DUAL-CHANNEL ELECTRICAL STIMULATOR FOR CORRECTION OF GAIT

Bogataj U., Kelih B., Maležič M., Filipič D., Kljajić M.

"Jožef Štefan" Institute, Ljubljana, YUGOSLAVIA

ABSTRACT

A dual-channel electrical stimulator has been designed for plegic and paretic patients. It could be used for therapy in hospital during the period of rehabilitation or every day at home as an orthotic aid after the rehabilitation program has been completed. The system consists of two devices: the stimulator and the programming unit. The stimulator is designed to be handled by the patient alone. All stimulation parameters except stimulation amplitudes which are set individually by the patient, are preprogrammed by the therapist through programming unit. The stimulator collects some statistical data about the patients' gait, which could be displayed by the programming unit.

KEY WORDS: Stimulation, gait, orthosis, multichannel stimulator

INTRODUCTION:

Hemiplegia is one of the typical diseases of the modern world. In developed countries this disease affects two to three people out of a thousand. Usually it occurs as a consequence of a cerebrovascular insult in all age groups; however it is more common in middle age and in eldery people. Besides this, there is another large population of patients with craniocerebral trauma, which is a consequence of accidents at work, in traffic, etc. In both groups the patients have similar disfunctions of locomotion. These patients have unaffected muscles, but their inervation from the central nervous system is impaired. The upper motor neuron lesions indicate the use of functional electrical stimulation (1,2). There are some reports on development of laboratory oriented dual channel devices (17,18), and some of them appeared on the market. These are all handsome cyclic stimulators, which are very convenient for therapy in rehabilitation institutions, but less applicable for gait for everyday homeuse. None of the stimulators has the ability of free seting of stimulation sequences, which diminishes number of muscles where the stimulator can be applied. The periode of cycler is in all cases constant as it was preset, which means constant walking speed, if the stimulator was used for the correction of gait.

BACKGROUND AND INDICATIONS

Neuromuscular electrical stimulation has been a part of training programmes in the rehabilitation of plegic and paretic patients for more than twenty years. Numerous stimulators have been designed for the surface stimulation of gait, from the simple single-channel to very sophisticated multichannel units. But only a few devices are convenient enough for home use. In most cases these are single channel peroneal stimulators for ankle dorsal flexion, which do improve and ease the patient's gait (3-10), but are more convenient for patients with less severe impairments. In the last few years multichannel electrical stimulation has been applied in severely involved patients, who could hardly walk or could not walk at all without considerable help from a physiotherapist (11-13). It has been shown that these patients started walking after two to three weeks of therapy with stimulation, using a crutch and some assistance from a physiotherapist (14,15). After finishing therapy such patients would in most cases need

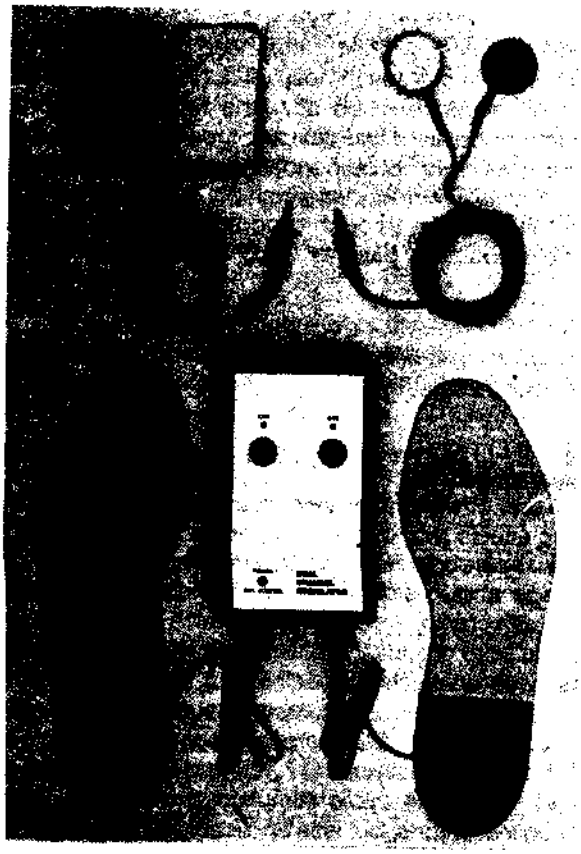


Figure 1. Stimulator set with the stimulator, two insole heel switches and two pairs of electrodes.

a dual-channel device for the stimulation of the peroneal nerve or pretibial muscle group for ankle dorsal flexion, and one of the following muscle groups: quadriceps muscle for knee extension, hamstring muscles for knee flexion, or gluteus maximus muscle for the hip extension. There is also a large group of patients who can walk, but have considerable problems with insufficient ekstension or with hyperextension of knee during the stance phase, or with insufficient ekstension of knee during the swing phase. Such patients are also candidates for dual channel stimulator as an orthotic aid. On the other hand, two to three channels of surface stimulation represent an optimal compromise between the correction of gait and what the patient can use by himself (16).

REQUIREMENTS

According to our experience with multichannel electrical stimulation, a dual-channel orthotic stimulator should have two galvanically separated channels, with 0 - 50 mA nomophasic or biphasic current stimulation pulses. The device should be as small as posible, with easy and independent settings of stimulation sequences for both channels in stance and swing phase. The duration of each stimulation sequence should adapt to the cadence of the patient's gait. The sequences should be triggered for each channel optionally by left or right heel-switch. Frequency and pulse width of the stimulation pulses should be settable in a wide range. Setting of stimulation parameters except stimulation amplitudes should not be accessible to the patient. Cyclic triggering of the stimulation sequences is also required for muscle training and for the selection of stimulation sites.

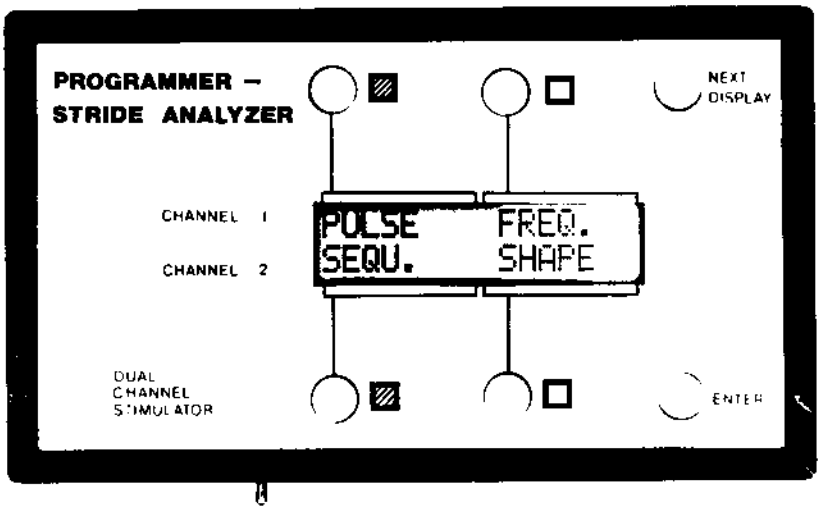


Figure 2. Programming unit with the displayed menue for selection of stimulation parameters

REALIZATION

While developing the main concept of the hardware of the stimulator, we decided that the stimulator set should consist of two units: a stimulator and a programming unit. Both units are mikroprocessor controlled and have been designed to be easy to handle. In the stimulator as shown in Fig. 1, there are amplitude knobs with on/off switch and connectors for electrodes and heel- switches which are accessible to the patient. There is also an indicator light, which emites green light when the stimulator is on and the battery is full, or it emites red light when the battery is low and it must be replaced within an hour of operation. All other parameters of stimulation are preprogrammed by the therapist with the programming unit and can not be altered by the patient, even when removing the battery. The stimulator has two independent channels with intermittent current stimulation pulses with amplitudes from 0 to 50 mA. There are two modes of operation: cyclic mode and walking rate dependent mode (WRD). When neither heel-switch is connected the stimulator operates in cyclic mode. The preprogrammed stimulation sequence is repeated in preprogrammed time interval. This mode is used for selecting the stimulation sites, for exercising of muscles, for pain relief stimulation, etc. When one or both heel-switches are connected, the stimulator operates in WRD mode, which is used for walking. In this case the same stimulation sequences are

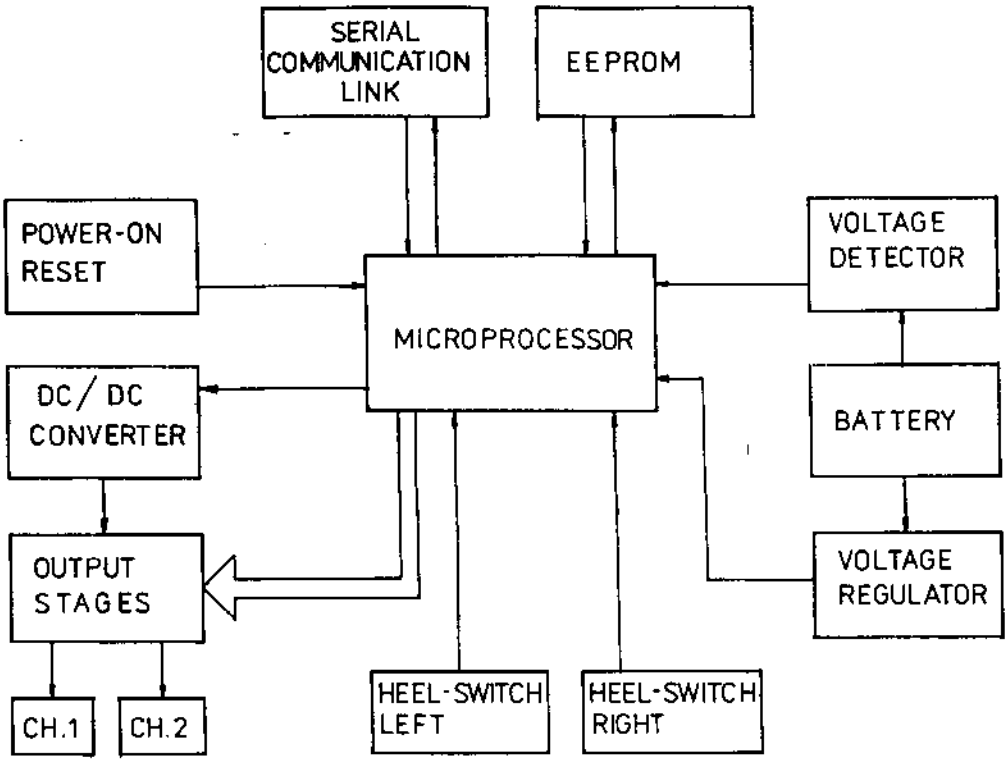
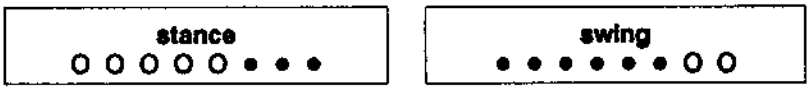


Figure 3: Block diagram of the hardware of the stimulator

optionally triggered by left or right heel-switch. The duration of the stimulation sequence is adapting to the patients speed of gait. According to the information obtained by one or both heel-switches the following statistical parameters of gait are also measured: number of steps and average heel-on and heel-off times with their standard deviations for both legs.

The programming unit as shown in Fig. 2 has been designed to be handled by the therapist. It comunicates with therapist through alpha-numeric display. Therapist can change different menues by pressing pushbuttons and set the following parameters for both channels together: stimulation frequency from 5 to 120 Hz, duration of the cycle from 2 to 12 sec and the following parameters for each channel respectively: pulse width from 0.05 to 0.5 msec, stimulation sequence, pulse shape (monophasic or biphasic) and triggering of each channel by left or right heel- switch. The chosen parameters can then be programmed through cable connection to the stimulator, or the programmed parameters could be read from the stimulator in order to check the setting. The statistical data could be read and displayed from the stimulator or the statistics could be cleared for a new measurement. The stimulation sequence setting is graphically represented for both channels respectively with 8 software switches for the stance and with 8 software switches for the swing phase. When the switch is on, the stimulation is on in the corresponding stance or swing time increment. For example, the stimulation which starts at 5/8 of stance after heel-contact and ends at 6/8 of the next swing after lifting the heel, requires the following position of the switches:

O - switch off ● - switch on



When the stimulator is operating in WRD mode, the patient can choose his own preferable speed of gait. The timings of stimulation sequences adapt to the patients gait. Prediction of the next stride phase time T(N+1) is based on linear or weighted extrapolation of the previous four stride phase times T(N)...T(N- 3). One of three extrapolation equations is choosen according to the gradient of previous stance and swing times respectively:

gradient of stride time	extrapolation formula
increasing:	T[N+1]= T[N]/2 + T[N-1]/4 + T[N-2]/8 +T[N-3]/8
equal:	T[N+1] = T[N]
decreasing:	T[N+1]= T[N]/4 + T[N-1]/4 + T[N-2]/4 +T[N-3]/4

Software is a crucial part of the stimulator due to its hardware concept shown in Fig. 3 and provides a large flexibility of functions. The software is stored in EPROM and can be easily changed or modified when functional changes in the stimulator are needed.

CONCLUSION

The stimulator described is a new orthotic aid the for correction of plegic or paretic gait, which can be used outside the clinical environment. It has been designed in the light of experiences from multichannel therapeutic stimulation, which indicated the need for a multichannel orthotic device. Implementation of that idea was enabled by VLSI technology and CMOS microcomputers integrated in a single chip. Complicated logical functions can thus be accomplished with little consumption of space and low power dissipation using a battery power supply. Some unique features, like walking rate dependent stimulation or the way of setting and representing of the stimulation sequences, are implemented in the dual channel stimulator.

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