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ANALYSIS AND ENHANCEMENT IN THE PERFORMANCE OF ELECTRICAL MUSCLE STIMULATOR

Mangala B. Satardekar*(ME Student), Deepak V. Bhoir (H.O.D. & Guide)
* Electronics Department, Fr. C. Rodrigues College of Engineering, India

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ABSTRACT
The nature of variety of classical biomedical applications covering basic electrophysiology to cardiovascular hemodynamics is nowadays PC-based and being automated using software tools. Muscle Stimulator is used by physiotherapist to give physiotherapeutic treatment to the patients who have muscle related problems. A patient is subjected to electrical pulses using electrodes and it heals the patient. These signals are produced by implementing a Virtual Instrument code using software tools. This system is more accurate, compact, more flexible and self diagnostic. This is implemented and GUI is developed for the simulation of different current waveforms such as Galvanic, Interrupted Galvanic, Faradic and Surged Faradic which are generated in this work. It has flexibility to adjust its amplitude, frequency and duty cycle values. This will have same functionality as of Electrical Muscle Stimulator like waveform generation, varying parameters of current waveform (voltage, frequency and duty cycle), waveform display, selection of required signal as per patient etc. Finally the system itself can behave/operate as the central controlling unit.
KEYWORDS: Electrotherapy, Muscle Stimulator, Virtual Instruments (VIs).

INTRODUCTION
Electrotherapy [1], employing low volt, low frequency impulse currents, has become an accepted practice in the physiotherapy departments. The effects of low volt currents help in management of diseases related to nerve and muscles. e.g. Treatment of paralysis with totally or partially degenerated muscles, for the treatment of pain, muscular spasm, peripheral circulatory disturbances etc.
Electrical Muscle Stimulator [1], is a physiotherapy device which is used for pain relief, treatment of paralysis, muscle re-education as well as for activation of muscles. Usually, two electrodes are connected from the machine to the patient’s skin. The electrodes are often placed on the affected area of pain or at a pressure point, creating closed circuit of electrical impulse that travels along nerve fibers. In general physiology nerves carry messages from the brain to the muscles. They also carry messages from sensors back to the brain. They are the 'wires' of the body. Nerves are like an elongated bag of salty water. The outside of the nerve is positively charged. In other words it is polarized. That charge is lost when the top end of a nerve cell is stimulated. This is called depolarization. The wave of depolarization runs down the cell from the brain to the muscle. The nerve swells out near the muscle at the 'neuromuscular junction'. The nerves cell releases a special chemical called Acetylcholine into the gap between the nerve and the muscle. Muscles have a polarized membrane surrounding them that is very similar to nerves. There are special receptors built into this membrane. When Acetyl-chorine attaches to a receptor the membrane is depolarized. The wave of depolarization runs over the muscle fiber and causes it to contract.
Stimulation of nerve impulse can be initiated by an electrical stimulus. To achieve this, varying current of adequate intensity must be applied. The plasma membrane of the nerve fiber forms a resistance which lies in series with the order tissues, so a potential difference is set up across it as the current flows. The surface of the membrane nearer to cathode becomes negative in relation to other surface. On the side of the nerve nearer to anode this increases the resting potential difference across the membrane, but on the side of the nerve nearer to cathode, the additional charges are of opposite polarity to those present on the resting membrane and so reduces the potential difference across it. If the potential difference falls below the level at which the membrane becomes permeable to sodium ions, these ions begin to enter the axon and initiate series of events so that a nerve impulse is initiated. A nerve stimulator supplies electrons to depolarize a nerve. The number of electrons supplied per

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stimulus equals the current. To make sure that the nerve is completely depolarized we keep winding up the stimulating current until the muscular response does not increase any more, and then we add another 10%. This is called the supra-maximal stimulus. At this point we assume that the nerve supplying the muscle is completely depolarized. As a result the muscle must be maximally stimulated by the nerve. The muscle contraction that results must also be maximal. The muscle response to the stimulus is called a twitch. The amount or strength of movement is called the twitch height. To allow comparison of twitches it is essential that this current remains constant to ensure the nerve is always completely depolarized. Fig.1.1 shows the generalized block diagram for stimulator.

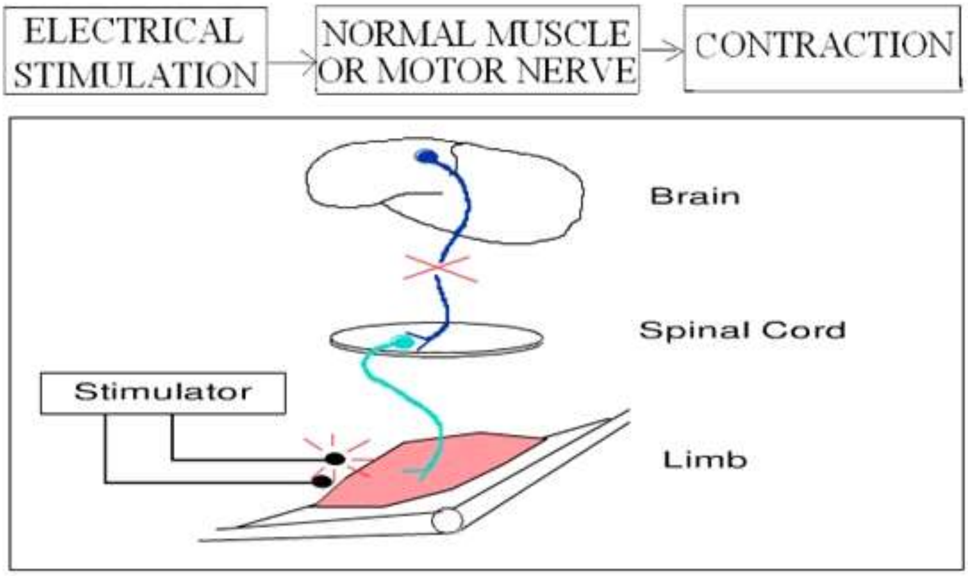

Fig. 1 General Principle of Stimulator

The primary uses of this treatment are pain relief, muscle re-education and for training a new muscle.

Types of current waveforms : The most commonly used pulse waveforms in muscle rehabilitation are (1) Galvanic Current (2) Interrupted Galvanic Current (3) Faradic Current (4) Surged Faradic Current.

1. Galvanic Current

Fig. shows a galvanic current. In this treatment method the duration of current flow is long and continuous. Galvanic current creates an electric field over the treated area that theoretically, changes blood flow.

Fig. 2 Galvanic current waveform

When steady flow of direct current is passed through a tissue, its effect is primarily chemical. It causes the movement of ions and their collection at the skin areas lying immediately beneath the electrodes. Direct Galvanic current is mainly used for iontophoresis/ Ionization i.e. transference of ions of drugs into the tissues through the skin by electrolytic means for pain relief, for stimulation of weak muscles, for preliminary treatment of atonic paralysis and disturbance in the blood flow. In general the intensity of current passed through any part of the body does not exceed 0.3 to 0.5 mA/cm2 of electrode surface. The duration of treatment is 10-20 minutes.

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2. Interrupted Galvanic Current

In an Interrupted Galvanic current, pulses are series of ongoing square pulses. The duration and frequency of impulses can be adjusted; duration of 100 ms is being commonly used. It is often an advantage to increase this to 300 or 600ms. Current pulses of about 100 ms duration, requires a frequency of about 30 per minute. The interval between the impulses should never be of shorter duration than the impulses themselves and is usually appreciably longer. The rise and fall of intensity may be sudden (square impulses) or gradual (trapezoidal, triangular and saw-tooth impulses). Fig. shows the unidirectional, interrupted galvanic pulses.

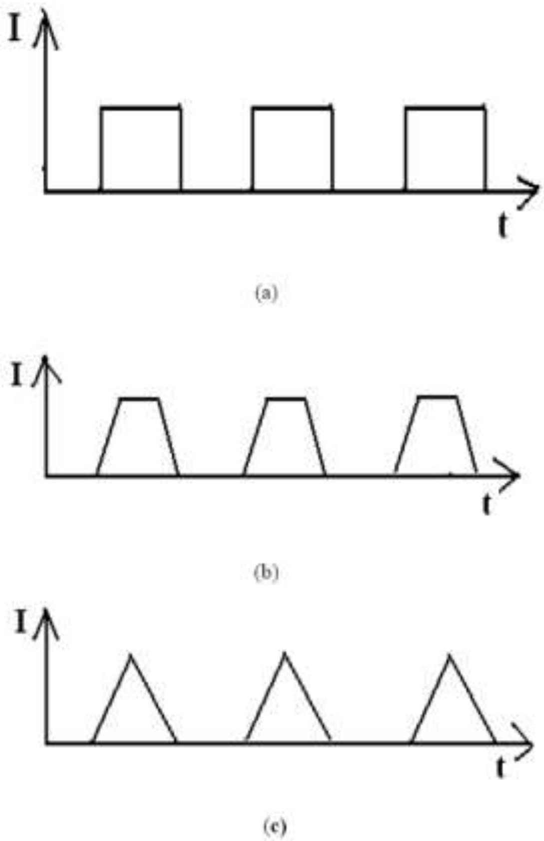

Fig. 3 (a) Square interrupted Galvanic Current waveform

(b) Trapezoidal interrupted Galvanic Current waveform

(c) Triangular interrupted Galvanic Current waveform

3. Faradic Current

Faradic current is a sequence of pulses with defined shape and current intensity, as shown in fig. The pulse duration is of 0.1-1 ms and frequency of 50-100 Hz. During such a waveform, the rise rate is rapid but not instantaneous, falling back rapidly to zero immediately after reaching the maximum i.e. spike. Faradic current acts upon muscle tissue and upon the motor nerves to produce muscle contraction. There is no ion transfer and consequently, no chemical effect. This may be used for the treatment of muscle weakness after lengthy immobilization and of disuse atrophy.

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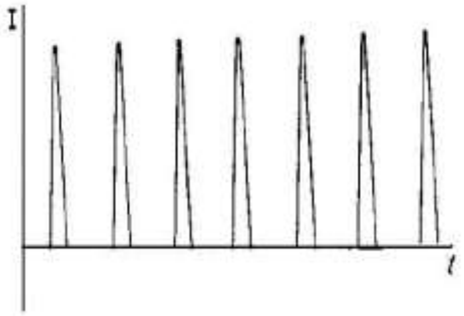

Fig. 4 Faradic Current Waveform

4. Surged Faradic Current

If the peak current intensity applied to the patient increases and decreases rhythmically, and the rate of increase and decrease of the peak amplitude is slow, the resulting shape of the current waveform is called a surging current. It is possible to produce surges of various durations, frequencies and waveforms. The main field of application of the Faradic surge current is in the treatment of functional paralysis. Surges can be adjusted from 2 to 5-second surge, continuously or by regularly selecting frequencies from 6 to 30 surges / minute. Rest period (pause duration) should be at least 2 to 3 times as long as that of the pulse to give the muscle the sufficient time to recover (regain its normal state). The ratio of interval to the duration of the surging is also adjustable so that graded exercise may be administered. This type of current is usually required for the treatment of spasm and pain. Fig. shows the Surged Faradic Current pulses.

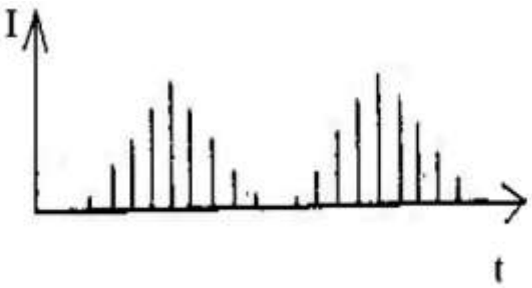

Fig. 5 Surged Faradic Current Waveform

LabVIEW as a Tool

The paper by Olansen et al. [2] has described implementation of Stimulator using LabVIEW tools. LabVIEW is a graphical programming language that uses icons instead of lines of text to create applications [3, 4]. In contrast to text-based programming languages, where instructions determine program execution, LabVIEW uses dataflow programming, where the flow of data determines execution. LabVIEW programs are called virtual instruments, or VIs, because their appearance and operation imitate physical instruments, such as oscilloscopes, multimeters etc. A VI contains the following three components:
Front panel—Serves as the user interface.
Block diagram—Contains the graphical source code that defines the functionality of the VI.
Icon and connector panel —Identifies the VI so that it can use the VI in another VI. A VI within another VI is called a subVI. A subVI corresponds to a subroutine in text-based programming languages.
Thus computer/system is made the uniform platform for any biomedical application. Using LabVIEW software tools, fundamental concepts of biomedical experimentation, from the instrumentation and data acquisition requirements to subsequent data analysis techniques can be implemented. Hence the stimulating signals in various modes required in Electrical Muscle Stimulator can be generated by implementing VI codes in computer/system. The results obtained for these modes are analyzed. Performance of EMS is compared and enhancement is observed for different waveforms.

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IMPLEMENTATION

First VI for each mode i.e. Galvanic, Interrupted Galvanic, Faradic and Surged Faradic waveforms have been generated individually by implementing a Virtual Instrument code using LabVIEW tools.

Step I : Galvanic Waveform : In Galvanic current treatment method the duration of current flow is long and continuous. The Simulate Signal Express VI simulates a signal based on the specified configuration. Different Galvanic current waveforms are obtained by keeping Signal Type = DC and Offset = variable in Configure Simulate Signal dialog box of Galvanic Signal Waveform.VI. Simulate Signal Express VI receives input from the controls and passes its result to the Graph.

Step II : Interrupted Galvanic waveform - In Interrupted Galvanic current treatment method the frequency and duty cycle of impulses can be adjusted. The interval between the impulses should never be of shorter duration than the impulses themselves and should be appreciably longer. Also, the rise and fall of intensity may be sudden (square impulses) or gradual (trapezoidal). Hence Interrupted Galvanic waveforms are obtained by varying frequency and duty cycle of Square wave by keeping Signal Type = Square, Amplitude = 0.5, Offset = 0, Phase (degree) = 0 in Configure Simulate Signal dialog box of Interrupted Galvanic Signal Waveform.VI. It is observed that proper Interrupted Galvanic waveforms are obtained for Frequency Range = 10 Hz to 60 Hz and Duty cycle = 20% to 40%

Step III : Faradic waveform - For the treatment of muscle weakness after lengthy immobilization and of tissue atrophy, Faradic Current waveform is used. It is a sequence of pulses with defined shape and current intensity. The pulse duration and frequency of Faradic waveform are fixed. Pulse duration is 0.1-1 ms and frequency is 50-100 Hz. Hence Faradic current waveform is generated for Frequency = 50 Hz and Pulse duration = 1 ms taking Signal type = Square, Frequency = 50 Hz, Phase (deg) = 0, Amplitude = 0.5, Offset = 0.5, Duty cycle (%) = 10, Samples per second (Hz) = 1000, No. of samples = 100 in Configure Simulate Signal dialog box of Faradic Signal Waveform.VI.

Step IV: Surged Faradic waveform - Here peak current intensity applied to the patient increases and decreases rhythmically and rate of increase and decrease of the peak amplitude is slow. The resulting shape of current waveform is called a surging current. To get Surged Faradic current waveform, in Surged Faradic Signal Waveform.VI, first triangular waveform is generated taking Signal type = Triangle, Frequency = 100 Hz, Phase (deg) = 0, Amplitude = 1, Offset = 1, Samples per second (Hz) = 1000, No. of samples = 100 in Configure Simulate Signal dialog box of Simulate Signal Express VI for Faradic Signal Waveform.VI. This triangular waveform is then multiplied with square pulse waveform of Simulate Signal2 Express VI so as to give Surged faradic waveform by selecting Signal type = Square, Frequency = 100 Hz, Phase (deg) = 0, Amplitude = 1, Offset = 1, Duty cycle = 50%, Samples per second (Hz) = 1000, No. of samples = 100 in Configure Simulate Signal2 dialog box of Simulate Signal2 Express VI for Faradic Signal Waveform.VI. It is observed that surges of various durations, frequencies and waveforms are possible to produce by varying frequency and duty cycle. Better Surged Faradic current Waveforms are obtained for Frequency range of 1 to 20 Hz for different duty cycles.

Step V : Then all sub-VIs are integrated in one VI. For selection of a particular waveform Select Signal Express VI is implemented. The subVI controls and indicators receive data from and return data to the block diagram of the calling VI.

This Electrical Muscle Stimulator using LabVIEW tools is tested for each type of signal by selecting it. Very high accuracy in waveform generation is achieved and there are minimalistic errors.

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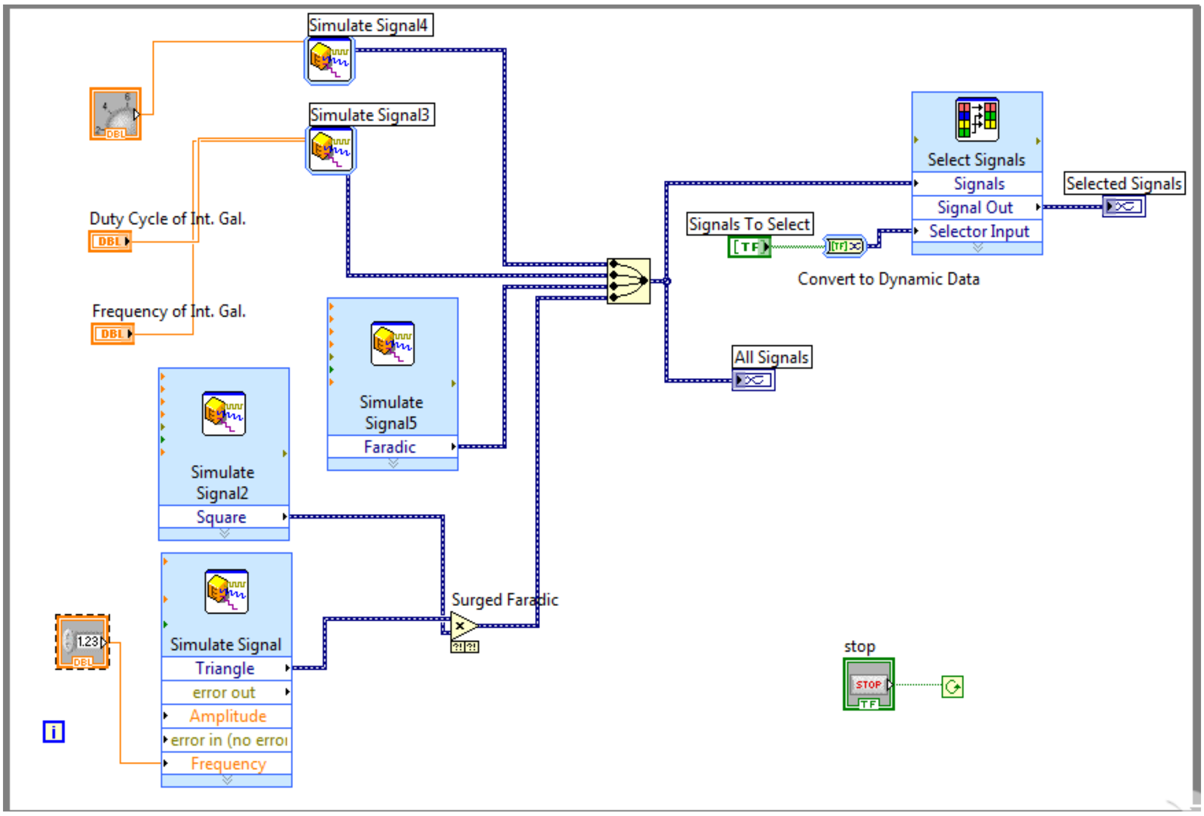

Fig. 6 Block diagram of Integration of all Modes/ SubVIs

RESULTS AND ANALYSIS

Highly accurate waveforms for Galvanic current and Faradic current are generated. Very high accuracy in Interrupted Galvanic current waveforms generation is achieved for frequency range 10 Hz to 60 Hz and duty cycle 20% to 40%. Very high accuracy in Faradic current waveform generation is achieved for frequency 50 Hz and Pulse duration 1 ms. In case of Surged Faradic current, highly accurate waveforms are generated for frequency range 1 to 20 Hz for various duty cycles. Finally the system itself can operate as the central controlling unit.

CONCLUSION AND FUTURE WORK

Electrical Muscle Stimulator uses electrical impulses to stimulate the nerve endings at or near the site of affected area and replacing it with a tingling or massage like sensation. It stimulates nerves, muscles and cells via surface skin by low electricity to make the brain produce endorphin naturally and then to reach the goal of relieving syndromes and stopping pain. There is at present abundant evidence that Electrical Muscle Stimulator provides a highly efficient tool for the activation of nerve-muscle without any side effects.

It is observed that Galvanic, Interrupted Galvanic, Faradic and Surged Faradic waveforms can be generated using LabVIEW tools and their frequency and duty cycle can be varied. Hence laptop can be used by physiotherapist as Electrical Muscle Stimulator to give physiotherapeutic treatment to the patients who have muscle related problems. It has flexibility to adjust amplitude, frequency and duty cycle values of different waveforms. This will have same functionality as of Electrical Muscle Stimulator instrument. Frequency range will be 50-100 Hz and duty cycle can be adjusted. Muscle Stimulator being made portable, we could install them in Ambulances. So many remote programs can be arranged by the government and NGOs.

The future work for this project is to derive Strength/duration relationship. It is concerned with the threshold relationship for a nerve trunk, i.e. the excitability properties of the nerve. Square-pulse current stimuli of variable amplitude (strength) and duration will be considered. Further several specific combinations of strength and duration will be carried out. It can result in the production of a conducted action potential. The strength/ duration curve represents a locus of critical points, which are values of strength and duration that result in the generation of an action potential. This curve separates the passive, sub-threshold, non-conducting state from the active conducting state. Muscle Stimulator can also be implemented along with EMG to observe behavior of the nerves and muscles.

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