for the patient, an isolation circuit was proposed which provide good isolation between the electrodes and the circuit working with analog signals. Our application will be limited in frequency domain. The actives filters are chosen in our application seeing their advantages like the ratio gain frequency and ease of choosing a given frequency. There are several types of active filter each having specific characteristics. Butterworth filters are the only linear filters whose general form is similar for all orders. To minimize possible interference, we had to choose a filter order as large as possible. The frequency domain in our application contain only low frequencies between 0,5 Hz and 500 Hz, the filter design will contain a high pass filter cascaded with another low pass.

In our case, we chose to perform high and low Butterworth filter with two 4th order cutoff frequencies. It was observed at the filter output a small signal attenuation requiring amplification for a best treatment, why we chose a non-inverting stage with a gain equal to 8. The reason that we shifted the signal from the amplifier stage is that the microcontroller accepts only positive voltages to make the A/D conversion. After testing, we have seen that the range of the signal swage from -2V to +2V, for this we set up the non-inverting output of the adder amplifier with a voltage of 2V at the entrance, Fig.5 shows the electrical amplifier circuit and Fig.6 shows the realization devices. The last part is dedicated to the design and implementation of a software system, devoted to store all information related to the patient in database and the signals acquired during clinical test. At the

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end, a calculation of response time will be performed to quantify the level of fatigue that will be our main parameter.

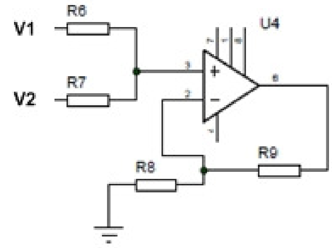

Fig. 5 Amplification circuit

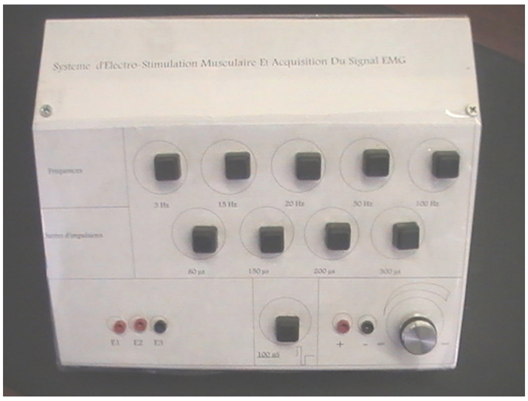

Fig. 6 EMS and EMG Realization devices

III. Experiments and Results

Before proceeding to the level of fatigue calculation, we tested each stage separately in order to ensure the good functioning of our system. For EMS tests, we used all combinations of frequencies and pulse width possible. And after viewing on digital oscilloscope, it was observed that more than the pulse width is small more, we will have a signal attenuation output due to the switching time of the MOSFETs. As example we have chosen pulse at a frequency of 50Hz with a pulse width equal to 0.3ms like is illustrated in Fig.7. Unlike the EMS, the EMG signal will be viewed by our performed interface; we make some tests on different muscles and nerves to confirm a good condition operation. Our results are illustrated in the Fig.8.

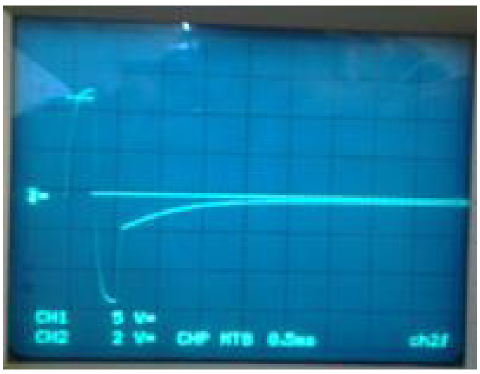

Fig. 7 EMS impulse signal

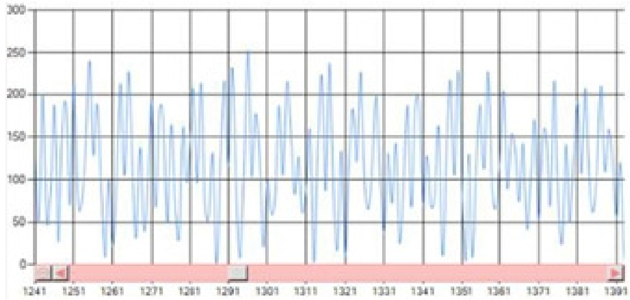

Fig. 8 Result of acquired EMG signal

For the validation of these tests, we took on patient report that has already made an experiment on the same arm at the nervous system functional exploration center by a neurophysiology specialist. The following Fig.9 shows us the signal of the voluntary activity of the muscle acquired by a clinical EMG device.

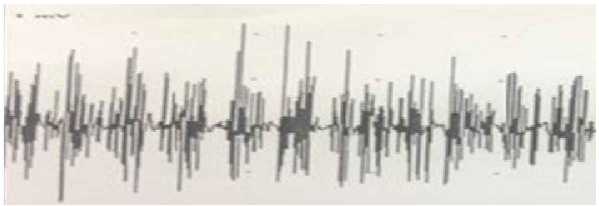

Fig. 9 Signal acquired by a clinical EMG device

Our application focuses on quantifying the degree of fatigue, and for this, we chose one of the parameters that define a muscle shock which is the latency, is determined by the time between the potential action and the beginning of muscle contraction. The experiment is done on the biceps muscle, we chose the biceps muscle because it has the type II and the type I fibers in same place, corresponding that the fatigue is low; however, the force developed by the motor unit is high.

The idea is to send an electrical pulse of 0.1ms with a push button, every press induce an impulse. When the muscle is stimulated, microcontroller timer starts count. The start of muscle contraction switches the comparator to a high state, and then trigger an interrupt, the role of the latter is to stop the timer count and read it value, this value defined the latency time. Knowing the value of the latency calculated by the microcontroller, it could be concluded if the muscle is tired or not referring to 10ms isotonic contraction time.

As we did not want to limit the use of EMS, we added several frequencies and several pulses widths to benefit several programs. The different programs presented by our EMS are three:

TENS: (transcutaneous electrical nerve stimulation): the intensity should be controlled between the perception threshold and discomfort threshold. The maximum limit is reached when the muscles surrounding the treated area begins to contract.

MAINTENANCE: dedicated to high-level athlete to keep and maintain a specific shape. It is designed with very short pulse and continuous mode with frequencies between 3 and 20 Hz.

CELLULITE: used for medical end to regain the muscle tone and the operation of some muscle.

IV. Conclusions

An easy and a low cost Electrical Muscle Stimulation (EMS) device have been realized, where preliminary results have shown the feasibility of such system. Due to the system developed and the tests performed, we were able to quantify the degree of fatigue through stimulation of a muscle or a nerve by collecting the EMG signal from the stimulation. Despite the results obtained, we envisage add like perspectives some improvements to the system. These improvements were quoted above: The integration of several programs such as automatic stimulation; the integration of multiple waveforms output, not just the two-phase form; display current stimulation and the computation of other parameters and not be limited only on latency time.

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