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Development of four channel programmable FES system using multi-tap transformers

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Spinal cord injuries are predominantly prevalent among younger individuals (> 55% in 16-30 age group). Functional electrical stimulation (FES) is electrical stimulation of muscle deprived of nerves control, with a view of providing muscular contraction and providing a functionally useful movement. The paper reports on the development of a FES system using multi-tap transformers, and also usefulness of the system on a complete paraplegic patient with injury level T-4 to T-12.

Keywords: Functional electrical stimulation, Multi-tap transformers, Spinal cord injuries

Introduction

The number of spinal cord injury (SCI) patients is on the increasing trend because of war, neurological diseases, and sedentary life style. SCI patients are rehabilitated or treated by applying electrical stimulation pulses to the affected area. Functional electrical stimulation (FES) is a means of generating contractions in paralyzed muscles by passing small electrical impulses through nervous tissue[1,2]. The paper presents a method to develop four-channel programmable FES system, which restores sitting - standing-sitting function of a completely paraplegic patient by using open loop control scheme to deliver electrical pulses to quadriceps and calf muscles[3]. The proposed design contains multi-tap transformers to generate high voltage stimulation pulses.

Materials and Methods

All the experiments were carried at GMCH, Chandigarh. The system was developed around Atmel 89C51 microcontroller, which was used to generate stimulation pulses pattern by using software routine (Fig. 1). These software routine toggles the selected port pins of the microcontroller. The variable pulse widths were achieved using different delays generated by software routines. The required pattern selection was done through frequency selection switches that are given at the front panel of the prototype model and configured to microcontroller, which generates predefined stimulation pulse pattern by detecting position of the frequency selection switch. User or hospital staff can also select different amplitude levels accordingly through amplitude selection switches. Variations in the frequencies and voltage levels can lead to different strategies during FES treatment[4]. Low frequency programmable pulses (16-40 Hz) are generated using microcontroller. Different pulse frequency is achieved by different software routines. The 5V pulses are raised to the level of 12 V using open collector buffer IC 74LS07. These pulses are switched using semiconductor switch and are applied to the input of multi-tap transformer, which provides different voltages (20-120 volts @100 mA). High voltage DC-DC converter can also be used for high voltage generation but they are bulky and costly. These transformers provide patient isolation. Every channel has the option to select independent voltage level. A single pole 10-way switch, which gives the selected voltage at the output channel, is used. Carbon rubber surface electrodes are used for applying FES to patient body. The diam of electrode is 6 cm with 2 mm of thickness. Surface electrodes are used as they are cheap, safe, easy to handle, and suit Indian environment conditions. New system has multiple frequency range(16, 25, 36 and 40Hz), which can be selected through frequency selection switch. Pulse width is 0.3 ms. Voltage level can vary (12-120 Volts) in steps of 12 V depending on the amount of

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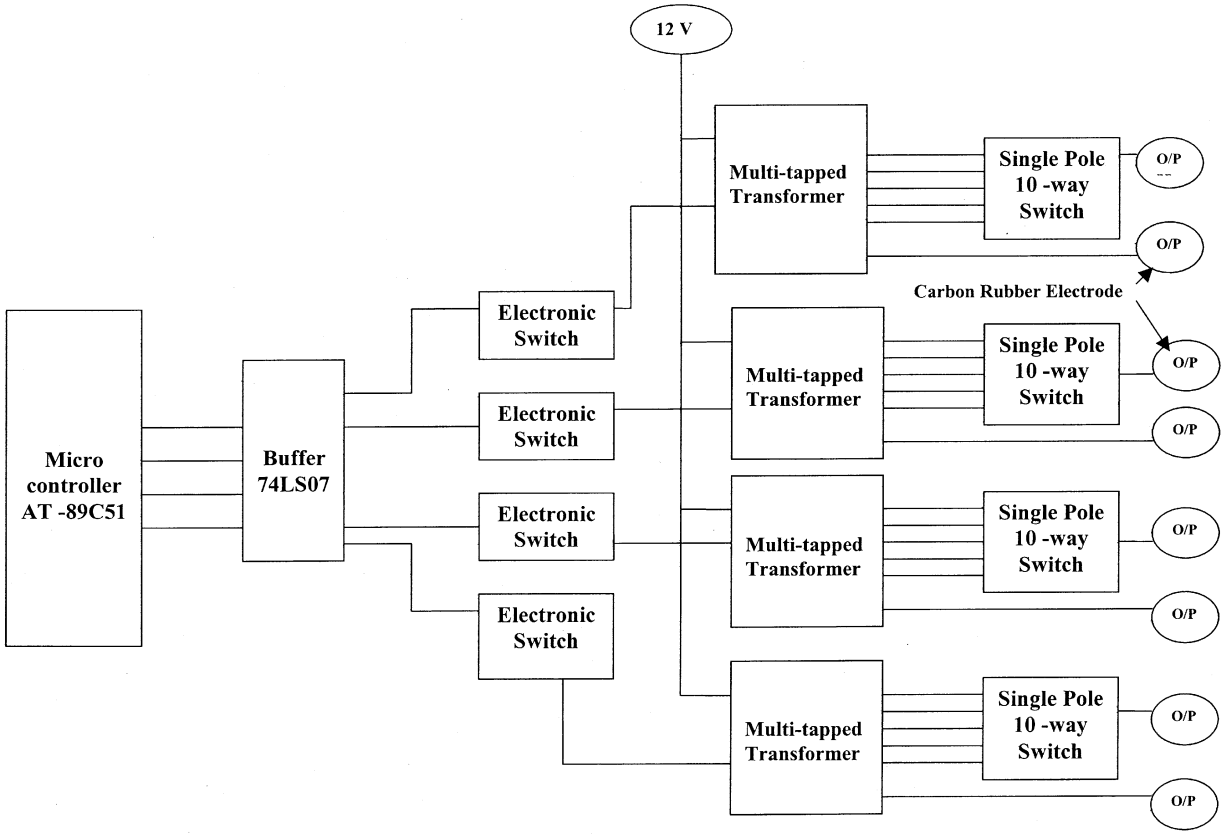

Fig 1 — Block diagram of FES system

Table 1— Amplitude vs contraction level

Amplitude level V	Contraction grade
24	Grade 1
36	Grade 2
48	Grade 3
60	Grade 4
72	Between Grade 4 & 5
84	Grade 5

contraction required. Maximum current delivered from instrument is 100 mamp at each channel.

Results and Discussion

The system delivers mono-phasic pulses of varying frequencies and amplitude levels. A complete paraplegic patient with SCI level T-4 was identified. FES was given to the patient by identifying correct location of muscles. Electrodes soaked with conducting gel were applied to the patient and tied with a welcrow straps so that they cannot move from their respective positions and remain in good contact with skin[5]. Tetanic contraction was observed after stimulation was given to the patient. Contraction grade varied with the amplitude and frequency of the stimulation applied (Table 1). These experiments were conducted at pulse pattern of 0.3ms, 40 Hz.

At low voltage and low frequency stimulation, contraction was low and of no use for FES activities. At high voltage and high frequency stimulation given to patient, muscle fatigue was early. Grade 4-5 contractions were required for limb movement for a complete paraplegic patient. Multi-tap transformers, instead of high voltage DC, make system more effective, efficient, smaller and cheaper. These transformers also help in providing patient isolation.

Conclusions

FES is one of the better alternatives for the rehabilitation of SCI patients. The developed prototype FES system, which provides benefits of FES to SCI and paraplegic patients, can also be used for therapeutic purposes for low voltage and low frequency muscle toning, and for physiotherapy exercises of SCI patient.

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