## SECTION 6. INFORMATION TECHNOLOGIES

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### 6.1 From Luigi Galvani's experiences to intelligent electrotherapeutic systems

**Abstract.** The purpose of the article is a retrospective analysis of the main stages in the development of electrotherapy and the determination of the prospects for the creation and development of intelligent electrotherapy systems. Results. The place of modern electrotherapy in medical practice is determined. The main methods of electrotherapy, which are usually classified taking into account the used part of the spectrum of electromagnetic oscillations, are considered. A description of the historical events that served as a scientific basis for the use of electrical energy for medicinal purposes is given. The path of development of circuit solutions for electrotherapeutic devices from the simplest circuits to combined control systems that combine regulation by deviation with regulation by input disturbance is analyzed. It is shown that the prospects for the development of electrotherapeutic equipment lie in the creation of intelligent electrotherapeutic systems with complete biocontrol.

**Keywords:** *intelligent electrotherapy system, control element, biocontrol, electrotherapy apparatus, biotechnical system*

**Introduction**. Modern electrotherapy is one of the largest sections of hardware physiotherapy, based on the use of electric currents, electric, magnetic and electromagnetic fields with different parameters in continuous or pulsed modes for treatment and prevention and rehabilitation purposes. Electrotherapy accounts for more than 70 % of all physiotherapy procedures performed in medical institutions [329].

Methods of electrotherapy and appropriate technical means (apparatus and hardware complexes) for the procedure of the accepted classification taking into account the used part of the spectrum of electromagnetic oscillations: low-frequency, high-frequency, light-optical, X-ray and radiological [330]. The division of electrotherapeutic methods and devices into low-frequency and high-frequency is to some extent conditional.

According to the International Radio Regulations, the low-frequency range of electromagnetic oscillations is from 3 to $3 \cdot 10^5$ Hz (ultra-low-frequency oscillations 3-30 Hz; ultra-low-frequency oscillations 30-300 Hz; infra-low-frequency oscillations $3 \cdot 10^2$-$3 \cdot 10^3$ Hz); $3 \cdot 10^3$-$3 \cdot 10^4$ Hz; low-frequency $3 \cdot 10^4$-$3 \cdot 10^5$ Hz). All low-frequency methods and devices are divided into two large groups in the form of active electromagnetic energy: for the influence of current and the influence of the field.

Among the methods and devices that act with current, three groups are usually distinguished: for exposure to direct current, pulsed or alternating current. Further classification is usually made according to the name of electrotherapeutic methods.

Direct current is mainly used for galvanization and drug electrophoresis procedures. The methods of exposure to pulsed currents include [331]: electrical stimulation of organs and tissues (0.5-120 Hz); diadynamic therapy (50 or 100 Hz); electrosleep therapy (5-160 Hz); electropuncture (20-250 Hz); short-pulse electroanalgesia (2-400 Hz); transcranial electroanalgesia (low-frequency mode 60-100 Hz, high-frequency mode 150-2000 Hz). Low frequency alternating current is used in interference therapy methods (3-5 kHz); amplipulse therapy (carrier frequency 1-10 kHz, modulating frequency 1-150 Hz); fluctuating (the frequency of the current changes continuously, while in various devices the lower limit of the range is from 0.5 to 100 Hz, and the upper limit is from 2 to 20 kHz).

Methods and devices intended for exposure to a low-frequency field are divided into groups according to the type of field: electric or magnetic, which in turn can be divided into subgroups depending on the type of field (constant, pulsed, variable).

A constant electric field of high intensity is used in the franklinization method, named after the American scientist B. Franklin. The use of a permanent magnetic field created by permanent magnets is today referred to as an alternative medicine method, since there is no consensus on its effectiveness in the world medical community yet. In pulsed and variable form, magnetic fields are widely used in medical practice. In this case, the frequency range of the magnetic field is from 0.125 to 1000 Hz.

High-frequency electromagnetic oscillations include oscillations in the frequency range from $3 \cdot 10^6$ to $3 \cdot 10^{11}$ Hz (high-frequency oscillations $3 \cdot 10^6$-$3 \cdot 10^7$ Hz; very high-frequency $3 \cdot 10^7$-$3 \cdot 10^8$·Hz; ultra-high-frequency $3 \cdot 10^8$-$3 \cdot 10^9$ Hz ; microwave $3 \cdot 10^9$-$3 \cdot 10^{10}$ Hz; extremely high-frequency $3 \cdot 10^{10}$-$3 \cdot 10^{11}$ Hz). High-frequency methods of electrotherapy and their corresponding devices, as well as low-frequency methods, are usually divided into two groups according to the form (current or field) of the electromagnetic energy acting.

Exposure to high-frequency (mainly in the form of harmonic oscillations) current is carried out in continuous or pulsed (series of harmonic current alternating with pauses) modes. It is customary to refer to the methods of exposure to high-frequency current: therapy with currents of supratonal frequency (22 kHz); local darsonvalization (200-500 kHz); diathermy (1.5-2 MHz); electrosurgery (200 kHz - 5.5 MHz).

Methods and equipment that act on a high-frequency field are divided into groups according to the type of field [330]: electric field (created using two electrodes), magnetic field (created using inductors), electromagnetic induction field, electromagnetic radiation field. The main high-frequency electrotherapy methods that use an electromagnetic field include: general darsonvalization (440 kHz); inductothermy (13.56 MHz); continuous and pulsed ultra-high frequency therapy (27.12 MHz and 40.68 MHz); decimeter wave therapy (460 MHz); centimeter wave therapy (2375 and 2450 MHz); extremely high frequency electrotherapy (42.194 and 53.534 GHz).

The use of the optical part of the range of electromagnetic oscillations for medical purposes is called phototherapy (an integral part of electrotherapy). All methods and technical means of phototherapy are usually divided into groups according to the part of the spectrum used: infrared radiation (far, wavelength range

$10^{-3}$-$5\cdot10^{-5}$ m; average $5\cdot10^{-5}$-$2.5\cdot10^{-6}$ m; near $2.5\cdot10^{-6}$-$7.6\cdot10^{-6}$ m); visible radiation (red $7.6\cdot10^{-7}$-$6.2\cdot10^{-7}$ m; orange $6.2\cdot10^{-7}$-$5.9\cdot10^{-7}$ m; yellow $5.9\cdot10^{-7}$–$5.8\cdot10^{-7}$ m, green $5.8\cdot10^{-7}$–$5.1\cdot10^{-7}$ m, blue $5.1\cdot10^{-7}$–$4.8\cdot10^{-7}$ m, blue $4.8\cdot10^{-7}$–$4.5\cdot10^{-7}$ m, violet $4.5\cdot10^{-7}$–$4.0\cdot10^{-7}$ m); ultraviolet radiation (long wave $4.0\cdot10^{-7}$–$3.2\cdot10^{-7}$ m; medium wave $3.2\cdot10^{-7}$–$2.8\cdot10^{-7}$ m; short wave $2.8\cdot10^{-}7$–$1.8\cdot10^{-7}$ m). It should be noted here that the use of the visible part of the spectrum for therapeutic purposes is commonly called chromotherapy [331]. In recent decades, laser therapy [332] and LED therapy [333] have been distinguished in phototherapy.

The use of X-rays (wavelength range from $10^{-7}$ m to $10^{-12}$ m) for therapeutic purposes is called X-ray therapy (section of radiotherapy). This type of therapy is currently going through the next stage of its development, which is characterized by the cooperation of specialists of different profiles, a combination of physico-diagnostic, technical, clinical and radiobiological approaches to the treatment of each patient [334]. For radiotherapy procedures, special devices with x-ray emitters are used. According to the mutual arrangement of the emitter and the patient, long-range devices are distinguished - for remote irradiation of internal organs, close-range - for irradiation of the skin and tissues located in their immediate vicinity, intracavitary - for contact irradiation of internal organs by introducing the emitter into the body cavity [335].

Radiation therapy also includes radiation therapy, which is used mainly for the treatment of malignant tumors using gamma radiation, beta radiation, neutron radiation and elementary particle beams. Unfortunately, as a result of such irradiation, not only the tumor itself suffers, but also the surrounding tissues. To reduce the negative impact of radiation on healthy tissues in modern medical equipment for radiation therapy, strict dosing of radiation and its focusing on the pathological focus are provided.

Some methods of electrotherapy have been actively used for only two or three decades, others have been effectively used for more than one hundred years.

Nevertheless, both long-known and new methods, as well as the corresponding devices for electrotherapy, are constantly being developed and improved along with the development of physics, electronics, computer technology, experimental and clinical medicine.

**The aim of the work** is a retrospective analysis of the main stages in the development of electrotherapy and the definition of prospects for the creation and development of intelligent electrotherapy systems.

**Where did it all begin.** The impetus for the scientifically based use of electrical energy for medicinal purposes is considered to be the experiments of the Italian doctor, anatomist, physiologist and physicist Luigi Galvani.

In his first experiment, L. Galvani observed contraction of the frog's gastrocnemius muscle under the action of bimetallic (Fe/Cu) tweezers on the sciatic nerve. Continuing his experiments, L. Galvani came to the conclusion that electric charges are generated as a result of some life processes in the frog's leg, since at that time physicists (including Galvani) believed that metals can only be conductors and cannot create electricity. Claiming that he discovered a new kind of electricity, Galvani cited electric fish as an example [336]. Their ability to inflict tangible electric shocks has been known since ancient times. There is evidence that even Roman doctors at the turn of the millennium of our era placed paralyzed patients in order to cure them in pools with electric rays.

Dealing with electric fish (one of them even bears his name today - “Galvani’s torpedo”), Galvani established himself in the opinion that if stingrays can generate electricity, then the muscles of any other animal should also produce it. At the same time, the Bologna professor emphasized in his treatise that he considers the electricity that appears during friction, as well as atmospheric and skate electricity, to be similar to the "animal electricity" that he discovered.

In 1791, L. Galvani published a Treatise on the Forces of Electricity in Muscular Movement, in which he describes the presence of an electric current in the muscles of animals. The book aroused great interest among physicists and doctors, who vied with each other to repeat the described experiments. Passion for experiments with static electricity has been inherent in the scientific community since the middle of the 18th century. Electrification tried not only to breed chickens, but also to treat people. Doctors electrified drugs, patients, and, regardless of the results, wrote about the "definitely positive effect." At that time, many "healers" arose who convinced that they had a particularly strong electrical effect and therefore could heal the sick. Even “methods of treatment” have arisen, according to which the paralyzed (paralyzed) people need to be charged with “positive” electricity to be cured, and insane people with “negative” electricity.

Luigi Galvani

In the midst of the triumph of galvanism, an article by Alessandro Volta, professor of physics at the University of Pavia, appeared in the Italian Physico-Medical Journal. He argued that in order to explain the experiments of L. Galvani, it is not necessary to assume the existence of some special "animal electricity". It's not at all about the poor frog and not about its severed leg. It's just that Galvani, without knowing it, brought two different metals into interaction. They gave rise to electricity. And the frog served only as a guide.

A. Volta wrote: “I have long been convinced that all action arises initially as a result of the contact of metals with some wet body or with water itself. Due to this contact, the electrical fluid is driven into this wet body or into the water from the metals themselves, more from one, less from the other (most from zinc, least from silver). When a continuous communication is established between the corresponding conductors, this fluid makes a constant circulation. And so, if this conducting circle or any part of it includes, as a connecting link, the femoral nerves of a frog, dissected in such a way that all or almost all of the electric current should pass through these nerves alone, or if such a link is some some other nerve that served to move this or that member of the body of some other animal, so long as such nerves retain the remainder of their vitality, then, controlled by such nerves, the muscles and members of the body begin to contract as soon as the circuit of conductors closes and electric power appears current” [337].

Alessandro Volta

Naturally, L. Galvani could not leave such an attack without attention. In the presence of witnesses, he dissected the frogs with an iron knife, placing them on an iron stand, connecting the muscle and nerve with a wire of the same metal. The paws were still twitching. “If this happens with one metal, then the source of electricity is in the animal!” – convinced L. Galvani.

“Not at all! - objected A. Volta. - Even a single piece of wire cannot be considered absolutely homogeneous. It may contain impurities. It can be tempered in different ways in length. And he demonstrated electricity, which was born without the participation of animals at all, from only dissimilar metals. A. Volta dubbed it "metal electricity".

The whole world of physicists is divided into two camps. Some supported L. Galvani and were called supporters of galvanism. Others adhered to the views of A. Volta. And it is difficult to say how this dispute would have ended in the 18th century if L. Galvani had not dropped out of the fight.

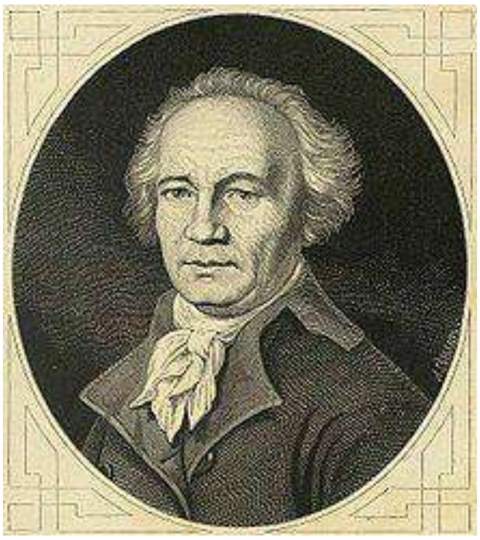
In 1796, French troops under the command of General Bonaparte invaded northern Italy under the pretext of war with Austria. All university professors were required to take an oath of allegiance to the new government. L. Galvani refused to do this and was fired. Left alone and without a livelihood, L. Galvani died of exhaustion on December 4, 1798.

The long-term dispute is over - both of its participants turned out to be right and are now recognized as the founders of the doctrine of electricity. L. Galvani's experiments with "animal electricity" formed the basis of a new scientific direction for that time - electrophysiology, and the method of using direct electric current for medicinal purposes was called galvanization. A. Volta became the creator of a chemical current source, which his contemporaries gave the name "voltaic column" [337].

Despite the fact that the fashionable European fad – electromedicine (the prototype of modern electrotherapy) came to Russia with a slight delay, it immediately took on a serious form, which made it possible to talk about the emergence of a new branch of medicine. At a time when Galvani was still conducting experiments with frog legs, the Russian scientist and inventor Andrei Timofeevich Bolotov had already opened an electric clinic and, as he believed, successfully treated almost all diseases known by that time.

At the junction of two interests - electricity and medicine, Andrei Timofeevich began to create a new science, simultaneously promoting both theory and practice. The theoretical part was formulated by him in several works published during the 1790s: "The History of My Electrification and Healing of Various Diseases by It", "A Brief Electric Medical Book", etc. The final work on electromedicine was published by Bolotov in 1803 and was called "Short and experience-based remarks on electricity and on the ability of electric machines to help from various diseases. In this book, the scientist described in detail the structure of his electric instruments, the principle of their operation, gave detailed instructions on the use of electricity in various medical cases.

In his clinic, Andrei Timofeevich offered to treat: colds, rheumatism, diseases of the heart, digestive organs, paralysis, contractures, neuropsychiatric disorders ... Describing the results of his medical work using electric charges, the scientist spoke of a cure for more than 1,500 people over two and a half years "not only from various mild diseases, but many times from the most serious, long-term, neglected, and several times even the rarest, unusual and such diseases that opposed all other medicines used before and even the healing of skilled physicians."



Andrei Timofeyevich Bolotov

Andrei Timofeyevich Bolotov simplified the design of the electrostatic machine and the Leiden jar as much as possible. This, according to the scientist, made it possible to produce miraculous electrical appliances everywhere, in the most primitive workshops, and to provide assistance to both the rich and the poor. The unique developments of A. T. Bolotov, although they aroused interest from scientists and doctors, however, did not receive the wide distribution that he expected. By the beginning of the 19th century, the excitement around the new panacea began to subside: the public expected a miracle from electromedicine, but it did not happen - it did not always help, and only within the limits of the possible. When A. T. Bolotov created his electric hospital and wrote works on electricity, ideas about the nature of electricity were still very limited. However, attempts to use electrical energy for medicinal purposes continued.

In 1802, V. Rossi first used direct current to introduce mercury salts into the body of a patient with syphilis, thereby laying the foundation for drug electrophoresis. The beginning of the scientific study of the therapeutic effects of a direct electric current of small strength was laid by the News of Galvanic Experiments, published by Academician of the Medical and Surgical Academy V.V. Petrov in 1803. Five years later, Professor of Moscow University F. Reis quantitatively described the phenomenon of electroosmosis, and in 1825 D. Charlander for the first time used electropuncture to influence deep-lying tissues [331].

For quite a long time, galvanic cells or batteries were considered the best current sources for galvanization and drug electrophoresis procedures. The main advantage of such sources at that time was seen in the absence of voltage and current ripples (unlike dynamos). For the procedures, the most suitable were galvanic cells consisting of coal and zinc immersed in a solution of ammonia. Batteries were used both lead and alkaline. To obtain a voltage of 60–70 V, galvanic cells or batteries were connected in series [338].

The current was supplied to the patient's body using tin or lead electrodes (due to their plasticity), which were connected to a current source using special wires. The thickness of the electrodes was usually 0.25-0.5 mm, and the shape and area depended on the area that was electrified. Between the electrodes and the patient's body, pads made of undyed cotton fabric were placed. For carrying out galvanization procedures, the gaskets were wetted with water, and during drug electrophoresis, one of them was wetted with a solution of a medicinal substance. In this case, the interelectrode section of the body had some electrical resistance $Z_{IE}$, containing ohmic and capacitive components.

During the first electrotherapy procedures (Fig. 1), the patient's condition was assessed only by visual control, and the process control was limited to connecting the patient to a battery of galvanic cells or turning it off. The system of interaction of an electromagnetic energy source with a patient and a doctor performing the control function is currently called a biotechnical system (BTS).

From the point of view of the theory of automatic control of BTS, shown in fig. 1 should be attributed to the class of the simplest open-loop systems, which, as a rule, do not provide the desired quality of the course of physiological processes and the required therapeutic effect. Feedback is set here only in the event of a critical or unforeseen situation, the elimination of which is carried out manually.

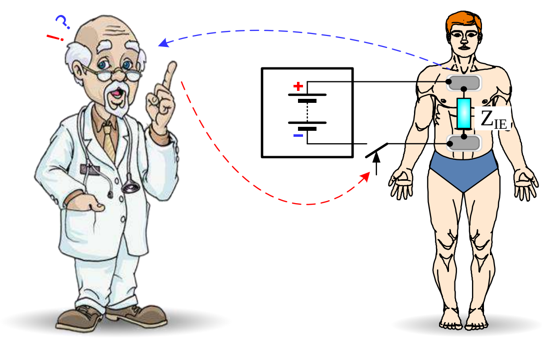



Figure 1. Carrying out the galvanization procedure with galvanic current sources

**Electrotherapy devices of yesterday and today.** The appearance in medical institutions of electrical networks of alternating voltage made it possible to abandon the use of galvanic cells and batteries during electrotherapy procedures. In medical practice, devices that receive electrical energy from the network began to be used. Let's consider the evolution of such devices on the example of the simplest of them, designed for electrotherapy with direct and pulsed current.

In the first devices for electrotherapy with direct current (Fig. 2), a transformer (T) was used to lower the alternating voltage $u_C$ of the supply network, the voltage was rectified first by lamp diodes, and later by semiconductor diodes (VD). Smoothing of rectified voltage ripples was provided by an LC or RC filter.

In this case, the combination of a transformer, rectifier diodes and a filter can be considered as an unregulated unstabilized secondary power source (UUSPS).

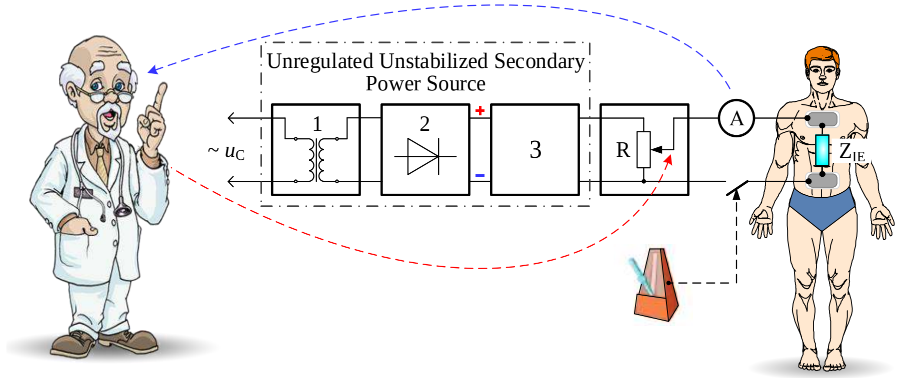



Figure 2. Device for electrotherapy with direct current,

where 1 – transformer (T), 2 – rectifier (VD), 3 – filter (LC / RC)

The doctor regulated the output current with the help of a rheostat R, observing the readings of the ammeter A and inquiring about the patient's feelings.

The main disadvantage of such an apparatus (devices made according to the scheme shown in Fig. 2 are still in operation) is that it does not allow strictly dosing the effect of electric current. There are two reasons for this. Firstly, the supply voltage $u_C$ is unstable (external disturbance), even the standard allows its deviation within 10%, and in real conditions it can be more (up to 20%). Secondly, the resistance of the interelectrode section $Z_{IE}$ during the procedure can change significantly (up to 40%) [340].

For example, in the device for galvanization and medicinal electrophoresis Potok-1, when the supply voltage changed by ± 10%, the output current also changed by ± 10%, and when the load resistance changed from 300 to 600 Ω, the load current changed up to 9% in the first subrange and up to 45% - in the second subrange of output current regulation [340]. Thus, to stabilize the current in the patient circuit, the doctor needs to control the readings of the ammeter A throughout the procedure and adjust the output current of the device using the rheostat R.

As the methods of conducting electrotherapeutic procedures improved, doctors came to the conclusion that it was expedient to use pulsed currents to stimulate the neuromuscular system of the musculoskeletal system. In some cases, metronomes were used to rhythmically interrupt the current. A special rocker with needles at the ends was attached to the metronome's pendulum. When the pendulum oscillated, the needles were alternately immersed in vessels with mercury, which led to the closing of the contact and the formation of a circuit for the current to flow through the patient [338].

In the considered BTS, with an open control loop, it is possible to change one parameter (regulation by the doctor of the current strength in the patient circuit) or two parameters of the impact (current strength and frequency of its interruption according to the time program specified by the metronome). Such a BTS should be considered as a discrete open-loop system with quantization as a function of frequency. In this case, there is no objective assessment of the effectiveness of the results of electrotherapy, the desired parameters of the signals of physical effects on the patient are still not formed. However, in such systems it is much easier to organize manual or automatic protection of the patient from inadmissible or uncomfortable current values, which frees the doctor from constant monitoring of the therapy process.

The desire to compensate for the instability of the supply voltage led to the fact that instead of UUSPS in electrotherapy devices (ETDs), they began to use unregulated but stabilized secondary power sources (USSPS) (Fig. 3). Stabilization of the output voltage was provided in them by a regulatory element (PE), which operated in a continuous or pulsed mode.

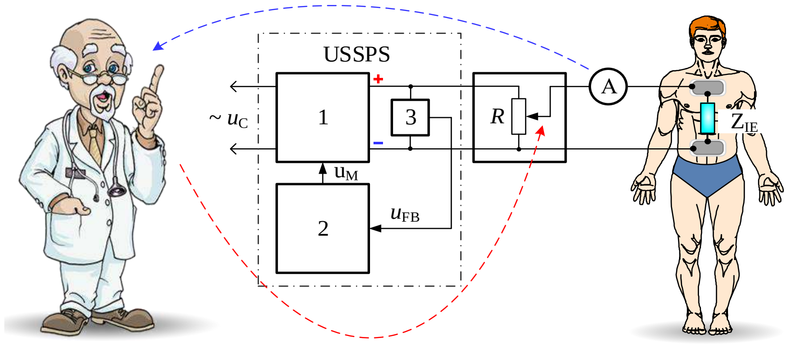



Figure 3. A direct current electrotherapy apparatus with an unregulated stabilized secondary power supply (USSPS), where 1 – regulating element (PE), 2 – voltage regulator (VR), 3 – output voltage sensor (OV)

The formation of the control action uM for PE was carried out using a voltage regulator (VR) taking into account the feedback signal uFB coming from the output voltage sensor (output voltage – OV) of the source. The doctor continued to regulate the output current using the rheostat R, observing the readings of the ammeter A and taking into account the patient's sensations. Such an approach, for example, in the device for diadynamic therapy AFT SI-01, allows you to fully compensate for changes in the supply voltage, but changes in the load resistance (by 50%) lead to a greater change in the output current (up to 80%) [339].

BTS in this case contains in its structure an electrical part, where local feedback is used to stabilize the voltage of the power source. However, even with a stable supply voltage, the main signal of physical impact on the patient - the electric current - depends on the conditions of contact with living tissues and their resistance, the change in the parameters of which are not known in advance and are of a very diverse nature. Predicting the actual course of the electrotherapeutic process is possible only when using the results of studies on various models (biological, physical, physico-chemical or mathematical).

The processes occurring in the electrical circuits and electronic elements of the BTS are described by differential equations. The same mathematical apparatus can be used if the electrical properties of biological tissues and the “electrode-skin” transition are represented in modeling by equivalent electrical circuits of body tissues [341].

The presence of such models makes it possible to obtain a transfer function that relates the Laplace images of the output (adjustable) current *I*(*p*) and the input voltage *U*(*p*) from the power source:

$$W(p) = \frac{I(p)}{U(p)} = \frac{(R_1 + R_2)Cp + 1}{R_1(R_2Cp + 1)} = \frac{k_{SE}(T_0 p + 1)}{Tp + 1},$$

where $k_{SE} = \frac{1}{R_1}$ – transfer coefficient "electrode-skin".

In other ETDs, UUSPS at the input (Fig. 4) was supplemented with an adjustable stabilized secondary power source (ASSPS), in which the current regulator (CR) formed the control action $u_M$, taking into account the control error determined by the algebraic sum of the signal setting $u_T$ and current feedback signal $u_{FB}$ from the current sensor (CS). Setting the current in the patient circuit is carried out by the doctor only at the beginning of the procedure, then the current strength is stabilized automatically.

In the presence of a CR regulator, a positive effect is manifested primarily in the fact that the intensity of the impact (strength of electric current) on the patient is maintained at a given level with a certain accuracy, regardless of changes in the resistance in the area of contact of the electrode with the skin or other factors. The electrical part of the BTS is a closed-loop automatic current stabilization system, which can provide a sufficiently high accuracy of the task signal processing with the introduction of special corrective devices.

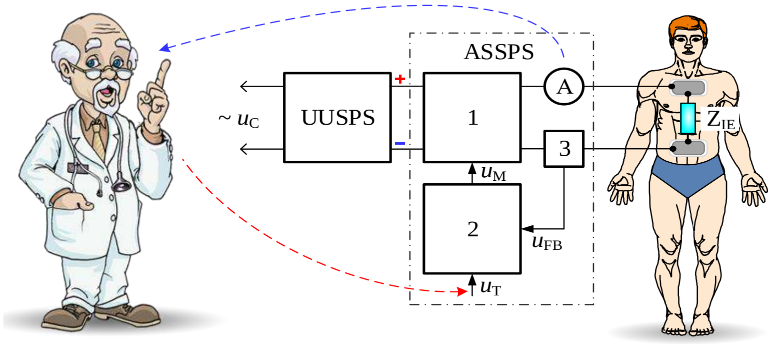



Figure 4. Device for electrotherapy with direct current with an adjustable stabilized secondary power supply (ASSPS) with output current feedback, where 1 – regulating element (RE), 2 – current regulator (CR), 3 – current sensor (CS)

However, this approach to building an ETD is not always efficient. For example, the load characteristics of the device for diadynamic therapy "Tonus-2M" turned out to be very acceptable (when the load resistance changed by ± 50%, the output current changed by no more than 0.6%), but when the supply voltage changed by ± 10%, the deviation of the output current in some cases reached 40% [339]. This is explained by the fact that diadynamic current pulses are formed using the mains supply, and the power supply level of the ASSPS, made in the form of a stabilizing amplifier with a large output impedance, also depends on the mains voltage.

Further studies have shown that a satisfactory result can only be obtained by compensating for the influence of disturbances both at the input of the ETD and deviations at its output.

In the simplest case, this problem can be solved by using two stabilized secondary power sources simultaneously (Fig. 5).

In the above diagram, USSPS with output voltage feedback provides compensation for the influence of mains voltage instability. ASSPS due to feedback on the output current ensures its stabilization with changes in load resistance. Thus, the influence of both perturbing factors is compensated, which makes it possible to fairly strictly dose the effect of electric current. Here, as in the previous case, the doctor sets the current strength in the patient circuit only at the beginning of the procedure, then the current is automatically stabilized.

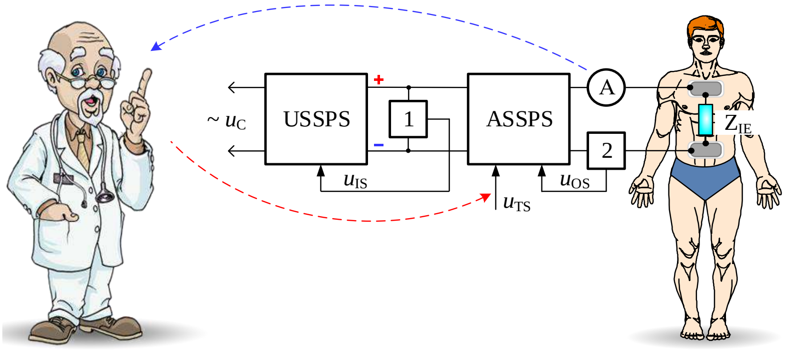



Figure 5. DC electrotherapy machine with USSPS and ASSPS with output current feedback, where 1 – voltage sensor (OV), 2 – current sensor (CS), ASSPS – adjustable stabilized secondary power supply, USSPS – unregulated stabilized secondary power supply

The considered principle of disturbance compensation is used, for example, in the apparatus for galvanization and medicinal electrophoresis "Elesculap", which has rather rigid load characteristics (deviations of the output current when the resistance changes from 300 to 600 Ω do not exceed 2%), and changes in the supply voltage by ± 10 % lead to deviations of the output current by no more than 2% [340].

In the electrical part of the device, the closed circuit for stabilizing the output voltage of the USSPS source is connected in series with the closed circuit for stabilizing the current. In general, this system can be considered as a multi-dimensional stabilization system with two adjustable coordinates (voltage stabilization applied to the ASSPS and current stabilization in the patient circuit). This embodiment eliminates the influence of supply voltage instability on the strength of the acting current. The advantage of the system is that electrical signals are used to organize feedback, which are relatively easy to amplify, transmit over a distance, display and process using modern electronic devices. Feedbacks of closed loops are, as a rule, a proportional link with a transfer function:

$$W(p) = \frac{Y(P)}{X(P)} = k,$$

or an inertial link with a small time constant ($T \cong 0$):

$$W(p) = \frac{Y(P)}{X(P)} = \frac{k}{Tp+1},$$

where $Y(p)$, $X(p)$ – Laplace image, respectively, of the output and input signal of the feedback sensor;

$k$ – encoder gain;

$T$ – time constant of the sensor, determined by its speed.

Another option to compensate for the effect of disturbances on the output current ETD is to use a combined control system (CCS) (Fig. 6), in which the control action $u_M$ is formed not only taking into account the reference signal $u_{TS}$ and the output current feedback signal $u_{OS}$, but also taking into account the input voltage feedback signal $u_{IS}$.

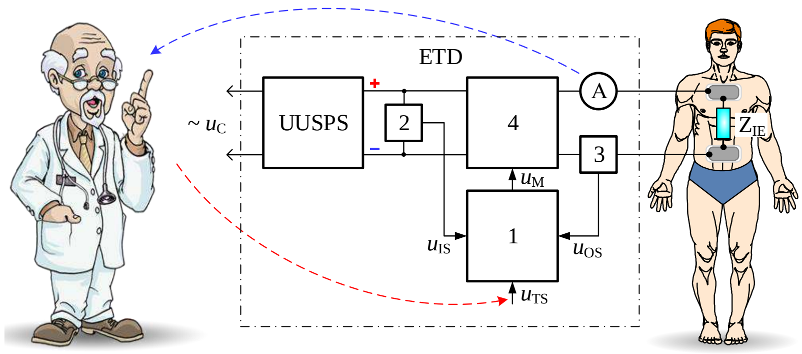



Figure 6. Device for direct current electrotherapy with a combined control system, where UUSPS is an unregulated unstabilized source of secondary power supply, 1 – a combined control system (CCS), 2 – voltage sensor (OV), 3 – current sensor (CS), 4 – regulating element (PE)

The advantage of CCS is that, due to its inertia at the input, it allows you to almost completely compensate for the effects of changes in the input voltage [342].

The doctor sets the current in the patient circuit before starting the procedure. During the procedure, the current stabilizes automatically, but if necessary, its value can be changed in the desired direction (output current setting signal $u_{TS}$). The principles of combined control were used in the development of an apparatus for galvanization and drug electrophoresis ANET-50 GT [343]. Studies of the device showed that the deviations of the output current in the entire range of its regulation (from 0.1 to 50 mA) did not exceed 1% both when the load resistance changed from 300 to 600 Ω, and when the supply voltage changed by ± 10% [340]. Additional functionality of the ANET-50 GT device is automatic limitation of the duration of the procedure at a given level; self-diagnosis of the device when connected to the network and during the vacation procedure; the possibility of exposure to continuous and pulsed current, which during the procedures of drug electrophoresis provides a greater depth of penetration of medicinal substances into the patient's body [344].

An analysis of the above ETD circuit solutions shows that in the course of their evolution they have gone from the simplest devices to fairly complex electrotherapeutic devices with broad functionality (due to microprocessor control) and the possibility of accurately dosing the parameters of exposure to electromagnetic energy during medical procedures.

**Electrotherapy devices and systems of today and tomorrow.** An analysis of trends in the further development of equipment for electrotherapy indicates that there are several main areas:

- use of microprocessor technology, which allows to significantly improve the quality (including the accuracy of dosing of exposure parameters) of medical equipment for therapeutic purposes, program exposure modes with automatic change in parameters, and improve operational performance;

- expanding the functionality of the equipment (several different methods of physiotherapy, including the possibility of their combined use) and the range of regulation of exposure parameters, which will improve existing and create new methods and techniques of physiotherapy;

- application of the principles of biofeedback using biofeedback (BFB), which allow therapeutic equipment to independently adjust the parameters of exposure, taking into account the state of the patient exposed to therapeutic effects of preformed physical factors.

The listed directions of development assume close cooperation of specialists in the field of biology, medicine, electronic, microprocessor, computer technology and programming.

The first two directions are already being successfully introduced into the medical technological process. As for the third direction, with all its prospects, so far only attempts to use the principles of biocontrol in electrotherapy can be noted. It should be noted here that, perhaps, for the first time, separate principles of biofeedback, namely automatic biosynchronization, were used for pacing. Stimulators are controlled from the P-wave or from the R-wave of the electrocardiogram, i.e. from the contraction potentials of the atrium or ventricle [330]. It should be noted that the function of a pacemaker with BFB is not only to synchronize the beginning of the formation of a stimulating impulse with one or another fragment of the electrocardiogram, but also to automatically switch to a fixed rhythm when the heart rate goes beyond the allowable range.

Recently, questions of biofeedback in physiotherapy have been raised more and more often. In particular, it is proposed to use signals from a pulse sensor and a respiration sensor to modulate laser radiation [332]. In this case, the laser radiation power is modulated by three signals. The initial modulation is carried out by a generator signal, the frequency of which periodically changes in the range from 7 to 14 Hz, which corresponds to many physiological processes in the human body. The result of such modulation is a decrease in the radiation power by a factor of three.

When a signal from the pulse sensor appears, the radiation power doubles, and when a signal from the breath sensor appears, it reaches its original value. Thus, in the phases of exhalation and diastole, the radiation power will be minimal, and in the phases of inspiration and systole (the most favorable interval for exposure) it will reach its maximum value.

The generalized scheme of the electrotherapeutic system with biosynchronization is shown in fig. 7. Dosing of exposure (frequency-time parameters, intensity and duration) to the patient by electromagnetic energy (EME) is carried out by the doctor taking into account the appropriate medical technique (setting signal $U_T$).

In the ETD, the alternating mains voltage (ETD connection to the mains is not shown in Fig. 7) is converted into the power supply voltage $u_{PS}$, not only taking into account the reference signal $U_T$ and the feedback signals necessary to stabilize the effect of feedback signals (not shown in the Fig. 7), but also taking into account synchronization signals $u_{S1}$–$u_{Sn}$, which come from sensors of physiological parameters (SPhP) $SPhP_1$ – $SPhP_n$ (in the general case, there may be several such sensors).

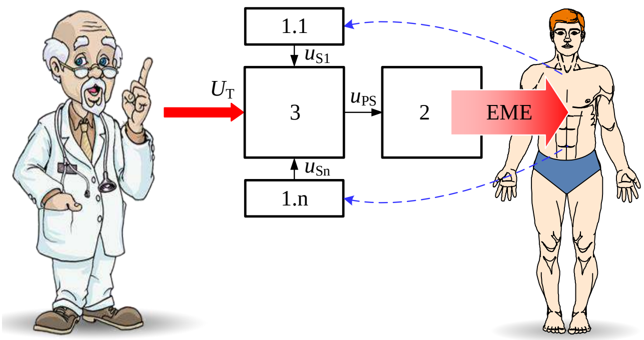



Figure 7. Electrotherapy system with biosynchronization, where 1.1 – 1.n – physiological indicators sensors ($SPhP_1$ – $SPhP_n$), 2 – executive agency (EA), 3 – electrotherapy device (ETD)

The executive body (Executive Agency - EA), converting the supplied voltage uPS, forms an interrupted (pulsating) flow of electromagnetic energy in one form or another (electric current, electric field, magnetic field, electromagnetic radiation). In this case, the intensity (or other parameters) of EME changes synchronously with rhythmically changing physiological parameters in the patient's body.

Another attempt to use the principles of biofeedback is the creation of complexes containing diagnostic instruments (DI) and therapeutic devices (in [343] see the Synergis rehabilitation and prophylactic complex and the Mitera diagnostic device). With the help of the device, continuous (during the procedure) monitoring of the physiological parameters of the patient is provided here, and with the help of the device and its executive body, a flow of electromagnetic energy with certain specific parameters is formed. The scheme of such a complex in a generalized form is shown in Fig. 8.

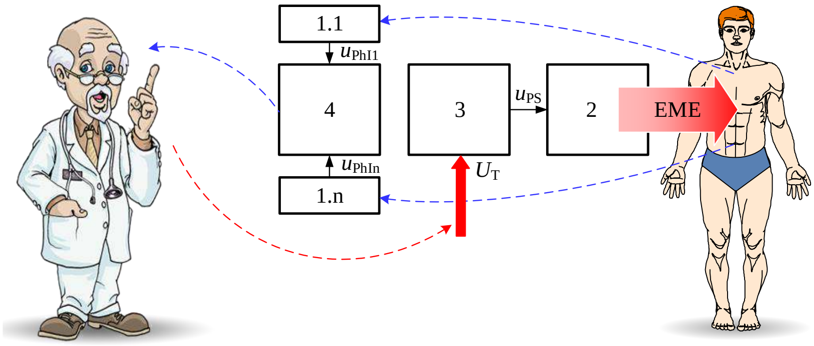



Figure 8. A complex with a diagnostic device and an electrotherapeutic device, where 1.1 – 1.n – physiological indicators sensors ($SPhP_1$ – $SPhP_n$), 2 – executive agency (EA), 3 – electrotherapy apparatus (ETD), 4 – diagnostic instrument (DI)

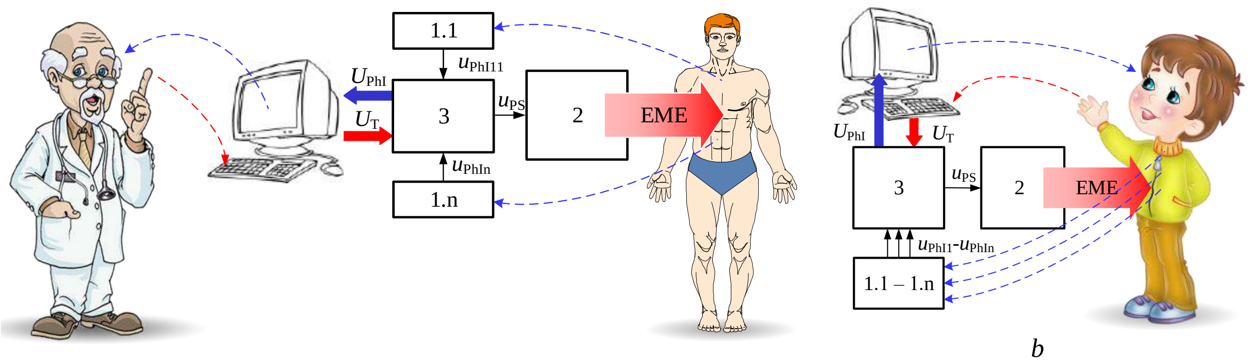
Prior to the start of the procedure, the doctor, in accordance with the chosen method of treatment, sets a certain set of amplitude-frequency-time parameters EME (setting signal $U_T$). In accordance with the task, the device converts the alternating voltage of the supply network (the connection of the ETD to the network is not shown in the figure) into the power supply voltage uPS of the executive body EA. It, in accordance with its purpose, converts the supplied voltage into one or another type of electromagnetic energy with specified parameters.

The diagnostic tool receives information (signals *u*PhI1–*u*PhIn) about the patient's condition, which is taken from his body by appropriate sensors SPhP1 – SPhPn. In the device, this information is converted into a form that is convenient for perception by the doctor. Now the doctor has objective information about the patient's condition. If necessary, he can correct any of the EME parameters within the specified range.

Further improvement of electrotherapy is possible with the creation of intelligent electrotherapy systems (intelligent electrotherapy systems - IETS) with full biocontrol. The essence of such control is that the parameters of EME, which affects a person with a therapeutic purpose, can not only be synchronized with his rhythmic physiological indicators, but also, if necessary, automatically change as a function of the values of such indicators, as well as taking into account anthropological features. The construction of IETS is carried out on the basis of personal computers or specialized microcontrollers (Fig. 9, a), which requires specialized software and methodological support. At the same time, IETS performs the functions of both a diagnostic device and an electrotherapy device. Setting the amplitude-frequency-time parameters of EME and entering the anthropological data of the patient here, the doctor performs using the keyboard and monitor (setting signal and data entry $U_T$). Taking into account all the given parameters and entered data, in IETS the mains voltage (IETS connection to the mains is not shown in the figure) is converted into the $u_{PS}$ power supply voltage for the actuator. EA converts the supplied voltage into electromagnetic energy with specified parameters. During the procedure, information about the physiological parameters characterizing the patient's condition enters the IETS from the outputs of the sensors $SPhP_1$ – $SPhP_n$ in the form of signals $u_{PhI1}$–$u_{PhIn}$. When changing the values of physiological indicators in IETS, a decision is made to automatically adjust the EME parameters, which is accordingly displayed on the monitor screen $u_{PS}$ for executive agency. EA converts the supplied voltage into electromagnetic energy with specified parameters. During the procedure, information about the physiological parameters characterizing the patient's condition enters the IETS from the outputs of the sensors $SPhP_1$ – $SPhP_n$ in the form of signals $u_{PhI1}$–$u_{PhIn}$. When changing the values of physiological indicators in IETS, a decision is made to automatically adjust the EME parameters, which is accordingly displayed on the monitor screen.

With the help of IETS, it is possible to carry out procedures without the participation of a doctor, provided that the patient correctly enters his anthropological data and selects the treatment program that corresponds to the medical purpose (Fig. 9, b).

**SUMMARY.** The most difficult task in the implementation of IETS (as well as similar systems acting on mechanical energy) is to determine such a functional relationship between the parameters of exposure and the physiological parameters of the patient, which would provide the maximum therapeutic effect. To determine such a relationship, the principle of successive approximation in changing the parameters of exposure as a response to a biological response can be used [345]. In addition, fuzzy and genetic algorithms, neural networks and mechatronic modules can be quite effective tools for solving this problem, which is possible due to the use of microprocessor technology for the implementation of IETS.




*a* *b*

Figure 9. Intelligent electrotherapy system with complete biological control: leave the procedure under the supervision of a physician (a); vacation procedure without the participation of a doctor (b), where 1.1 – 1.n – physiological indicators sensors (SPhP1 – SPhPn), 2 – executive agency (EA), 3 – intelligent electrotherapy system (IETS)

Equally important is the choice of the physiological parameters themselves or their various combinations. We would like to draw the attention of developers here, first of all, to bioelectric potentials, since they reflect the most subtle changes in the functioning of organs and tissues of the body. Another criterion for choosing physiological parameters may be the very appointment of physiotherapy, as a means, the purpose of which is the restructuring of the pathological process towards normalization. Thus, by controlling the state of the pathological process (and not only by methods of functional diagnostics), it is possible to optimize the therapeutic effect.

Medical studies show that the use of electrotherapeutic complexes and systems with BFB allows today to reduce the drug load by 1.5–2 times in many chronic diseases; to reduce the number of long-term and frequently ill patients by 50%, in approximately 60% of patients with neurosis, depressive and anxiety disorders, and to completely exclude the use of drugs during treatment. The uniqueness of electrotherapy methods involving the use of BFB is that, being included in the standard program of rehabilitation therapy and rehabilitation, they reduce the recovery time by 2–5 times, and also significantly reduce the frequency of repeated visits and improve the quality of life of patients [345].