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INFORMATION TECHNOLOGY FOR PERSONALIZED CONTROL OF THE COORDINATION OF CYCLICAL MOVEMENTS OF THE LIMBS

The theoretical and practical foundations of the synthesis of information technology for personalized control of the coordination of cyclical movements of the limbs are considered. The technology is implemented by two modifications of 4-channel programmed myostimulators, "TrenKorSyntez-4" and "MioAktyvSyntez-4". In contrast to existing devices, the developed ones use a flexible structure of muscles involvement in cyclical movements, which is aimed at successful performance of a motor task. Displaying the movement program (model) on the front panels is an additional tool for its adjustment and making changes to the planned model. The results of clinical tests of operating model of "TrenKorSyntez-4" device are considered. The advantages of digital-analog technical implementation of "MioAktyvSyntez-4" for the practical usage of the technology and expansion of its functional capabilities are discussed.

Keywords: *information technology, personalized control, coordination, cyclical movements, adjustment, limbs, programmed myostimulator, movement model.*

Introduction

Movement control is the ability of the central nervous system to coordinate certain movement programs with the aim at optimally solve the motor tasks that arise in human life. A movement program is a certain set of commands from the central nervous system, which provide the movement performance due to contraction of the necessary muscles in a strict order and with the necessary effort. According to the definition of Professor N.A. Bernshtein: "The coor-dination of human movements consists in getting rid of unnecessary freedom degrees in movement due to the optimal interaction of all participants in movement creation" [1]. The functional role of muscles in performing the motor acts is quite diverse. Some two-joint muscles perform flexion in one joint and extension in other. The antagonist can be excited at the same time as the agonist to provide the movement accuracy, and its participation helps to perform the motor task. In this regard, taking into account the functional aspect of coordination in each specific motor act, it is advisable to distinguish the main muscle (agonist, main engine), auxiliary muscles (synergists), antagonists and stabilizers (muscles that fix the joints, which do not participate in the movement). The role of muscles is not limited by strength generation. Antagonists and stabilizers often function in a stretch mode under a load. This mode is used for smooth braking of movements, shock absorption.

In the formation of motor skills, there is a change in the movements coordination, in particular, mastering the inertial characteristics of organs in motion. In a formed dynamically stable movement, all inertial movements are automatically balanced without producing a special impulses for correction. When human muscles interact harmoniously and effectively, we can talk about good movements coordination. People with good coordination, as a rule, perform movements easily and without apparent effort, such as, for example, professional athletes. Therefore, the movements coordination is understood as the process of coordination of a body's muscles activity, which is aimed at the successful performance of a motor task.

Good coordination is important not only in movements performing, but even, for example, we sit in an office and look at a monitor. Muscle coordination determines in particular, muscle tone in a relaxed state. When we sit, the trapezius muscles, some small muscles of spine and legs contract involuntarily. For example, convulsion is the result of poor muscle coordination. Poor movements coordination may be corrected. It trains with three things: joint warm-up, physical exercises, and flexibility exercises.

The purpose of the paper is to consider the theoretical and practical foundations of the synthesis of information technology for personalized control coordinates cyclic movements of limbs, which is provided by a certain sequence of involvement of muscles in movement to perform a motor task.

Functional Requirements for Devices to Control Coordinated Cyclic Movements of Limbs

The control of complex coordinated cyclic movements of the limbs, which performance is provided by a certain sequence of involvement of muscles in movement, puts forward the special requirements for a structure of electronic devices that implement such a control. In this case, the synthesis of multichannel (at least four channels) electrical myostimulators, which main function is a synthesis of program for control the multi-channel myostimulation, is advisable. That control program provides a certain time distribution of muscle involvement (generally agonists, synergists, antagonists, and stabilizers) to perform a coordinated movement. The structure of a program is an rotation of zones of influence (muscles contraction) and pauses (passive relaxation) in each channel. The time distribution of these zones in all channels should consider to some extent the motor coordination of the stimulating muscles, i.e. to form the coordinated muscles activity of the limbs aimed at a motor task performance.

To obtain artificially synthesized programs that are close to natural ones, it is necessary to provide the freedom of changes in duration of "packets" and "pauses" of stimulation pulses in each channel of a multi-channel system and the freedom of combinations of different durations of "packets" and "pauses" in the channel and between channels. The duration of "packets" of impulses determines the duration of the active phase of muscle contraction, and the duration of "pause" determines its passive relaxation. Only a sufficiently flexible structure of an artificially synthesized motor program can pro-

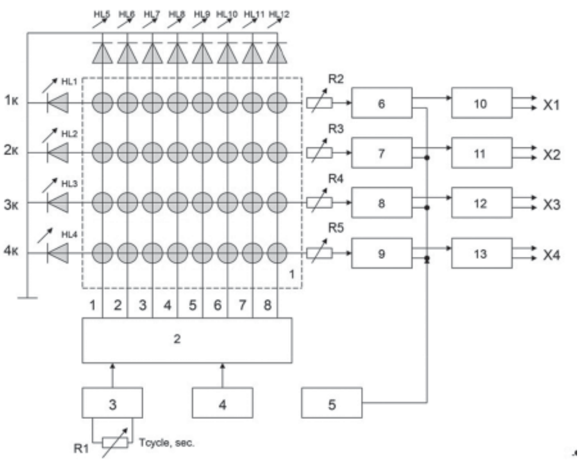


Fig. 1. Structural and functional model of the four-channel myoelectric stimulator "TrenKorSyntez-4" (explanations are in the text)

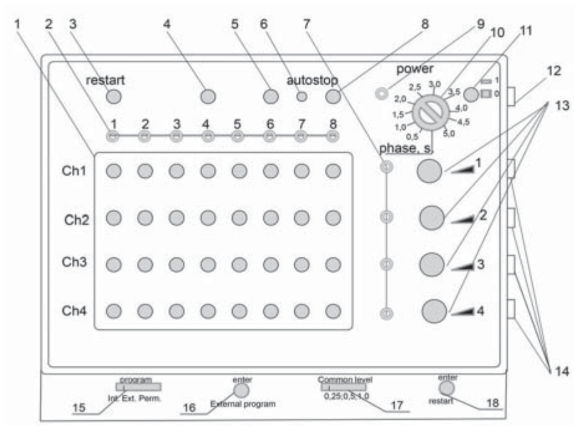


Fig. 2. Front panel of the four-channel programmed myoelectric stimulator "TrenKorSyntez-4" (explanations are in the text)

vide the complex relationships between the moments of involvement of the stimulated muscles to perform complex coordinated movements of the limbs.

The biggest problem to recover the coordinated cyclic movements of the limbs affected due to pathology (stroke, cerebral palsy, traumas and injuries, postoperative complications) is the correct formation of coordination. Only then muscle strength should be increased. Muscle strength must be "dressed" on proper coordination [1]. This applies not only to the lower, but also to the upper limbs.

In the research, the theoretical foundations of synthesis were developed and two modifications of four-channel programmed myoelectric stimulators were technically implemented. These stimulators implement personalized adjustment of separate phases of activity of muscles involved in performance of coordinated cyclic movements of the limbs. Both modifications are programmed myoelectric stimulators "TrenKorSyntez-4" and "MioAktyvSyntez-4" have a flexible, non-deterministic structure of a synthesis of myostimulation programs depending on the functional task of adjustment, and on a specific motor task.

Four-Channel Programmed Myoelectric Stimulator "TrenKorSyntez-4"

Unlike well-known stimulators with deterministic artificially synthesized programs (e.g. "Amplipuls" [2], "Mioritm" [3], Enraf Nonius Endomed 682 and Enraf Nonius Myomed 632, etc. [4-7]), myoelectric stimulator "TrenKorSyntez-4" provides a non-deterministic synthesis of an electromyostimulation program, which depends on the assigned task for performing a certain cyclic motor task with the limbs.

The structural and functional organization of the synthesis of an electromyostimulation program (Fig. 1), its display on the front panel – interface of the "TrenKorSyntez-4" myoelectric stimulator, where the program's controls are located (Fig. 2) provide the usability for practice the program – changing the duration of "packets" and "pauses" of stimulation pulses in each channel of the four-channel system, combinations of different durations of "packets" and "pauses" in the channel and between channels by both a physician and a patient.

According to the structural and functional model of the "TrenKorSyntez-4" device (Fig. 1), the function of program's synthesis for control the four-channel myostimulation, which provides a certain time distribution of muscle involvement for performing the coordinated movement, is implemented by a number of units:

1 – coordinate field of 4 lines by 8 columns, which nodes are push-buttons with fixation of the pressed position;

2 – ring cycle switch for sequentially scanning the columns;

3 – cycle generator to determine the scanning speed;

4 – the unit to control the modes provides the possibility to shorten the cycle, to autostop the cycle and to force its start.

The sequence of active phases formed by the user (physician) with the help of push-buttons is sent through the level regulators of the stimulating signal to the first inputs of amplitude modulators (6-9) of stimulation signal. The stimulation signal from generator (5) is sent to the second input of the modulators. The modulated signal through the output amplifiers (10-13) and the contacts of sockets (X1-X4) is sent to the stimulation electrodes.

The stimulation signal is smoothly regulated by the level on the load equivalent from 0 to 50 V, it is a unipolar asymmetric pulse: the pulse length is 90 μs; frequency is variable (automatic frequency modulation in the range of 10-180 Hz with variable duty cycle); the cycle repetition duration is smoothly adjustable in the range of 4-40 s.; the stimulation signal rising duration is not less than 0.25 s.

The elements to control, check and connection of the front panel of the "TrenKorSyntez-4" device - the interface for a patient and a user (physician), are shown by the digital items in Fig.2:

1 – a coordinate set field of independent push-button switches with fixation of the pressed position for the synthesis of sequences of control signals in the stimulation channels; 2 – eight light indicators of the presence of a high level signal from the outputs of the ring switch; 3 – "*Restart*" is the button without fixation to provide a forced return of the current state of the switch to the cycle's beginning; 4 – the button with fixation to provide the organization of a shortened scanning cycle of four phases and the subsequent return to the beginning; 5 is the button with fixation to provide the organization of a shortened scanning cycle of six phases and the subsequent return to the beginning; 6 – the light indicator of the "autostop" mode, which is active when the "*Autostop*" button is pressed; 7 – the light indicators of the presence of control signals appropriately for each of the channels; 8 – "*Autostop*" is the button with fixation to provide the stop mode of the switch after the end of the cycle, and the stop will take place outside the coordinate field (all light indicators of item 2 and item 7 will not light); 9 – the two-color power indicator light: green color – the device is turned on and powered by an internal source, red color – an external charging source is connected (the device is turned off), mixed colors – an external charging source is connected (the device is turned on); 10 – "*Phase*" is the regulator of length of the cycle's one phase; 11 – "*Power*" is the power switch; 12 – the socket for connecting an external charger (8-12 V, 500 mA); 13 – the regulators of the stimulation influence level in channels; 14 – "*Output*" are the sockets for connecting a stimulating electrodes to the channels; 15 – the three-position switch of a program type for forming the control influences: influences are formed by an internal synthesizer (internal program), influences are formed by an external synthesizer (external program); influences are present on the outputs constantly (permanent program); 16 – the socket for connecting an external synthesizer; 17 – the three-position switch – divider of the output stimulating effect in parallel in all channels; 18 – a socket for connecting an external "*Restart*" button.

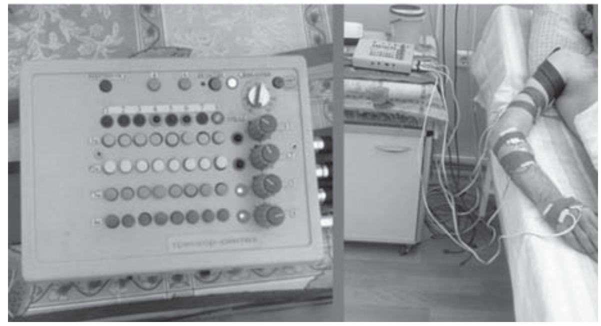


Fig. 3. Four-channel programmed myoelectric stimulator "TrenKorSyntez-4" in the complex movement training of the upper limb

This event of autostop (item 8) will occur if the short cycle organization buttons (items 4 and 5) are deactivated. With the activation of the buttons of item 4 or item 5, the cycle will stop after scanning appropriately four and six inputs, and the indicators (item 7) will display the state of fixation in the 5th and 7th column. The fixation of these states leads to the appropriate fixation of stimulating effects on the muscles as needed. The return to the

Procedural sheet No. 1

№	Training movement	Topology of electrodes' location	Cycle's duration, s.	Cycle's phases 1	2	3	4	5	6	7	8
1.	Extension of a hand	1st: the upper third of the forearm closer to the outer edge, above the common extensor of the fingers (m. extensor digitorum); 2nd: over the same muscle at a distance of about 2 cm from the first electrode	16	■							
2.	Abduction of fingers from the middle line	1st: between the second and third femurs, 2nd: between the fourth and fifth femurs				■					
3.	Abduction of a hand	1st: in the upper part of the forearm close to the outer edge 2 cm below the olecranon above the ulnar extensor carpi ulnaris (m. extensor carpi ulnaris) 2nd: the lower third of the forearm, above the long radial extensor of the wrist (m. extensor carpi radialis longus)						■			
4.	Abduction of a thumb	1st: above the region of the rise of the thenar thumb, proximally, closer to the outer edge above the short muscle that abducts the thumb (m. abductor pollicis brevis) 2nd: the lower third of the forearm, medially, above the abductor pollicis longus muscle (m. abductor pollicis longus)								■	

Procedural sheet No. 2

№	Training movement	Topology of electrodes' location	Cycle's duration, s	Cycle's phases 1	2	3	4	5	6	7	8
1.	Extension of a hand	1st: the upper third of the forearm closer to the outer edge, above the common extensor of the fingers (m. extensor digitorum); 2nd: over the same muscle at a distance of about 2 cm from the first electrode	8	■	■						
2.	Abduction of fingers from the middle line	1st: between the second and third femurs, 2nd: between the fourth and fifth femurs				■	■				
3.	Abduction of a hand	1st: in the upper part of the forearm close to the outer edge 2 cm below the olecranon above the ulnar extensor carpi ulnaris (m. extensor carpi ulnaris) 2nd: the lower third of the forearm, above the long radial extensor of the wrist (m. extensor carpi radialis longus)						■	■		
4.	Abduction of a thumb	1st: above the region of the rise of the thenar thumb, proximally, closer to the outer edge above the short muscle that abducts the thumb (m. abductor pollicis brevis) 2nd: the lower third of the forearm, medially, above the abductor pollicis longus muscle (m. abductor pollicis longus)								■	■

Fig. 4. Procedural sheets for training the fine motor skills of the hand in patients after a stroke using the "TrenKorSyntez-4" device (developed by researchers Ye. Halian and O. Pidopryhora)

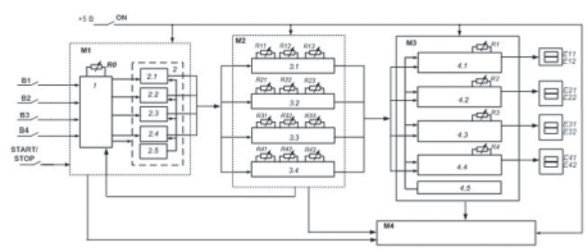


Fig. 5. Structural and functional model of the digital-analog device "MioAktyvSyntez-4" (explanations are in the text)

cycle's beginning with its subsequent stop in accordance with the state of short cycle organization buttons is carried out by the "*Restart*" button. With the deactivation of the "*Autostop*" button the cycle continues from the same place.

Light-emitting diode (LED) indicators HL1-HL4 provide information on the presence of control signals for channels 1-4 appropriately (Fig. 1).

The cyclic ring switch (2) with eight outputs (generally, the number of outputs can be voluntary) sequentially from left to right connects its outputs to the columns' lockers, as evidenced by the sequential light (a light dot motion) of the columns' indicators HL5-HL12. This is *the axis of time*. After the light point passed through the last column, it moves to the first column, etc. The information on a high level signal from the ring switch outputs is the cycle's phases. The transit time of high-level signal on all phases is the cycle's period. The light time of one indicator is the minimum length of a cycle's active phase. Fixation of any button at the intersection of a column and a line is an argument for activation in the appropriate line at the appropriate scan time of a cycle of an active stimulation phase.

With determination on what sequence and at what time of the cycle the active phases of stimulation should appear in the lines (channels), we press the appropriate combination of buttons. Therefore, the topology of the pushed buttons visually reflects the spatio-temporal arrangement of the active stimulation phases in the cycle (motion model).

Since the time of cycle's repetition is common for all channels, and all cycle's segments for stimulation channels are synchronized with each other in time, it is possible to formalize the type of program for a specific patient in the form of set field blanks, in which to push those buttons where and when the stimulation phase should be active. I.e. it is possible to form an artificially synthesized stimulation control program in advance.

The given structural and functional organization of the synthesis of an electromyostimulation program (model) (Fig. 1), its display on the front panel – the interface of the "TrenKorSyntez-4" myoelectric stimulator (Fig. 2) became the basis of the technical implementation of the working layout of the four-channel programmed myoelectric stimulator "TrenKorSyntez-4".

Due to the openness of the architecture of the synthesis of an electromyostimulation program, which depends on the performance of a certain cyclic motor task by the limbs, on the selection of the necessary number of channels and the number of cycle's fragments (the more of them, the more accurate the control), this approach enables to create multi-channel myoelectric stimulators for the personalized formation of complex movements of the limbs and adjustment of coordination (interaction) of separate phases of performing a complex movement.

The four-channel programmed myoelectric stimulator "TrenKorSyntez-4" has undergone preliminary clinical testing in practice the formation of movements of an upper limb, its proximal and distal parts, as well as fine motor skills of the hand in patients after a stroke. The test results are shown in Fig. 3 and 4.

The procedural sheets No. 1, No. 2 shown on Fig. 4 which give the movements selected for training, the change in a cycle's duration (16 or 8 seconds, i.e. slower-faster) and the change in training cycle phase (active phase of stimulation – pause) provide clear examples of the practical usage of the "TrenKorSyntez-4" device for training a various movements of fine motor skills of the hand with a change in load (the load during movements training by procedure sheet No. 1 is less than by No. 2). It should be noted that a load depends not only on motor functions state, but also on the patient's general condition. ***The consideration of load in training is important not only after stroke, but also after traumas and injuries.***

Four-Channel Programmed Myoelectric Stimulator "MioAktyvSyntez-4"

"MioAktyvSyntez -4" is a new class of digital-analog multi-channel myoelectric stimulators for personalized formation of complex movements and correction of coordination (interaction) of individual phases of complex movement performance. Like the "TrenKorSyntez-4" device it has a flexible architecture for the programs synthesis for muscle involvement in the performance of a complex movement, which enables to perform personalized formation/training of a complex movement, to work out individual phases of its performance depending on the functional task, to make adjustments to the involvement of muscles to the performance of a motor task by a limb.

The feature of the synthesis of programs for muscles involving in the complex cyclic movement performance in general and separate phases of their performance by the "MioAktyvSyntez-4" device is that formed and tested program determines the program cycle's duration, regardless of whether the channels work one by one, whether completely or partially coincide in time. This approach to formation of a program presupposes the promt introduction of changes to the program and signal parameters in view of the functional aspect of coordination.

The device provides electrical stimulation in four channels with program signals with the following parameters of the stimulation signal: unipolar pulse with frequencies from 40 Hz to 400 Hz, duty cycle , the amplitude of the stimulation signal 50 V on the load equivalent (in parallel R_L – 1kΩ and C_L – 0.068 μF) . Each channel provides independent adjustment of program parameters, control of its performance and the possibility of its changing during performance. The stimulation current level is smoothly adjustable in each channel from 0 mA to 50 mA per load equivalent.

The pulse signal generator is designed so that each channel receives from it a signal shifted in time related to the signals of other channels in order to prevent mutual influence.

The structural and functional model (Fig. 5) of the digital-analog device "MioAktyvSyntez-4" consists of functional units: the selection of stimulation channels unit M1, the synthesis of stimulation programs unit M2, the stimulation unit M3 and the user interface unit *M4*. The model was developed taking into account the implementation of units M1 and M2 on a modern element base using microcontrollers.

The ON button is common for all units. It turns on the power supply of all units: +5 V power is supplied to the inputs of the units.

The function of s***election of stimulation channels unit* M1** (Fig. 5) is formation of control signals for launching synthesis subunits of the stimulation program in the M2 unit. In this unit non-locking buttons B1-B4 set the stimulation channels, and the START/STOP button starts the stimulation process. To perform this unit on a modern element base using a microcontroller and to build an algorithm for its operation, the principle of its op-

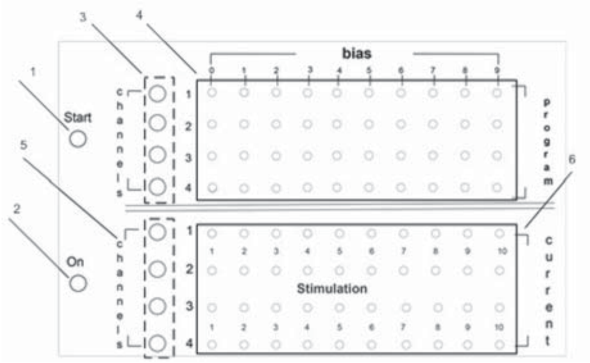
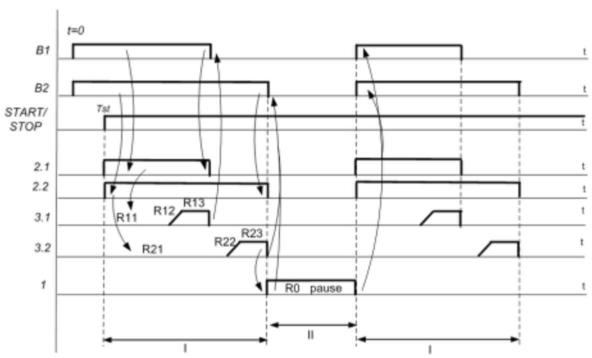


Fig. 6. "MioAktyvSyntez-4". The display panel



The marking: I – cycle, II – pause, B1, B2 –buttons for channels 1 and 2 activation, 1 – one-shot timer, 2.1, 2.2 – logic elements of channels 1 and 2; 3.1 and 3.2 – synthesis subunits of stimulation programs of channels 1 and 2

Fig. 7. Algorithm of the operation of the digital blocks of the "MioAktyvSyntez-4" device in the form of the time sequence diagram of pulses

eration is described below, taking into account the following components: a channel selection subunit (*1*) with a one-shot timer, a potentiometer for adjusting the pause between program cycles (R0) and a recording element on triggers, and program repetition subunit (2) with channels' logical elements (2.1-2.4) and a trigger (2.5).

To start the stimulation in the selected channel, it is necessary to activate this channel with the appropriate button (B1-B4), to activate the START/STOP button, and also to set the control signals' high level for the start of M2 unit.

The function ***of the synthesis of stimulation programs unit* M2** (Fig. 5) is the synthesis of the stimulation program in each of the independent channels. From the M1 unit to the inputs of the M2 unit the control signals are sent to start the corresponding synthesis subunits of the stimulation program of each channel (3.1 – 3.4). These subunits on their outputs give the stimulation signals shapes that go to the stimulation unit M3 inputs. With the activation of the required synthesis subunit a pulse is generated with the duration regulated by the potentiometer R_i1 (where *i* - the channel's number) in the range from 2 s to 90 s related to other channels to establish the time of stimulation program activation of this channel.

This pulse by rear edge triggers the formation of a stimulation control signal. The shape of this signal consists of a leading edge and a phase, the durations of which are regulated by potentiometers R_i2 and R_i3 (where *i* - the channel's number) in the range from 2 s to 15 s, appropriately. The shape of the stimulation signal with an amplitude of 5 V appears at the output of the appropriate synthesis subunit, goes to input of the stimulation unit M3, and also reduces the number of installed channels in the M1 unit by the rear edge (feedback on channel's performance in the current cycle). The leading edge, phase, as well as the time ratio of the active stimulation phases in channels' work can be changed in each channel independently from the others by potentiometers.

The function of the ***stimulation unit*** *M3* (Fig. 5) is outputting in each channel an analog stimulation signal for the performance of a specific motor task. This unit contains stimulation amplification units for each channel (4.1-4.4) and pulse generators (4.5). The generators are on 12 kHz and 100 kHz.

The 12 kHz pulse generator synthesizes pulses of a constant level, which are spaced in time for each channel to avoid the mutual influence of one channel on another, as well as short-circuit pulses of the stimulation electrodes E*i*1, E*i*2 (where i – the channel's number). The 100 kHz generator synthesizes pulses for the stimulation current measurement schemes and to check the integrity of the stimulation electrode circuit, which is checked in this unit.

The formed stimulation programs and the signals from generators (3.5) go to the amplification subunits of the appropriate channels, and the analog signals of the selected channels go to the stimulation electrodes. At each subunit for stimulation amplification, the amplitude of the stimulation current is set by potentiometers R*i* (where *i* - the channel's number). The signals' amplitude from the stimulation pulses generator changes according to the law of changes in the levels of pulses of stimulation programs that go to the subunits of M3 unit. The modulated stimulation signal is amplified to the level that is necessary to stimulate the patient's muscle (from 0 V to 50 V). The method of shorting the electrodes is used for the pause period between stimulation cycles to improve the effectiveness of the impulse signals.

***The user interface unit** M4* (Fig. 5) provides the necessary information on the movement program (model), its adjustment and making changes in it. This unit consists of the display panel and the control panel. The inputs of the unit receive power and signals from units M1-M3, that control the appropriate LEDs' light on the display panel (Fig. 6). On this panel the LED indicators of channels, bias of each channel start separately related to the start of entire program, duration of leading edge and phase of each separate channel, level of electrical stimulation current, program's start, stop and pauses are located.

The marking of items on the display panel (Fig. 6):

1 – "Start" LED is the display of start of the myoelectric stimulation program by the START/STOP button and repeating this program. Signals from the M1 unit by the rear edge light the LEDs in green color, and during the pause period – in yellow color.

2 – "On" LED is the display of turning on the device in red color.

3 – the channel selection LEDs are indicators of selected channel. Signals from the M1 unit by the rear edge light the LEDs in green color. Signals from the M2 unit light the LEDs in yellow color during the period of stimulation program, and in green color – after its completion.

4 – bias LEDs are the display of the begin of a selected myostimulation channel program's start related to the begin of the stimulation program's start in each selected channel, time distribution of active phases of stimulation, which clearly displays the selected program. The appropriate channel activation signal from the M2 unit lights the leftmost LED in red color.

5 – LEDs of the channels' stimulation phases are a display that informs on the phases of the stimulation signals in the selected channels. The signal from the M2 unit at the time of program activation lights the appropriate LED in green color during the period of the leading edge of the stimulation signal and red color – during the period of the active phase.

6 – the stimulation LEDs are a display of the current's level (intensity) of stimulation in the selected channels. Signals from the M3 unit by the rear edge activate the appropriate LEDs in red color.

Algorithm of Operation of Digital Blocks of the Device "MioAktyv-Syntez-4"

With the help of digital logic [8], the algorithm of operation of the digital blocks of the "MioAktyvSyntez-4" device is presented in Fig. 7 in the form of a time sequence diagram of pulses under normal conditions on the example of the operation of two activated channels according to the structural and functional model of the device (Fig. 5).

The time line of the device's operation is marked on the horizontal axis, and the numbers and names of the components of the structural and functional model of the device are marked on the vertical axis. The pulses caused by activation of the *START/STOP* button, channel buttons, pause, start the stimulation cycle, repeating the cycle of stimulation programs are shown in Fig. 7.

We believe that all the necessary adjustment of bias, leading edge, phase in the selected channels has been made, as well as regulation of a pause duration between the stimulation programs' cycles. The channels are set with the necessary buttons without fixation (B1, B2) (time t=0) (Fig. 7), and a constant high level signal is formed. These channels are stored in the device's memory. With the *START/STOP* button activation (time *Tst*), a constant high level signal is also formed.

The program cycle begins from the moment the first channel is activated and ends when the last channel is activated. After that there is a pause, and after it the cycles are repeated until the *START/STOP* button is pressed again.

If the necessary channels are activated and the stimulation programs are started in the channels by the *START/STOP* button, then control high level pulses are formed on the logic elements' outputs (2.1, 2.2). These control pulses start the subunits for generating the stimulation signals (3.1, 3.2) – at the outputs of the appropriate subunits we get shapes of stimulation signals.

The stimulation signal's pulse by the phase's rear edge (transition from the state of a logical one to a logical zero) transfers the channel setting signal (B1, B2) to the state of logical zero, i.e. suspends the operation of the appropriate channel. It is also similarly for other selected channels. Since in this example the operation of channel 2 occurs after the operation of channel 1, the stimulation signal's pulse by the phase's rear edge of channel 2 not only suspends the operation of its channel, but also starts the one-shot timer (1) to set the pause. The pause signal's pulse by the leading edge overwrites the channels set from the device's memory, and with the rear edge it restarts the entire cycle of stimulation programs again until the next pause.

Conclusions

Developed and technically implemented the new class of four-channel devices for personalized control of coordination of complex, in particular cyclic, limbs' movements such as "TrenKorSyntez-4" and "MioAktyvSyntez-4" use in contrast to existing devices for deterministic program synthesis a flexible architecture of synthesis of a program for muscle involvement in a complex movement's performance in general and separate phases of their performance - movement model, and enable to practice the separate movement phases and to make changes in a program (movement model) to perform a motor task, taking into account the functional aspect of coordination.

The feature of both devices is a visual display on the front panels of a program (movement model) created for practicing coordination. This visual display serves for a patient and a physician as an "interface" – a visual biofeedback. *It helps a patient to consciously control the performance of the program, which contributes to the involvement of a patient's additional reserves on coordination recovery; for a physician such an interface is an additional tool for practicing the program to control the movement coordination and separate phases of its performance, as well as making changes in program (model) of coordinated movement, as needed.*

The feature of the structural and functional organization of the synthesis of a program by the "MioAktyvSyntez-4" device is that a tested program determines the total duration of the movement cycle, taking into account the pauses (rest) of the working muscles. This presupposes the promt introduction of changes to program (movement model), which takes into account, in particular, the regulation of muscle load; however, this assumption needs to be verified.

The preliminary clinical testing of the "TrenKorSyntez-4" device's layout in practise of the coordination abilities of fine motor skills of the hand in patients after a stroke gives the examples of the device's usage for training the movements with a change in load (rest period). This is also important for general movements of the upper and lower limbs, their proximal and distal parts, and not only after a stroke, but also after traumas, injuries, and postoperative complications.

Further research is aimed at expanding the functional possibilities of using the digital technologies in devices such as "TrenKorSyntez-4", "MioAktyvSyntez-4", in particular, equipping the devices with modern interfaces, means of control, diagnostics, which will contribute to their practical usage.

REFERENCES

1. *Bernshteyn N.A* Physiology of movement and activity. Moscow: Nauka, 1990. 496 p. (in Russian).
2. Amplipuls-5. URL: http://www.medsnab.ru/catalog/40/102/ (last accessed: 01.06.2022) (in Russian).
3. Myoritm-040. URL: http://www.mioritm.pro/catalog/oborudovanie/komplekt-mioritm-040 (last accessed: 01.06.2022) (in Russian).

4. Enraf Nonius Endomed 682. URL: http://www.manet.si/uploads/ docs/enraf_nonius_endomed_684_682_en.pdf (last accessed: 01.06.2022).
5. Enraf Nonius Myomed 632. URL: http://www.scottmedical.com/item/enraf_myomed_632x/174/37/833/ (last accessed: 01.06.2022).
6. Myostimulator B-333 (China). URL: https://www.radiumbeauty.com/b-333-body-shaping-system-manual (last accessed: 01.06.2022).
7. Myostimulator Compex SP 4.0 (Switzerland). URL: https://www.manualslib.com/products/Compex-Sp-4-0-4158619.html (last accessed: 01.06.2022).
8. *Riabenkyi VM, Zhuikov V.Ya., Hulyi VD* Digital circuitry. Lviv: Novy svit-2000, 2009. 736 p. (in Ukrainian).

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ІНФОРМАЦІЙНА ТЕХНОЛОГІЯ ПЕРСОНАЛІЗОВАНОГО КЕРУВАННЯ КООДИНАЦІЄЮ ЦИКЛІЧНИХ РУХІВ КІНЦІВОК

Вступ. Керування складними координованими циклічними рухами кінцівок, виконання яких забезпечується певною послідовністю залучення м'язів у рух, висуває особливі вимоги до структури електронних виробів, які реалізують технології персоналізованого формування / коригування координації рухів.

Мета статті – розглянути теоретичні та практичні засади синтезу інформаційної технології персоналізованого керування координацією циклічних рухами кінцівок, яке забезпечується певною послідовністю залучення м'язів у рух для виконання рухового завдання.

Методи: структурно-функціональне моделювання, алгоритми, цифрова логіка.

Результати. Розроблено теоретичні і практичні засади синтезу інформаційної технології персоналізованого керування координацією циклічних рухів кінцівок. Технологію реалізують дві модифікації 4-канальних програмних міостимуляторів «ТренКорСинтез-4» і «МіоАктивСинтез-4». На відміну від існуючих розроблені апарати застосовують гнучку структуру синтезу програми виконання циклічного руху залежно від функційної задачі. Відображення на передніх панелях апаратів програми (моделі) руху є додатковим інструментом для її коригування та внесення змін у модель. Розглянуто результати клінічних випробувань діючого макету апарата «ТренКорСинтез-4». Обговорено переваги цифро-аналогової технічної реалізації апарата "МіоАктивСинтез-4" для практичного використання технології та розширення її функційних можливостей.

Заключення. Подальші дослідження спрямовано на розширення функційних можливостей застосування цифрових технологій в апаратах типу "ТренКорСинтез-4" і "МіоАктивСинтез-4", зокрема дообладнання апаратів сучасними інтерфейсами, засобами контролю, діагностики, що сприятиме їхньому практичному використанню.

Ключові слова: *інформаційна технологія, персоналізоване керування, координація, коригування, циклічні рухи кінцівок, програмний міостимулятор, модель руху*.