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Dear colleagues!

The Federal State Budgetary Institution «All-Russian Scientific-Research Institute for Electrification of Agriculture” is celebrating its 85^{th} anniversary!

Our Institute was set up for the solution of essential macroeconomic tasks in the period of intensive industrialization of agriculture. Electrification was rightfully considered a key factor of intensive economic development and improvement of social standard of the country population.

The Institute team successfully coped with all the tasks the country set for them. It is difficult to overestimate the works carried out at VIESH, which served as the basis of the development of the systems of distributed and centralized electric power supply to agricultural enterprises, of electro-techologies and electric automated systems in animal breeding and fodder production.

Scientific potential of the Institute was so high that during the Great Patriotic War our researchers successfully solved applied military problems. It can be said with confidence that at present the Institute has maintained and expanded all glorious traditions established by preceding generations of scientists.

Our researchers are working in seven comprehensive fields covering the whole range of scientific and technological problems of electric power and energy supply to agricultural enterprises. The Institute is well-known abroad. We maintain good relations with colleagues not only from the countries of the former Soviet Union, but also with scientists from Poland, the Czech Republic, India, Spain, Germany, Norway, the USA and other countries.

Considering all the aforesaid, we are justifiably proud of our Institute and are looking to the future with optimism!

Congratulations with the Institute anniversary, dear colleagues!
New successes in your creative work!

D. STREBKOV,
Editorial Chief

CONTRIBUTION OF VIESH TO THE CONTEMPRORARY PHOTOVOLTAIC TECHNOLOGY

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Development of solar power engineering must be based on original innovative Russian and world technologies. It is necessary to develop promising Russian technologies of manufacturing of photovoltaic cells and semiconductor materials: chlorine free technology for obtaining solar silicon; matrix solar cell technology with an efficiency of 25–30% upon the conversion of concentrated solar, thermal, and laser radiation; encapsulation technology for high voltage silicon solar modules with a voltage up to 1000 V and a service life up to 50 years; new methods of concentration of solar radiation with the balancing illumination of photovoltaic cells at 50–100 fold concentration; and solar power systems with round the clock production of electrical energy that do not require energy storage devices and reserve sources of energy. The advanced tendency in silicon power engineering is the use of high temperature reactions in heterogeneous modular silicate solutions for long term (over one year) production of heat and electricity in the autonomous mode.

Keyword: *solar power engineering, photovoltaic cells, matrix solar cells, high voltage solar modules, solar concentrators.*

Introduction

The role of solar power engineering in the power engineering of the future is determined by possibilities to develop and use new physical principles, technologies, materials, and constructions for development of competitive converters of solar energy [1, 2].

Photovoltaic cells (PCs) or solar cells (SCs), because of ecological purity, inexhaustibility of the power-supply source, and the potential possibility for providing great (lens of gigawatts) outputs with the existing technology are the most practically developed means at present for power generation from the energy of the Sun [3, 4].

The main advantages in the development of the photovoltaic method for power conversion are connected with the development of a planar SC in 1954, whose radiation flux is perpendicular to the plane of *p-n* junction [5]. As a result of the improvement of technology, optimization of physical parameters, and development of production capacities, the efficiency of the planar SC of silicon increased to 15-20% and the cost of SCs decreased by greater than a hundred limes. In connection with the continuous expansion of volume and fields of the application of SCs, physicist and technologist are confronted with problems on the development of SCs of principally new types with parameters that are difficult to obtain by means of planar SCs. For example, the energetic application of the SC is reasonable if the energy flux density through it and the output voltage are commensurable with the parameters of the traditional energy generators. This means that the SC must have a voltage of 100-1000 V and efficiency greater than 20% at energy fluxes around 10 W/cm^2.

Solar photovoltaic plants have been used since 1958 for the power supply of space vehicles and from 1964 for ground consumers [1, 6]. Subject to the high ecological safely, giant renewable solar energy resources, and the fifty-year experience of the development of photovoltaic technology, it becomes more evident that solar photovoltaic plants will play the strategic role in the future power production in the world.

In Russia 40 years ago, models of SCs were proposed that used new physical principles, materials, and structures. These were two-sided SCs transparent for infrared radiation behind the edge of the main absorption band, SCs with the variable energy gap width with a maximum efficiency up to 93%, and matrix solar cells (MSCs) [1, 4, 6]. The theory of the photovoltaic effect during the conversion of the concentrated solar radiation and MSCs with a linear dependence of current and power on the intensity of the concentrated solar radiation in all range of the illuminance, which can be made by modern solar concentrators, were developed. Simultaneously, new types of concentrators and solar modules based on it had been developed. The modern approaches to enhancing the efficiency are connected with the use of the concentrated solar radiation, multistage heterostructures, and nanocrystalline solar cells [7, 8].

Solar grade silicon

Modern solar power engineering is generally based on planar low-voltage solar silicon modules without concentrators with an efficiency of 15% with module production volumes of 37 GW/yr and solar silicon ones of 2×10^5 t/yr.

At the existing level of the SC production (37 GW in 2013), solar modules (SMs) of silicon are greater than 95% output. According to the forecasts of specialists and experts, solar silicon will further predominate in the photovoltaic industry according to the principle that the structure of the resource consumption in the long-term outlook lends to the Earth storage structure. The Earth crust is composed of silicon by 29.5%; only the content of oxygen is greater. The validity of such forecasts is supported by indium costs, which rose after establishment of production of thin-film SMs based on $CuInSe_2$ in 2008 because of a demand increase from $90 to $1000/kg. Solar silicon costs increased also, but this is connected not with resource limitation but with giant paces of the development of silicon solar power engineering by 50% per year.

In spite of the fact that silicon is greater by 98300 times than uranium in the Earth crust, the cost of monocrystalline silicon is only somewhat less that the cost of uranium, which is connected with the outmoded dirty chloric technology of production (Siemens-process) [9]. The All-Russia Research Institute of Agriculture Electrification (VIESH) developed unique chlorine-free technologies of silicon production with low energy losses, which received eight RF and US patents [4].

The use of electric-arc and plasma technologies makes it possible to obtain silicon raw product with purity corresponding to the purity of silicon with solar quality at energy consumption by ten limes less than at with chlorosilane technology. Russia has giant reserves of naturally pure quartz, which make it possible to develop solar power plants of crystalline silicon with a power greater than 1000 GW.

The SPP with a power of 2.5 TW corresponding lo the total power of all ground power plants will demand 3×10^5 t of silicon at a concentration of 100, which is comparable with the silicon production volume for electronics and solar power engineering.

Specimens of solar cells were made under the laboratory and experimental-industrial conditions on the basis of polycrystalline silicon ribbons on ceramics and graphite cloth, dendritic-web silicon ribbons, and profiled silicon ribbons obtained by drawing through dies, including ones in the form of thick-walled tubes and polyhedrons. The efficiency of solar cells of ribbon silicon attains 14%. Production technologies for thin ribbons of polycrystalline silicon have been developed beginning in 1967; however, their efficiency is no greater than 14% up to now.

Heterophotovoltaic cells

The St. Petersburg Physicotechnical Institute under the direction of Zh.I. Alferov and V.M. Andreev developed the technology for GaAIAs-GalnAs high-efficiency multistage heterophotovoltaic cells. The heterophotovoltaic cell properties to maintain the efficiency at a thousandfold concentration of solar radiation make it possible to develop high-efficiency specimens of modules with the concentrators of a power 10-15 W and power generating units based on such modules with a power to 500 W [10]. Therefore, recognizing and emphasizing the outstanding role of heterophotovoltaic cells based on A_3B_5 and other semiconductor materials in the development of photovoltaic technology, solar silicon by its resource capabilities and prospects for cost reduction may by considered as the general material for large-scale solar power engineering in the future. This is conditioned by the low cost of planar silicon SCs. In 2012, planar solar silicon modules cost $1 per 1 W at the cost of SMs based on A_3B_5 of $350/W. To occupy the market niche in large-scale solar power engineering at a level of 1 TW, solar modules with multistage heterostructures must use 500-1000-fold concentration and have no resource limitations with respect to gallium; silicon SCs have a 3-5-fold concentration now and, possibly, one-fold concentration in the future with a decrease in the cost of silicon occupying 60% in the SC cost structure. The thousand fold concentration requires precision tracking systems, whose cost is $200/kW together with the concentrators field. In addition, high-precision concentrators use only direct solar radiation, which is no greater than 50% total solar radiation under condition of the median belt of Russia. With developing plasma technologies for obtaining silicon and the presence of unbounded resources of silicon raw materials on Earth, the silicon SM cost will decrease to $0.5/W in the next 10 years. The single and very significant parameter of SMs, where silicon is worse than A_3B_5 by a factor of 1.5-2 in industrial specimens, is the efficiency of solar cells. The fast development of solar nanocells in recent years leads to doubling the efficiency of the nanocrystalline silicon SCs and to shortening the discontinuity in the efficiency of solar energy conversion between SCs of silicon and compounds A_3B_5.

New photovoltaic technologies, semiconductor materials, and new types of solar cells have been developed that make it possible to enhance their efficiency and to decrease the cost of the electric energy output [4, 8, 11].

Film solar cells have been developed on the basis of heterojunctions with the use, as base materials, of cadmium sulfide, cadmium telluride, triple compound $CuInSe_2$, and amorphous compounds of silicon, germanium, and silicon carbide and on the basis of nanostructures and organic semiconductors [12]. The greatest efficiency is attained on $CuInSe_2$ heterostructures; however, the efficiency of film SCs is lower than the efficiency of SCs of monocrystalline materials. This substantial lag with respect to the efficiency will also remain in the future.

High Efficiency silicon solar cells

Physical principles of the photovoltaic conversion of the concentrated radiation have been developed. In this case, the concentration of radiation-injected carriers exceeds the concentration of majority carriers, the usual theory of the linear photoresponse stops to operate, and new physical phenomena occur |7]:

(i) photoconduction permitting for eliminating the problem of internal Joule power losses;
(ii) increase in life time of minor charge carriers;
(iii) formation of volume electric voltages;
(iv) enhancement of the efficiency of separation of generated carriers; and
(v) an increase in the voltage on the *p-n* and isotype p-p^+ junctions to a value equal to the equilibrium potential barrier height.

In the field of theoretical investigations, a set of complex theoretical models and constructions of SCs has been constructed and developed, maximum efficiencies for various models have been found, and conditions for realization of different models of SCs with the variband structure were determined. These efficiencies correspond by 93% to the thermodynamic Carnot cycle. In the case of the n^+-p-p^+ structure in which the photo-emf generation occurs also on the isotype p-p^+ junction, the coincidence of conditions of complete carrier collection, photo-emf generation close to the value determined by the energy gap width, and obtaining a maximum efficiency of 44% for silicon SCs turn out to be possible [7].

The scientific organizations and firms in many world countries develop solar silicon modules of the third generation with an efficiency of 25% and more, which are applicable to large-scale industrial production. The planar solar silicon cells and modules with efficiency to 25% were developed by Professor M. Green from New South Wales University (Australia); however, they are not produced because of the complex and expensive technology of their manufacture. Planar SMs with an efficiency of 20% are produced by Sun Power Co. (United States) on an industrial scale; however, they have a high cost that limits their application. None of the known planar silicon SMs are used at concentrated solar illumination because of an abrupt decrease in the efficiency with increasing the illuminance. At present, all works in Russia and abroad produce silicon SMs with an efficiency of 15-18%. To increase the efficiency of SMs greater than 25% under mass production, there is a need to apply new physical principles, new construction, and new technologies for making SMs.

Up to now, it is assumed that the *p-n* junction, in the electric field of which the separation of minor charge carriers generated by solar radiation occurs, plays the key role, and its area must correspond to the SM area. However, the *p-n* junction has negative properties. Its region has recombination losses. The dark current of saturation, which is connected with the thermal generation of charge carriers, flows through the *p-n* junction that results in a decrease in the photo-emf. The alloyed layer over the plane of the *p-n* junction has a great spreading resistance that increase ohmic loss especially at the conversion of the concentrated solar radiation. The alloyed layer absorbed the short-wave fraction of solar radiation because of loss on free charge carriers, and its effect on the photocurrent is insignificant because of the recombination of charge carriers on defects of the crystalline structure and impurity centers in the strong-alloyed semiconductors.

Scientists of VIESH proposed to separate the spatially illuminated surfaces of SMs on regions of the charge carrier generation and regions with the *p-n* junction, which are chargeable for separation and collection of carriers. At the same time, the area of the alloying layer with the *p-n* and p-p^+ junction on illuminated surfaces is decreased greater than fifty times, and 99% of the surface area is allotted for generation of electron-hole pairs under the direct interaction of quants of solar radiation with the base region of the SM [8].

High Voltage Solar Modules

In Russia in 1967, high-voltage solar modules (HSMs) of the first generation were made in the form of a silicon solid-state matrix of the tandem or parallel commutated microelements with vertical *p-n* and *p-n* junctions. The density of microelements on the operating surface of the HSM was 25 cm^{-2}, and the efficiency was 1-2% at an illumination intensity of 7700 kW/m^2.

In 1970, the ion implantation technique was used for development of HSMs of the second generation with an efficiency of 10% at an illuminance of 2.5 kW/m^2. The microelement density was increased tenfold to 250 cm^{-2}, and the voltage of the HSM with an area of 4 cm^2 was 400 V. The solar battery of HSMs with an area of 1 m^2 and voltage of 32 kV was developed and tested in 1972. The solar module 40 × 100 mm in size with an operating voltage of 28 V was mounted on the Venera-70 interplanetary station and successfully tested. The efficiency of 36% and electric power of 3.6 kW/cm^2 were obtained at the 10 kW/cm^2 intensity of the illumination of the HSM by a pulse neodymium laser [8].

Among foreign authors, D.L. Sater is the most well known, who developed experimental specimens of HSM with an efficiency of 20% at an illuminance of 2500 kW/m^2.

The VIESH is developing high-voltage solar silicon modules with a voltage of 1000 V with an efficiency to 25% at a solar radiation concentration of 50-100 and a service life to 50 years [8]. The test record sheet of an independent foreign laboratory supports the high efficiency of HSMs. The parameters of solar cells of various types are listed in Tables 1 and 2.

High-voltage solar silicon modules have two times the service life (40-50 years) and an efficiency of 18- 22% at 50-200-fold concentration. The HSM efficiency of 18-22% remains at an increase in temperature to 60°C that makes their cooling system to be simplified at the operation with concentrators. Increasing service life can be provided, if solar module operation temperature will be not higher 80^{o}C.

The operating voltage of 1000 V makes it possible to use HSMs with transformerless invertors and to connect with high-voltage line of direct current with a voltage of 110-500 kW without converter substations. To obtain an operating voltage of 1000 V with the use of traditional planar solar modules, there is a need to connect sequentially greater than 1800 planar solar cells 150 × 150 mm in size with a total module length exceeding 300 m.

All existing constructions, materials, and technologies for making solar modules provide the twenty-year service life of modules in a tropical climate and 25 years in moderate climate with a loss to 20% of power to the end of the service life. The cause is the ultraviolet and temperature degradation of polymeric sealing materials - ethylene vinyl acetate and other plastics. The operated technique for module lamination includes vacuumizing,

Table 1

Parameters of photovoltaic cells of various types for spacecrafts

Parameter	**Type of SC**		
	planar silicon [14]	**planar multistage heterogeneous gallium arsenide-based [14]**	**matrix silicon with concentrators [8]**
Efficiency at an atmospheric mass spectrum of 0 and a temperature of 28°C	14-16	19	19
Specific power at an atmospheric mass spectrum of 0 and a temperature of 28°C, W/m^2	150-175	260	260
Operating voltage, V/cm^2	0.5	2.0	16.0
Temperature coefficient of efficiency, deg^{-1}	-2.5×10^{-3}	-1.4×10^{-3}	-1.4×10^{-3}
Cost of 1 kW, arb. units	1	500	2
Manufacturer	Kwant Соф., www.nppkvant.ru Saturn Corp., www.saturn.kuban.ru	Spectrolab Inc., www.spectrolab.com Emcore, www.emcore.com Azur Space Solar Power GmbH, www.azurspace.com	VIESH, www.viesh.ru

Table 2

Characteristics of planar and high-voltage silicon SMs

Parameter	Solar module	
	high-voltage	planar
Voltage, V	1000	12-24
Service life, years	40-50	20-25
Average efficiency ai a solar radiation of 1 kW/m^2, atmospheric mass spectrum of 1.5, and temperature of 25°C, %	12-15	15
Efficiency at a concentrated solar radiation of 100 kW/m^2, atmospheric mass spectrum of 1.5, and temperature of 25°C, %	18-22	1

Table 3

Economic characteristics of solar modules of various types

Characteristic	Standard modules with EVA sealing	Modules of VIESH with sealing by silicon gel
Service life of modules, years	25	40
Electric energy output for service life, kW h/kW:		
in Russia	25000	40000
in south countries	37 500	60000
Income of the electric energy sale for the service life of modules with a power of 1 kW:		
in Russia at a cost of 9 ruble/(kW h), rubles	225000	360000
in southern countries at a cost of $0.48/(kW h), $	18000	28800
Income of the electric energy sale for the service life of modules with a power of 2 MW:		
in Russia, rubles	450000000	720000000
in southern countries, $	36000000	57600000
Income of the electric energy sale for 5 years of line operation at a module production of 2 MW/yr:		
in Russia, rubles	2250000000	3600000000
in southern countries, $	180000000	288000000

heating to 150°C, and compacting with an electric energy consumption of 80000 kWh for making 1 MW solar modules. Ethylene vinyl acetate and lamination in a new technique developed in the VIESH are changed for pouring with a silicon composition with aftercuring the liquid component in polysiloxane gels. This increases the service life of solar modules twice (to 40-50 years), the electric power of modules rises owing to the high transparency of gel and decreasing the operation temperature of SCs, and power inputs for making modules decrease by 70000 kW h/MW. In addition, because of doubling the service life, the power production increases by 20 million kW h per 1 MW of peak power [13].

Let us calculate production volumes of the production and sale of electric energy in the case of solar modules with increased service life.

For Russia, 1 kW of solar modules produces 1000 kWh of electric energy in year. The electric energy production in southern countries is 1500 kW h/yr.

Table 3 lists economy characteristics of solar modules of VIESH technology with sealing by silicon gel and standard silicon gels with sealing by the ethylene vinyl acetate (EVA) film.

The cost of the electric energy of the solar power plant 100 kW in power in Belgorod oblast is 9 ruble/(kW h); and that of the solar power plant 100 kW in power in Ukraine is $0.48/(kW h).

At the total volume of the SM production in 10 MW tor five years, the anticipated income of the sale of electric energy with the use of modules with increased service life is greater than of the sale of electric energy with the use of solar modules with EVA sealing in Russia by 1.35 billion rubles and in southern countries by $108 million.

The development of the production technology for HSMs of third generation based on single-crystalline silicon makes it possible to produce solar power plants with concentrators [15] at lower specific costs per 1 kW of the installed capacity and higher efficiency of the electric energy production in comparison with thermal power plants operating on coal. The HSM production technology is prepared to conditions of mass output and does not require the application of silver, meshgraphy, photolithography, and other labor intensive operations and expensive materials. The modern processes of semiconductor electronics and nanotechnologies make it possible in the next years to enhance the efficiency of the conversion of the concentrated solar radiation with the use of HSMs based on matrix solar silicon cells in the industrial production by 25% and a maximum electric power to 50 W/cm^2 at the conversion of the concentrated solar radiation.

Solar Concentrator Modules

The VIESY developed and patented solar concentrators with Sun tracking with a concentration of 50-500 and stationary concentrators without Solar tracking with a concentration of 3—5. Both types of concentrators provide the uniform illumination of solar photovoltaic modules that is extremely significant during the operation of SPPs with concentrators. Nontracking concentrators concentrate not only direct but a greater fraction of the diffuse (scattered) radiation in the range of the aperture angle, which increases the installed capacity of the SPP and the electric energy production. Designs and technologies of the production of HSMs and SPPs with concentrators were protected by greater than one hundred RF patents [16].

Solar planar silicon modules have been sold in 2014 by a prime cost of $0.945/W in Germany and $0.792/W in China [17]. The module cost is $141.75/m^2 in Germany and $ 118.8/m^2 in China at an average efficiency of 15%. In spite of the fact that the cost of the installed power of solar power plants is lower than for coal and nuclear power plants, the cost of the electric energy output by solar power plants exceeds this parameter for traditional energy sources. The general cause is the low installed capacity utilization factor (ICUF) of solar power plants: from 0.114 in Germany to 0.17 in Anapa (Russia) and 0.25 in equatorial countries. To compensate the low ICUF, there is a need to decrease further the cost of solar sells and modules and to use solar concentrators.

The main requirements for solar concentrators for planar solar silicon modules are the concentration coefficient no greater than 5 under condition of the natural cooling of modules and the use of diffuse radiation in a range of the aperture angle of the concentrator. Such concentrators are developed in Russia in the stationary performance for the coverings and elevations of buildings and with tracking systems for installation on the ground [16]. At the cost of specular reflectors of $20/m^2, concentration of 5, optical efficiency of 85%, and electrical efficiency of 15%, the cost of the solar module with the concentrator will be $86.58/m^2 and $0.378/W for Germany; i.e., it decreases by a factor of 2.5. At the same time, costs of the concentrator and the receiver will be approximately equal and be 50% of the cost of the module. The cost of the solar module with the concentrator for China decreases to $52/m^2 and $0.349/W, i.e., by a factor of 2.27.

The optimum concentration for high-voltage solar silicon modules is 50-60 under condition of decreasing temperature coefficient of the efficiency by twice in comparison with temperature coefficient of the silicon HSM without concentrators [8]. At the same time, the cost of the solar concentrator module is determined not by the cost of the photodetector but by the cost of the concentrator and the system of cooling and Sun tracking. Heat dissipation arrangements include water circulation unit and heat exchanger.

Solar power engineering

The European Photovoltaic Industry Association (EPIA) published the forecast of the development of solar power engineering in 66 countries, presenting 95% of the population. According to the forecast of the EPIA, the electric power of SPPs in these counntries will be 60–250 GW to 2020 and 260–1100 GW to 2030 or 27–58% of total power of SPPs on Earth. The cost of the electric energy of SPPs will be 6–12 eurocent/(kW h) [$(0.076–0.152)/(kW h)] in 2020 and 5–8 eurocent/(kW h) [0.063–0.101 US dollar/(kW h)] in 2030.

The problem of the continuous round-the-clock and year-round energy output by solar power plants is general in the development of the global nonfuel power engineering and in the provision of its competitiveness with the fuel power engineering. The VIESH developed and patented regional and global solar power systems that make it possible to output and deliver electric energy to consumers independently of the time of day and seasons without the application of storage devices and standby generators [18].

Let us consider another possible field of the use of silicon as fuel for energy output. This field can be named silicon power engineering by analogy

Table 4

Comparison of the combustion heat of silicon and hydrocarbons

Reaction	Fuel	Combustion heat, kJ/mol
(1)	Silicon	858
(2)	The same	858
(2) + (3)	*n*	1144
(4)	*n*	754
—	Methane	879
—	Coal	812
(3)	Hydrogen	286
(5)	Sodium silicate	35.6×10^6
—	Fuel oil	$35.6 \times I0^3$

with hydrocarbon power engineering. Four ways of silicon application for power engineering purposes are well known [18]:

(i) combustion of silicon within atmospheric oxygen

$$Si + O_2=SiO_2. \quad (1)$$

(ii) catalytic combustion of silicon within water

$$Si + 2H_2O=SiO_2 + 2H_2; \quad (2)$$

$$2H_2+O_2=2H_2O. \quad (3)$$

(iii) catalytic combustion of silicon within nitrogen

$$Si + 2N_2=SiN_4. \quad (4)$$

(iv) physicochemical reactions within the melt of sodium silicate

$$sNa_{2r}\ SiO_{(2r+s)} \Rightarrow Na^+ + Si_mO_n. \quad (5)$$

Table 4 lists combustion heats of silicon and hydrocarbons.

Analysis of Table 4 shows that the raw and end products of silicon power engineering are non-radioactive, do not pollute environment, and do not produce greenhouse gases. Silicon, as a fuel, is twice better than coal and approximately equivalent to natural gas by the combustion heat at burning in air and also twice better than coal on binding with nitrogen during oxygen-free burning. The thermal energy of high-temperature physicochemical reactions in heterogeneous media of high-modular silicate solutions, for example, sodium silicate, exceeds by 1000 times the combustion heat of the hydrocarbon fuel with the same mass [18].

The estimated cost of electric energy, which is obtained from the electrochemical current source with the melted electrolyte of the nonstoichiometric composition based on sodium silicate with the megawatt power level, is €80/(MW h).

Dynamically developing solar power engineering based on the innovative Russian and world technologies is the alternative to fuel power engineering, will prevail in 2050 on the market of energetically pure technologies, and will provide 75-90% of total Earth demands in electric energy to the end of the 21st century [19].

Conclusions

1. The development of solar power engineering must be based on the original innovative Russian and world technologies.

2. There is a need to apply VIESH technologies for manufacturing photovoltaic cells and semiconductor materials:

(a) chlorine-free technology for obtaining solar silicon;
(b) matrix solar cell technologies with an efficiency of 25–30% upon the conversion of concentrated solar, thermal, and laser radiation;
(c) encapsulation technologies for high-voltage silicon solar modules with a voltage up to 1000 V and a service life up to 50 years;
(d) new methods of concentration of solar radiation with the balancing illumination of photovoltaic cells at 50-100-fold concentration;
(e) solar power systems with the round-the-clock production of electrical energy, which are not required energy storage devices and reserve sources of energy.

3. The promising tendency in silicon power engineering is the use of high-temperature reactions in heterogeneous modular silicate solutions for long-term (over one year) production of heat and electricity in the autonomous mode.

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NONCONTACT POWER SUPPLY FOR LAND AND MARINE ELECTRIC TRANSPORT

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Noncontact electric power supply with the use of cable line is an innovative trend in the development of electric transport. Work to develop such systems is carried out in the USA, South Korea, Germany, Israel, the Russian Federation.

The VIESH researchers have developed and patented experimental models of a car and a tramway of the future without accumulators, which receive energy from external energy system through air gap from a single wire cable laid under the surface of road pavement. Noncontact systems for electric power supply to transport are developed at VIESH on the basis of resonant methods of electric power supply through a single-wire cable. This is a basic difference of the technology under consideration from similar ones.

Electric power from the source is supplied to an electrical receiver through the air gap between the car bottom and road pavement where single-wire line has been laid. When a car is in motion, electric power costs will amount to 1 USD per 100 km of the road. Electric cars price will be reduced twice due to the absence of accumulators and will be less expensive than cars with internal combustion engines. Moreover, ecological problems of large cities and highways will be completely solved. Electric power supply systems without trolleys will increase reliability of tramways and high-speed trains and will allow to use heavy electric trucks on inter-city highways.

Our experiments demonstrate that electric energy can be transmitted through the sea water. The working prototype of the motor boat with water drive through the speed reduction gear from the direct current motor has been developed and fabricated. Energy to the motor boat is supplied through the water volume where the boat is, as water plays the role of a single-wire electric power transmission line.

Keywords: *electric car, electric submarine, noncontact electric power supply, Tesla transformer, noncontact charging.*

Introduction

Noncontact electric power supply with the use of cable line is an innovative trend in the development of electric transport. Work to develop such systems is carried out in the USA, South Korea, Germany, Israel, the Russian Federation (Fig. 1, 2).

N. Tesla patented the contactless method of electric power supply to rail vehicles from single-conductor cable laid in ground. In his letters dated June 14 and 17, 1905 N. Tesla wrote: «…by the use of a generator [transmitter] of stationary waves and receiving apparatus properly placed and adjusted in any other location, however remote, it is practicable to transmit intelligible signals or to control or actuate at will any one or all of such apparatus for many other important and valuable purposes... [or] other features or property of disturbances of this character.

Electricity is displaced by the transmitter in all directions, equally through the earth and the air;

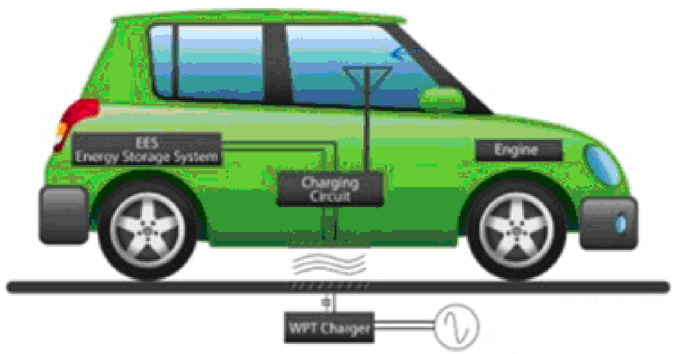


Fig. 1. Stationary charging system for a vehicle-borne battery

Fig. 2. Contactless energy supply system for eco-friendly vehicles

that is true, but energy is expended only at the place where it is collected and used to perform some work. Although the electrical oscillations would manifest themselves all over the earth, at the surface as well as high in the air, virtually no power would be consumed.

Electromagnetic energy of the transmitter is sent to any place on Earth or its atmosphere where there is a receiver with resonant frequency, tuned to the transmitter‘s frequency».

Noncontact single-wire cable power system

The VIESH researchers have developed and patented experimental models of a car and a tramway of the future without accumulators, which receive energy from external energy system through air gap from a single wire cable laid under the surface of road pavement. Contactless systems for electric power supply to transport are developed at VIESH on the basis of resonant methods of electric power supply through a single-wire cable (Fig. 3). This is a basic difference of the technology under consideration from similar ones [1].

Electric power from the source is supplied to frequency converter 1, resonance contour 2 step-up Tesla transformer 3, single-wire line 4, an electrical receiver through the air gap between the car bottom and road pavement where single-wire line has been laid (Fig. 4). Than to step-down Tesla transformer 5, resonance contour 6, rectifier 7, inverter 8, electric drive 9, electric motor 10.

At Fig. 5-9 the models for electric induction wireless power transmission are demonstrated.

When a car is in motion, electric power costs will amount to 1 USD per 100 km of the road. Electric cars price will be reduced twice due to the absence of accumulators and will be less expensive than cars with internal combustion engines. Moreover, ecological problems of large cities and highways will be completely solved. Electric power supply systems without trolleys will increase reliability of tramways and high-speed trains and will allow to use heavy electric trucks on inter-city highways.

Electric tractors and robotized automobiles used in agriculture, will receive electric energy from

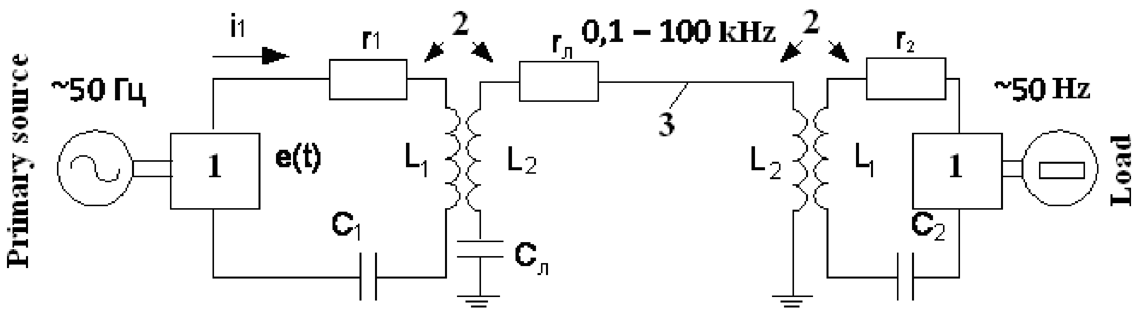


Fig. 3. The resonant system for electric power transmission:
1 - frequency transformer; 2 - resonant high-frequency Tesla transformer; 3 – single conductor line

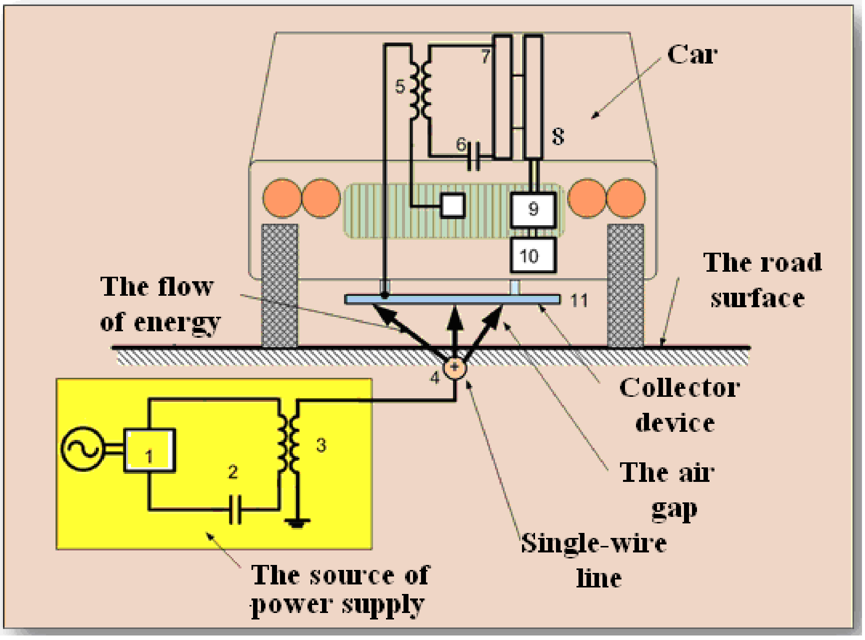


Fig. 4. The diagram of energy supply for noncontact high-frequency electric vehicles

Fig. 5. The component of the physical demonstration model for electric induction noncontact power transmission (assembly stage)

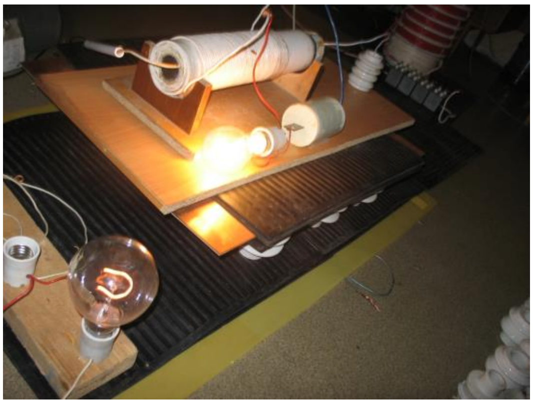


Fig. 6. The component of the physical demonstration model for electric induction noncontact power transmission (tests: load power – 1 kW; transmission distance – 0.1 m; efficiency – no less than 0.9; 16 kHz; 6.5 kW)

Fig.7. The prototypes of the systems for noncontact electric power supply to electric tractor

Fig. 8. The prototypes of electric car with power supply from single conductor cable line laid in road pavement

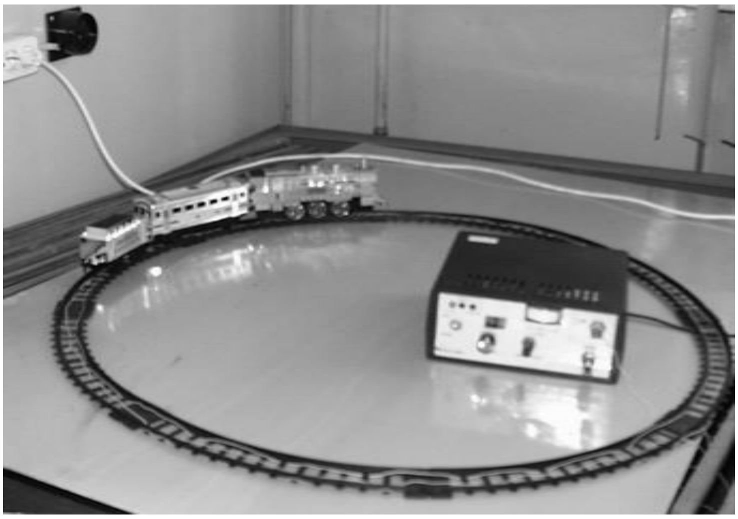


Fig. 9. The prototype of electrified railway with a single conductor resonant system for electric power supply

a cable laid in ground, but for this purpose a special permanent track for left and right trains of wheels of electrified automobiles should be provided. Electrified mobile robots with external wireless electric power supply will make it possible to organize agricultural production on the basis of the principles “Industrial Plants on Fields” with full automation of technological processes.

Marine electric power system

Sea space is also excellent conductive medium for transmission of energy and information between equipment on the shore and sea ships with the use of resonant methods.

That is what N. Tesla wrote on this issue: “In the near future we shall see a great many new uses of electricity aiming at safety, particularly vessels at sea. We shall have electrical instruments for preventing collisions, and we shall even be able to disperse fogs by electric force and powerful and penetrative rays. I am hopeful that within the next few years wireless plants will be installed for the purpose of illuminating the oceans. The project is perfectly feasible, and if carried out will contribute more than any other provision to the safety of property and human lives at sea. The same plant could also produce stationary electrical waves and enable vessels to get at any time accurate bearings and other valuable practical data without resorting to the present means. I t could also be used for time signaling and many other purposes of similar nature.

The new principle can also be applied to a submarine, and, particularly in connection with control from great elevation, it will afford the most perfect means for coast defence so far devised. But its full possibilities will only be appreciated when the use of certain electrical waves to which the earth is resonantly responsive becomes general. It will then be practicable to dispatch a crewless boat or balloon to distances of hundreds of miles, guide it along any chart at will and release its potential energy at any point desired” [1].

Electromagnetic waves are weakly absorbed by sea water and ground and thus can be used in the systems for underwater and underground information transmission. Electromagnetic waves attenuation in sea water is as follows:

$$\alpha(f) = 0{,}00345\sqrt{f} \quad \text{dB/m}.$$

At frequency f = 100 Hz wave attenuation at 300 m depth amounts to 90 dB.

Our experiments demonstrate that on sea water and ground not only electronic information but also electric energy can be transmitted. This means, for example, that marine transport vehicles can receive energy and information from water without any elevated antennas (Fig. 10-20) [2].

At Fig. 10 the high-frequency energy source 1 is connected through the capacity 2 with the low-voltage winding 3 of the step-up Tesla transformer 4. The high-voltage lead 5 of the high-voltage winding 6 is connected with natural capacity 7 made in the form of a sphere and installed at regulated height h_1 from sea surface 8 at the shore 9. The low potential lead 10 of the high-voltage winding 6 of the Tesla transformer is connected by the electrically insulated cable 11 with sea medium 8 with cable immersion depth h_2. At the end of the cable 11 in the sea medium 8 wide-band or narrow-band antennas for electric power transmission in the intended direction, can be installed. The energy source 1 with resonant capacity 2 and the step-up high-frequency Tesla transformer 4 are placed in the container 12 on the shore 9 of the sea 8. Electric power from the energy source 1 is transmitted from the seashore to the submarine ship 13. Aboard the submarine ship 13 inside the hull 14 the high-frequency step-down Tesla transformer 15 is installed. The high potential lead 16 of the high-voltage winding 17 is connected with the natural capacity 18, installed inside the ship 13. The low potential lead 19 of the high-voltage winding 17 is connected with the use of the cable 20 with sea medium 11. The low-voltage winding 21 of the high-frequency Tesla resonant transformer 15 is connected through the capacity 22 and the inverter 23 with the electric load 24. As the electric load 24, electric circuits of the submarine ship and the energy storage system are used (not shown at Fig. 10).

At Fig. 11 electric power from the energy source 1 on the shore 9 of the sea 8 is transmitted through sea medium 8 to the step-down high-frequency resonant transformer 15 with the capacity 22 and the inverter installed in the container 25 aboard the surface ship 26. The natural capacity 18 is installed over the ship at regulated height h_3.

At Fig. 12 the container 12 with the high-frequency source of electric energy 1, the capacity 2 and the step-up Tesla transformer 4, is installed aboard the surface ship 27. The natural capacity 7 is installed over the ship 27 at the regulated height h_4. Electric power from the source 1 aboard the surface ship 27 is transmitted through sea medium to the resonant step-down transformers 15 with the capacity 22, the inverter and natural capacity 18 installed aboard the submarine ship similarly to Fig. 10 and aboard the surface ship 29 similarly to Fig. 11.

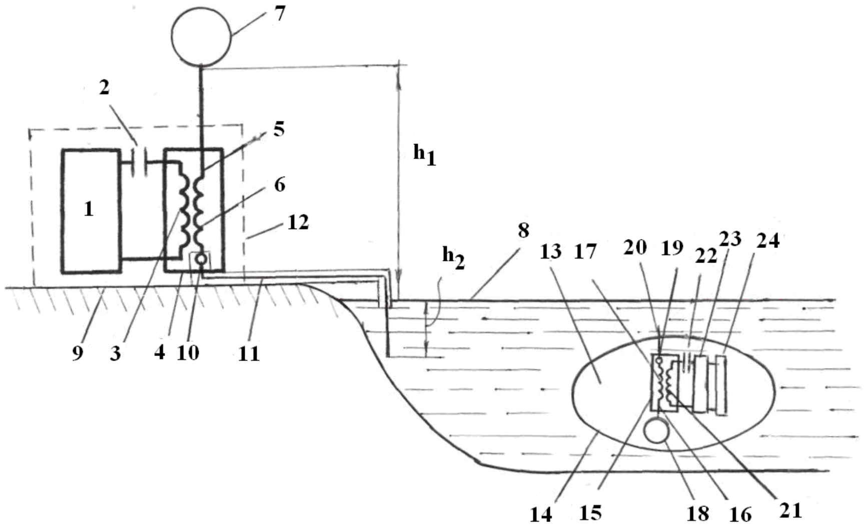


Fig. 10.The resonant wireless system for electric power transmission from the energy source on the sea shore to the submarine ship

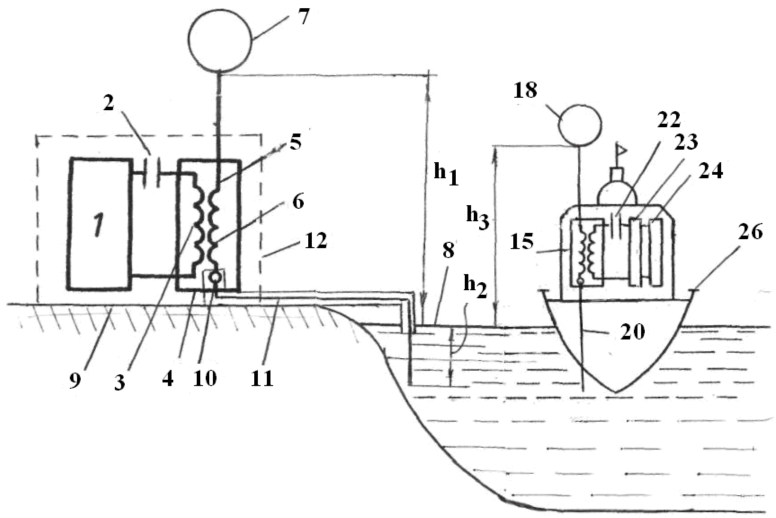


Fig. 11. The resonant wireless system for electric **power transmission from the energy source on the shore to the surface ship**

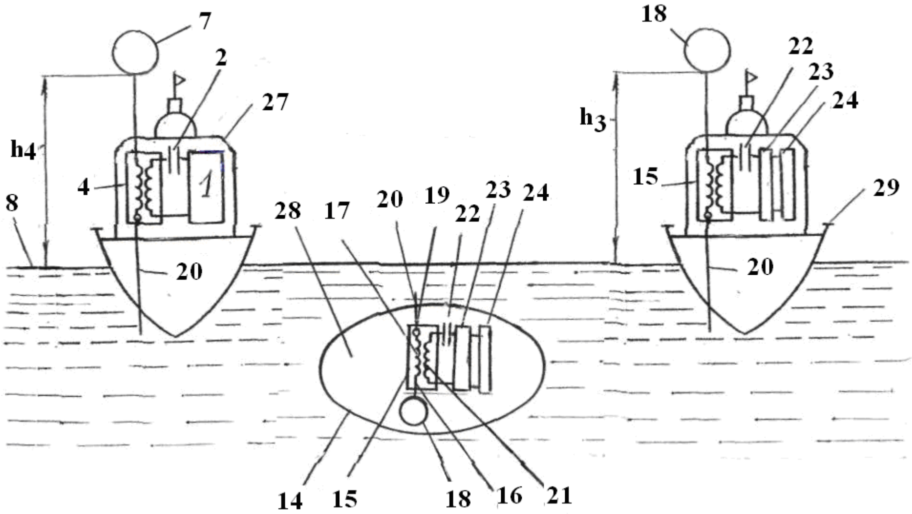


Fig. 12. The resonant wireless system for electric power transmission from the energy source at the surface ship to the submarine and surface ships

At Fig. 13 the high-frequency source of electric energy 1, the step-up high-frequency resonant Tesla transformer 4 with the capacity 2 and the natural capacity 30 are installed aboard the submarine ship 31. Electric power from the source 1 is transmitted through the sea medium 8 to the resonant step-down high-frequency transformers 15 with the capacity 22 and the natural capacity 18 installed aboard the submarine ship 32 similarly to Fig. 10 and aboard the surface ship 33 similarly to Fig. 11.

At Fig. 14 the high-frequency energy source 1 is connected through the resonant capacity 2 with the low-voltage winding 3 of the step-up resonant Tesla transformer 4. The low potential lead 5 of the high-voltage winding 6 is grounded. The energy source 1 with the resonant capacity 2 and the step-up high-frequency resonant Tesla transformer 4 are installed in the container 7 at the shore 9 of the sea 8. The high potential lead 10 of the high-voltage winding 6 of the Tesla transformer 4 is connected through electrically insulated cable 11 with the conducting channel 12 of the pipe 13 made of electrically insulating material with internal build-in shield 14. Insulating jacket of the pipe is made of two-layer fiberglass or cross-linked polyethylene between which screening layer of copper, aluminum or steel is imbedded. The pipeline 13 is filled with sea water and installed at the bottom of the sea 8 between the energy source 1 and submarine apparatus 15 consuming electric energy. At the ends of the pipe 13 electrically insulated inputs 16 and 17 are installed for electric power supply and extraction. Electric power from the energy source 1 is supplied from the sea shore through the conducting channel 12 with sea water to the submarine apparatus 15. Aboard the submarine apparatus 15

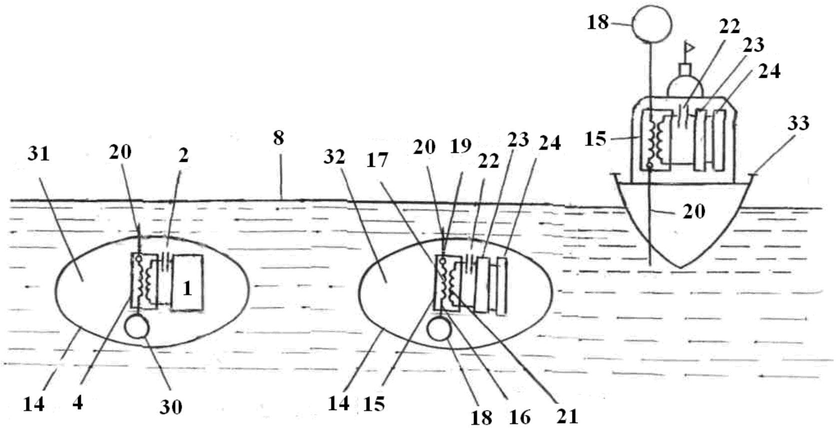


Fig. 13.The resonant wireless system for electric power transmission from the energy source aboard the submarine ship to the submarine and surface ships

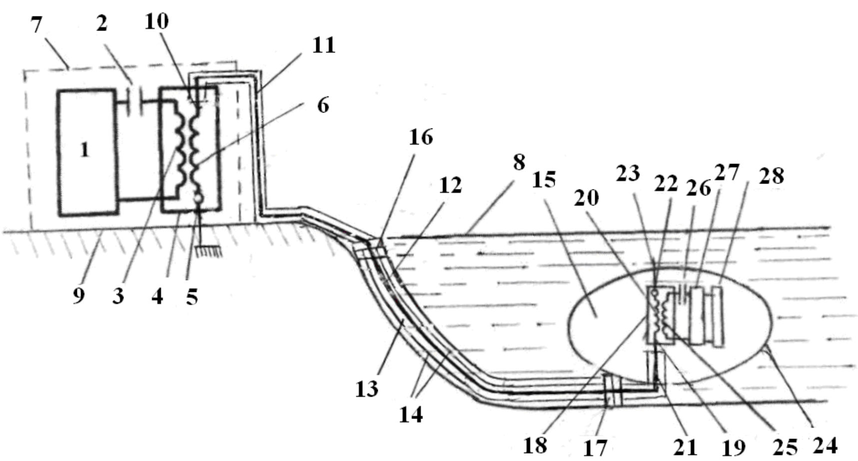


Fig. 14. The resonant system for electric power supply to stationary submarine units

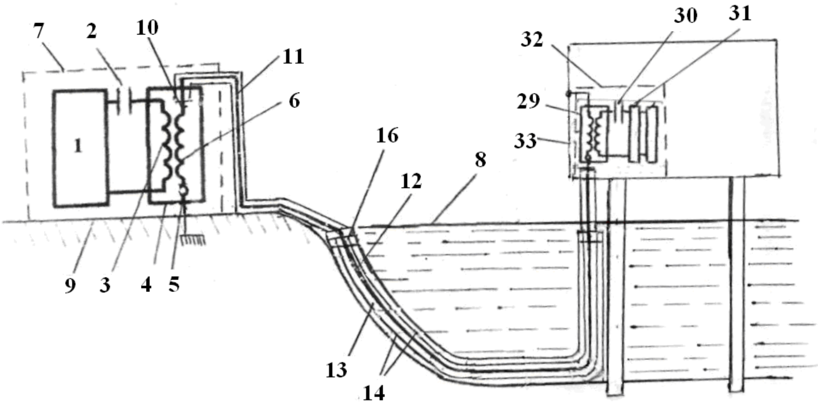


Fig. 15. The resonant system for electric power supply to drilling platforms in the shelf area

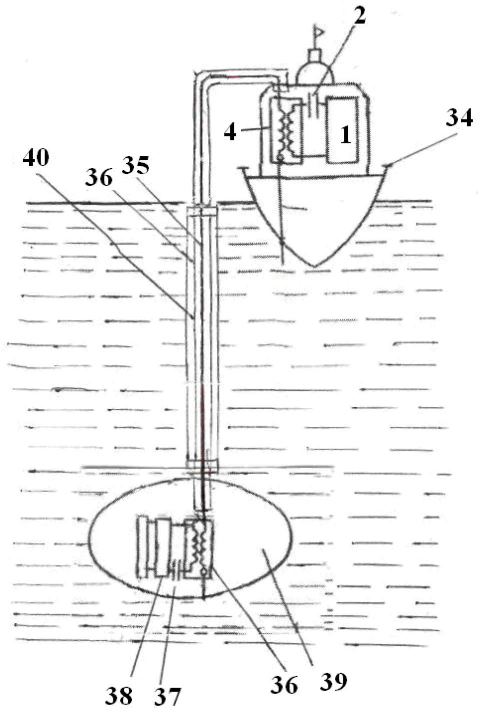


Fig. 16. The resonant system for electric power transmission to the deep-sea vehicle

inside the hull 16 the high-frequency step-down resonant Tesla transformer 18 is installed. The high potential lead 19 of the high-voltage winding 20 is connected by the electrically insulated cable 21 with the opposite end of electrically insulated pipeline 13 filled with sea water. The low potential lead 22 of the high-voltage winding 20 is connected by the cable 23 with the hull 24 of the submarine apparatus 15. The low-voltage winding 25 of the step-down high-frequency resonant Tesla transformer 18 is connected through the capacity 26 and the inverter 27 with the electric load 28. As the electric load 28, the electric systems of the submarine apparatus and energy accumulators (not shown at Fig. 4) are used.

At Fig. 15 electric power from the energy source 1 at the shore 9 of the sea 8 is transmitted through the conducting channel 12 with sea water to the step-down resonant transformer 29 with the resonant reservoir 30 and the inverter 31 installed in the container 32 at the drilling platform 33 on the sea 8. The resonant system at Fig. 15 makes it possible to transmit electric power to any stationary objects aboard the sea ships lying out far from the shore, etc.

At Fig. 16 the container 32 with the high-frequency source of electric energy 1, capacity 2 and the step-up Tesla transformer 4 is installed aboard the surface ship 34. Electric power from the source 1 aboard the surface ship 34 is transmitted through the conducting channel 36 with sea water to the resonant step-down transformer 36 with resonant capacity 37, the inverter 38 installed aboard the submarine ship 39 similarly to Fig. 14. The pipeline 36 is made of electrically insulated material with zero buoyancy, and the coating of the pipeline 36 with the inbuilt shield 40 has density close to that of sea water. In the result, the mass of the pipeline 36 with the conducting channel 35 is reduced, thus providing the possibility to transmit electric power to deep-sea vehicles with depth of immersion down to 10 km and more. In addition, there is the possibility of vertical movement of the deep-sea vehicle at the cost of changing the length of the pipeline 36 and the possibility of horizontal movement of the deep-sea vehicle.

At Fig. 17 the high-frequency electric energy source 1, the step-up high-frequency Tesla transformer 4 with the resonant capacity 2 are installed at the submarine unit. Electric power from the energy source 1 is transmitted through the conducting channel 42 in the electrically insulated pipeline 43 with sea water to the resonant step-down high-frequency transformers 44 with the resonant capacity 45 that are installed at the submarine unit 47 similarly to Fig. 15.

The working prototype of the motor boat with water drive through the speed reduction gear from the direct current motor has been developed and fabricated. Energy to the motor boat is supplied through the unearthed water volume where the boat is, as water plays the role of a single-wire electric power transmission line.

The general view of the motor boat prototype receiving electric energy through surrounding water in unearthed water medium, and the flow diagram of its electric power supply in water medium are presented at Fig. 18 - 20.

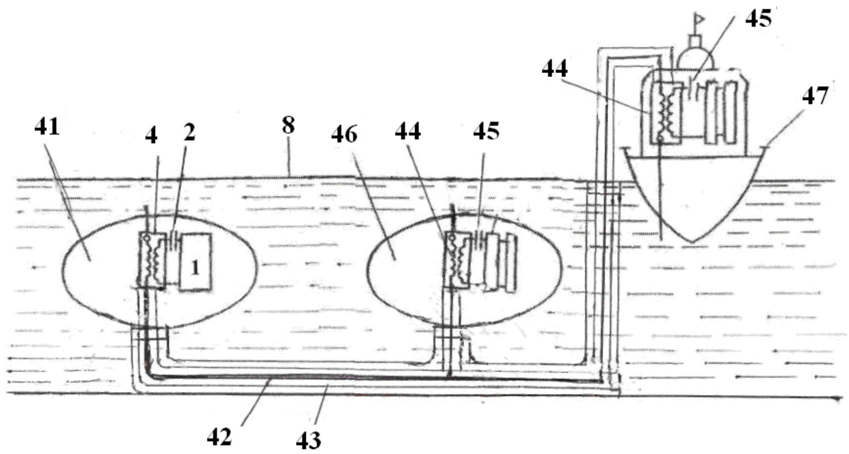


Fig. 17. The resonant system for electric power transmission between the stationary submarine and surface energy consumers

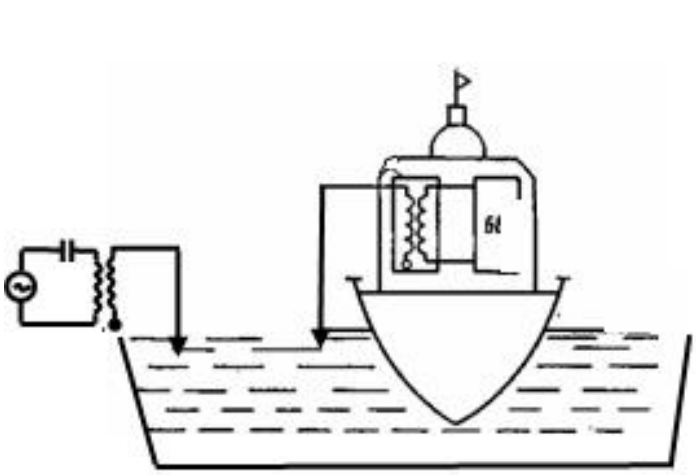
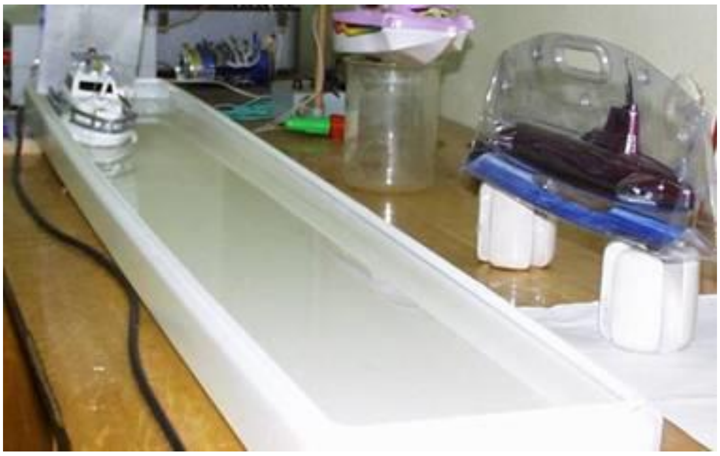


Fig. 18. The diagram of electric power transmission to water transport with the use of the water conducting channel; testing of the prototype of an electric river boat at the VIESH laboratory with the use of tap water as a single-wire wave guide. The transmitting unit has 100 W electric power and 1 kV voltage



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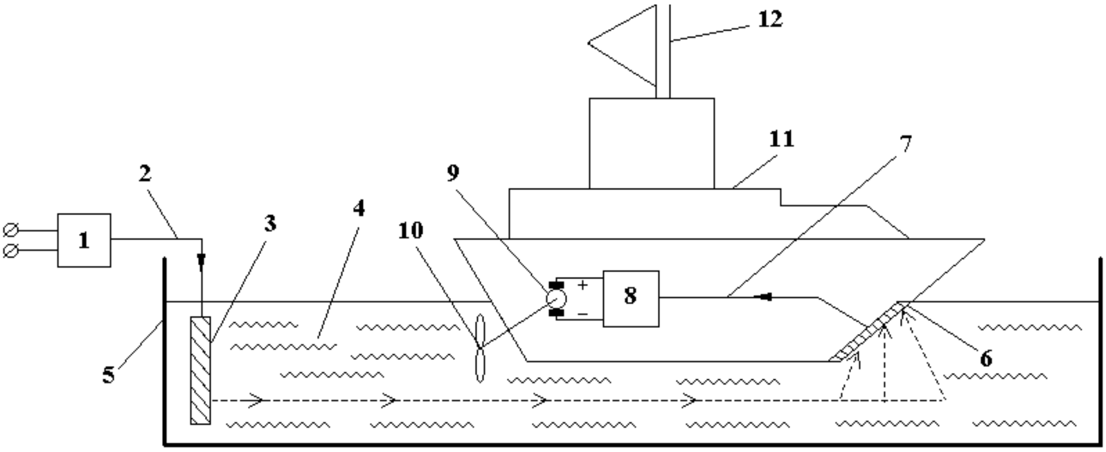

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Fig. 19. The prototype of the electric motor boat (a);
the flow diagram of electric power supply in water medium (b):
1 – resonant generator; 2, 7 – single-wire line; 3 – transmitting electrode; 4 – water; 5 – tank; 6 – receiving electrode; 8 – receiving unit; 9 – electric drive; 10 – propeller; 11 – motor boat; 12 – natural capacity

Fig. 20. The motor boat receiving electric energy through sea medium

At Fig. 19 the lead of the transmitting step-up transformer of the resonant generator 1 is connected with the electrode 3 located at any point of the unearthed channel with tap water, and the receiving electrode 6 fixed at the boat hull, is connected with the high-voltage lead of the receiving step-down transformer of the receiving unit 8 installed at the boat as well. Voltage lowered down to 12 V and rectified, is supplied to the direct current motor 9 setting in motion the propeller 10.

Conclusions

1. Noncontact electric power supply with the use of cable line is an innovative trend in the development of electric transport. Work to develop such systems is carried out in the USA, South Korea, Germany, Israel, the Russian Federation.

2. The VIESH researchers have developed and patented experimental models of a car and a tramway of the future without accumulators, which receive energy from external energy system through air gap from a single wire cable laid under the surface of road pavement. Noncontact systems for electric power supply to transport are developed at VIESH on the basis of resonant methods of electric power supply through a single-wire cable. This is a basic difference of the technology under consideration from similar ones.

3. Electric power from the source is supplied to an electrical receiver through the air gap between the car bottom and road pavement where single-wire line has been laid. When a car is in motion, electric power costs will amount to 1 USD per 100 km of the road. Electric cars price will be reduced twice due to the absence of accumulators and will be less expensive than cars with internal combustion engines. Moreover, ecological problems of large cities and highways will be completely solved. Electric power supply systems without trolleys will increase reliability of tramways and high-speed trains and will allow to use heavy electric trucks on inter-city highways.

4. Our experiments demonstrate that electric energy can be transmitted through the sea water. The working prototype of the motor boat with water drive through the speed reduction gear from the direct current motor has been developed and fabricated. Energy to the motor boat is supplied through the water volume where the boat is, as water plays the role of a single-wire electric power transmission line.

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STANDARD REQUIREMENTS TO ELECTRONIC TRAINING OF SAFETY OF PRODUCTION

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The first edition of the national standard "Information and communication technologies in education. Electronic training of safety of production. General provisions". Requirements to innovative processes of preparation, instructing and certification of the personnel with use of information and communication systems and technologies are considered. Standardization of requirements to electronic training of the personnel on safety of production is a necessary factor of impact on decrease in operational injuries and is production the caused incidence.

Keywords: *national standard, safety of production, electronic training, preparation, instructing, certification.*

The existing normative documents regulating a training order on safety of production and labor protection contain the general requirements to the organization of training, instructing and examination that defines their importance, but thus in them doesn't contain any requirements to the computer programs and systems applied to automation of these processes. Meanwhile computer preparation and personnel certification on safety of work are the prevailing form of training and educational activity in the sphere of safety of production now.

Now accurate criteria of an assessment of computer programs aren't created, there is no uniform terminology, aren't formulated generalized, clear for developers and consumers of the requirement to computer training and control of knowledge of safety of production. All this doesn't allow users to show the reasoned («lawful») requirements for the quality of the specified software products. High-quality and timely preparation, objective certification of the personnel for safety of production are an important factor of impact on decrease in operational injuries and is production the caused incidence of employees of the organizations and enterprises.

The first edition of the developed national standard "Information and communication technologies in education. Electronic training of safety of production. General provisions" establishes the general requirements to systems of electronic training of safety of production, an order of formalization of knowledge of safety of production, ways of use of the formalized knowledge and data during the training and personnel certification, to an order of formation of the electronic worker and reporting documentation. Requirements to the contents and the maintenance of educational programs for safety of production by certain professions and professional groups aren't considered. Systems of electronic training of safety of production are considered as the multipurpose professional tools for the experts who are organizing and carrying out preparation and personnel certification within the approved (operating) educational programs for safety of production which is supplementing and increasing possibilities of professionals, but not excluding their obligatory participation during the training and certification of the personnel [1-7].

The first edition included sections: Scope, Standard links, Terms and definitions, General provisions, Structure of systems of electronic training of safety of production, Functional purpose of systems of electronic training, Formalized data of systems of electronic training, Formalized knowledge of systems of electronic training, Processes of preparation, instructing, certification, Requirement to an order of formation of electronic documentation, Reporting documentation, Requirements to efficiency of systems of electronic training of safety of production, Indicators of quality of systems of electronic training.

At realization of preparation, instructing and certification for safety of production various forms of the organization of electronic training, including mobile, network, autonomous, mixed, joint, and various educational technologies, including with use of remote educational technologies are used.

For preparation, instructing and examination on the basis of electronic training it is necessary to use the formalized knowledge on the basis of the existing specifications and technical documentations and rules in the form of the text and graphic descriptions including system of the interconnected text descriptions in the form of questions, answers and explanations to them and the system of graphic descriptions supplementing them in the form of set of the dynamic pictures changing depending on the executed actions.

The electronic system of training has to ensure safety of production formation of information model of competences of the worker on the safety of production allowing to define and quickly to adjust the program of individual vocational electronic training of workers for safety of production for the subsequent procedures of electronic certification of the personnel for realization of the operated personnel policy and creation of safe working conditions on production.

Systems of electronic training of safety of production should be carried out in the form of easily adaptable user covers on the basis of the expert technologies consisting of independently working modules allocated on a functional purpose and type of the knowledge and actions having the multilevel interrelations excluding accumulation of contradictory knowledge and incorrect data localized in each module (fig. 1).

Necessary simplicity and availability of operation of systems of electronic training has to be reached by control of systems for a certain professional level of the examined or trained worker, for performance of a separate task, group of tasks or for work with their totality.

Systems of electronic training should be intended for realization of the following main functions:

- maintaining base of professional data on the personnel having training, instructing and certification and about the personnel organizing these processes;
- maintaining base of data on instructing on a workplace;
- electronic control and reminder of the dates of the instruction and knowledge tests;
- formation of additional target systems of electronic training, questions and comments to them, designing of graphic descriptions according to requirements and rules of any subject domain;
- preparation according to the document or the created program (on the allocated group of text and graphic descriptions in the demanded volume) in full accordance with order of instructing and certification, both in browse mode of questions and answers, and in a verification regime of knowledge, at the request of the trainee;
- control of knowledge with an assessment only correctness of the answer, with possibility of obtaining explanations to the wrong answers, with an assessment of a total time of certification of the worker;
- formation and the printing of the current working documentation – electronic sheets and protocols of preparation and certification taking into account the information fields which are in addition entered by the user.

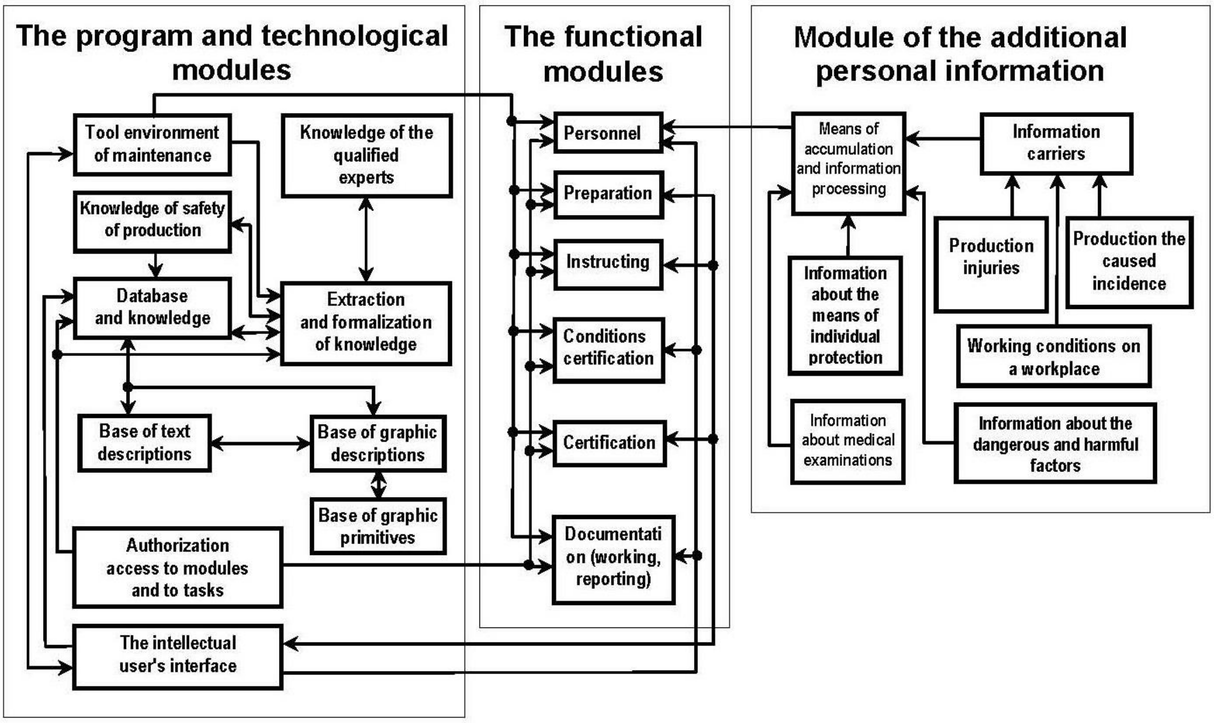

Fig. 1. Functional and technological structure systems of electronic training of safety of production

Intellectual systems of electronic training it is necessary to realize the following additional functions:

- maintaining base of data on harmful production factors, medical examinations, means of individual protection, short data on accidents with the workers involved in preparation, instructing and certification;
- formation of electronic programs of preparation, instructing and certification with use of system signs (types of documents, types of installations, characteristics of installations), keywords and phrases;
- formation and the printing of reporting output documentation, including in professional editors, including the magazine of registration of instructing on a workplace, the magazine of examination on labor protection, the minutes of the commission on examination;
- the centralized updating of questions and graphic representations of target electronic systems and addition of the target electronic systems entering industrial delivery;
- authorization of group and personal access to modules, actions and functions of systems of electronic training depending on category of the user.

Network systems of electronic training it is necessary to support:

- possibility of an operating control and intervention in the modes of training and examination;
- comparison of the formalized knowledge and results received in the course of preparation and certification on network objects;
- use of means of the operational network electronic help;
- confidential character of the formalized data circulating in networks all and knowledge of safety of production.

The data on the personnel applied in systems of electronic training on safety of production are subject to single input and repeated use in various modules, the accompanying, working and reporting documentation and make the personified knowledge of systems of electronic training with the base of text and graphic descriptions corresponding to them.

Knowledge of safety of production has to make a basis of all procedures of training, instructing and control of knowledge, formations of the accompanying documentation, to be applied in filling of all system actions and functions of systems of electronic training.

The technology of accumulation and replenishment of the knowledge base has to allow the user nonprogrammer to develop and adapt easily system of electronic training for concrete production features, independently to reflect changes in subject domain (the operating system of rules and requirements), to accumulate knowledge, experience and skills of professionals.

The technology of replenishment of professional text knowledge in system of electronic training has to include the simple easily acquired procedures of formalization of text information with use of multilevel structures of obligatory data input with control of an inaccuracy, consistency and repeatability of data.

The standard technology of auto formalization of the text knowledge used in systems of electronic training has to be designed for not programming professional and to include use of semantic (text) structures (QUESTION – ANSWERS – JUSTIFICATION CORRECT ANSWER) in the form of productions (rules) like «IF... THAT», possessing modularity and allowing to organize their effective search, adjustment and compilation.

The question, answers to it and justification of the correct answer have to be strictly logically interconnected, and the question and the correct answer have to reflect fully and unambiguously contents of a certain requirement, situation or its part if that can be allocated without violation it to logical integrity, and promote fixing of skills and abilities of workers. Justification of the correct answer has to include at least full contents of a certain requirement, provisions.

Answers to a question (correct and incorrect) have to be under construction with semantic distinctions, the having different semantic accents and with the minimum differences in completeness, accuracy and visual configuration, without allowing use trivial (the well-known, very simple) information as distinctive signs of answers.

The finished semantic (text) representation describing some finished task and beginning with the functional verb indicating the main operation of the performed work has to be the main form of the answer.

When using in systems of electronic training of graphic descriptions for formalization of knowledge of safety of work these descriptions should be carried out in the form of the interconnected drawings reproduced by sets of primitives in which transition from display of current state of a situation to everyone to the subsequent has to be made at the corresponding actions with elements current accompanied with text messages.

Creation of the graphic descriptions imitating the adverse working conditions, emergency situations, accidents arising at operation of various types of the equipment has to be made by search and configuration of primitives from an arsenal available that has to provide public structuring experience and knowledge of highly qualified specialists for acquisition by trainees of steady professional skills with the subsequent objective control of results of preparation.

The volume of text and graphic descriptions according to the concrete normative document (subject domain) has to reflect completely the requirements of this document available to formalization by text, text and graphic and graphic procedures, and if necessary, can be supplemented with audio and video materials.

For preparation and certification of the personnel for a concrete profession, the specialty, technological process, a type of works, etc. responsible for preparation and control of knowledge the relevant groups of questions and graphic descriptions are formed (in the presence) to which unique names are appropriated.

The formed modular electronic program of preparation and certification has to consist of the blocks containing the general professional and obligatory knowledge, skills, abilities; skills and knowledge of safe performance of separate production targets and concrete works; if necessary facultative knowledge in the form of system of professionally significant safe actions and operations.

The modular electronic program has to provide its modification in individual taking into account the order for training, the level of the available preparation, information model of competences of the worker on safety of production.

Systems of electronic training are developed and delivered as the program covers developed in use accumulating and showing knowledge not only the qualified specialists responsible for preparation and certification, but also knowledge of the instructed and trained workers.

Process of preparation of the personnel on safety of production has to be organized irrespective of other functional elements of system of electronic training taking into account type and the characteristic of the served equipment, professional criterion of the trainee with control according to a certain information requirement and information model of competences of the worker on safety of production.

The module of preparation has to be available to the trainee without preliminary control by the expert responsible for preparation, at any convenient time, both before certification, and after it.

By electronic preparation the feedback mechanism, fixing of knowledge and skills should be provided with fast and unambiguous response of system of electronic training to each specific action of the trainee with expeditious presentation of estimates, justifications of the correct decision (answer) and possibility of repeated repetition of procedures of training.

As a basis of universal processes of preparation it is necessary to use the standard emergency situations structured with use of descriptions of violations of operating modes of the equipment and installations, accidents and injuries and formalized in the form of rules and graphic images as a part of the knowledge base and if necessary to include audio and video of representation.

Systems of electronic training it is necessary to maintain confidentiality of preparation which excludes negative emotions by search of the correct answer and possibility of obtaining information by other trainees on degree of correctness of answers.

Processes of electronic instructing should be organized in addition to oral work responsible for briefings (instructing) which include acquaintance and studying of safety requirements of production and the labor protection containing in local regulations of the organization, instructions on labor protection, technical, operational documentation.

It is necessary to provide possibility of fixation of data on the instructed worker in necessary volume for formation of the electronic magazine of registration of instructing which structure is approved by existing rules.

In the special module of system of electronic training it is necessary to concentrate the necessary actual knowledge and data on conditions of control of knowledge of workers formed responsible for certification, including as the obligatory:

- the name of group of the certified workers and the skill level corresponding to it reflecting degree of complexity of questions;
- order of presentation of justification of the correct answer at certification;
- number of questions for certification;
- quantity of questions in the ticket on a certain type of the document (subject domain) from among the certified which are earlier chosen according to this document for this group;
- conditions of calculation of an assessment of certification for the «tough» scheme of the correct and wrong answer or on the «soft», considering degree accuracy of answers;
- time of the answer to one question;
- condition of presentation to time for the answer certified the rest;
- the total time spent by the certified worker for control of knowledge.

Questions and graphic descriptions are shown certified in limited volume (in the form of a certain ticket) from among earlier selected for this professional group and used by electronic preparation, in a random way with an exception of repetitions in the subsequent tickets (for example, in the subsequent to five), with control of the set number of questions according to this document in the ticket.

Possibility of fixation of data about certified in necessary volume for formation of electronic sheets and protocols of certification, magazines of examination which final structure is established responsible for certification has to be provided or is approved by existing rules.

Output documentation of systems of electronic training has to have the flexible structure which is adjusted by the user and reflect the established existing requirements to reporting documentation and need of the user for fixation of the data, knowledge and data necessary for the organization of effective preparation, instructing and examinations of the personnel in production and in training centers.

By means of a special module of system of electronic training should ensure implementation of custom procedures for forming and printing of magazines of instructing and control of knowledge, protocols for examination according to the requirements to reporting documentation existing at the moment.

When forming reporting documentation in electronic form it is necessary to provide possibility of entering of necessary changes and additions into structure and contents of documentation, its placement on the firm carrier.

Should provide the ability to print documents in the public reporting a text editor (for example, Microsoft Word) while maintaining it in a unique file in the form of fully corresponds to the image copy format. Editing the contents of each file, including change of an arrangement and contents of graphic and text information, with technology, habitual for the editor's user, has to be allowed.

System effectiveness of electronic training of safety of production can be estimated by a complex of technical, economic, social indicators by results of improvement of a security status of production and working conditions, to be considered proceeding from interests and opportunities of concrete production and to make a main objective of life cycle of systems of electronic training.

Quality of systems of electronic training of safety of production should be determined by functional suitability, reliability, efficiency, applicability, maintainability, mobility.

Conclusions

1. Standardization of requirements to electronic training of the personnel on safety of production should be considered a necessary factor of impact on decrease in operational injuries and it is production the caused incidence of employees of the organizations and enterprises in the conditions of universal application for preparation and control of knowledge of workers of software which quality influences formation of steady safe production skills.

2. Systems of electronic training on safety of production have to be carried out in the form of open software in telecommunication networks of the organizations supporting possibility of filling of systems if necessary additional knowledge and information of corporate appointment, simplicity of operation as not programming professional users, and any users regarding functions and modules for them intended without any special training with preservation of the demanded confidentiality level.

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REGULARITIES OF CHANGING OF SPECIFIC INDICATORS OF ELECTRIC ENERGY CONSUMPTION IN ANIMAL BREEDING

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The article presents the dynamics of standard capacity of electric drive of technological equipment used in animal breeding, the analysis of factors lowering standard capacity and their relation with standard electric power consumption.

Keywords: *standard capacity of electric equipment, energy consumption in animal breeding, reduction of energy consumption.*

Manufacturing of products, including agricultural ones, demands consumption of energy – fuel, electric and thermal power. The development of prospective specific indicators (standards) of energy and electric power consumption is necessary for determination of demand for energy resources, the elaboration of measures for rational energy supply, improvement of energy use efficiency. In this connection, it is important to reveal causes, to assess affecting factors and to determine regularities of development of standards and amounts of energy consumption both at present and in the long term.

In the total amount of electric energy consumption in animal breeding over 75% is accounted for by energy consumption by electric drives and heating elements of plants used for technological processes: manure removal, feeding, ventilation, water supply, as well as equipment repair and maintenance. To study regularities, quantitative indicators of electric drives capacity (kW) and equipment capacity for performance of specific work (in tons, $м^3$) have been analyzed. This specific indicator have been chosen as “standard capacity” per unit of work: kW/ m^3 – for ventilation plants, plants for water supply and water consumption and kW/ton for plants transporting bulk products. Changes of values of specific capacity of electric drives of agricultural equipment in various periods of agriculture development have been analyzed [1]. The dynamics of changes of specific capacity (established standard) as time function is decreasing. Dependences for assessment of changes of specific capacity (established standard) of drives for basic processes – feeding, manure disposal, indoor ventilation, are given in Table 1. High values of certainty factor of approximation (R^2) and their decreasing character confirm certainty of calculated dependencies.

Table 1

Process	Dependence	R^2
Feeding	$y = 0,3733\ e^{-0,159x}$	**0,9417**
Manure disposal	$y = 0,8952\ e^{-0,137x}$	**0,7932**
Ventilation plants	$y = 4,4159\ e^{-0,946x}$	**0,9863**

The analysis has shown that the rates of decreasing of the values of specific capacity of equipment used in animal breeding were higher in the period before 1990. Slowing of decreasing rates is most significant after 2000. The lines of values trends are described by exponential equations. The properties of exponential functions allow to use these equations for assessing the character of behavior of the value being described, that is, of *required* power in the near and long range. The dynamics of the values of the equipment specific capacity per unit of equipment, including their long term values, can be the basis for determination of prospective values of energy consumption for processes, technologies, as well as for determination of long-term electric power consumption in various branches of animal breeding.

Such dynamics of lowering of equipment specific capacity is accounted for by scientific and technological progress, introduction of new technologies and more advanced equipment, as well as by influence of outrunning growth of electricity tariffs. Electricity tariffs growth requires the development and use of more energy-saving equipment and implementation of measures for raising energy efficiency. The dynamics of reduction of specific capacity of equipment being used for various periods of time demonstrates the progress in improvement of equipment, increasing of its capacity, reduction of metal consumption and changing of some technical and economical features reducing energy costs per unit of work.

While determining required capacity of the transporters electric drive, major factors are (Formula 1) the volume and mass of load being transported, dead load of equipment, distance and speed of load transportation. In addition it is necessary to consider reserve capacity at start of the engine, as well as the plant efficiency. In general form the equation for calculating the required capacity of the electric drive can be written as :

$$P_{\text{р}} = k_{з} \frac{F_{\text{м}} v}{\eta_{\Sigma}}, \qquad (1)$$

where $P_{\text{р}}$ – calculated capacity of the electric drive; $k_{з}$ – coefficient of reserve (increased capacity for safe start of the engine); $F_{\text{м}}$ – mechanical force (weight of load being transported); v – speed of movement, η_{Σ} - total efficiency of the plant (engine, transmission).

Decreased dead load of the equipment, increased scope of work being performed and higher efficiency of the plant (from 0.4-0.6 to 0.7-0.9) also contribute to reducing power consumption of the electric drive. While calculating the required capacity of the electric drive for plant operation it is necessary to multiply capacity value by coefficient $k_{з}$ equal to 1.3-1.5 depending on starting method and the engine control. In the process of improvement of transporters, reduction of required capacity of the drive is achieved by decreasing reserve coefficient, which has become possible due to the use of advanced plants with soft start and control of the electric drive speed. Due to advanced methods of the electric drive control, reserve coefficient has been considerably decreased and now amounts to less than 1,2 [2]. Improvement of the technological process itself involves the rule and requirement of increasing energy efficiency. Thus the use of frequency regulation made it possible to transfer to continuous water supply with lesser power energy consumption per 1m^3 and spent for required pressure generation.

Over 50% of total amount of consumed energy is spent on providing microclimate, including ventilation plants, that is, on the ventilator drive. Lowering of equipment required capacity is achieved through stage-by-stage replacement of centrifugal ventilators in the system for air supply through transfer ducts. The use of distributed air ducts for inlet ventilation demands high capacity and energy consumption because of considerable aerodynamic resistance in the sophisticated air supply system. For organized supply of fresh heated air advanced technologies increasingly use roof and ducted ventilators with imbedded heating systems. The implementation of ventilation plants with improved aerodynamic and technical characteristics also contribute to reduction of required capacity (established standard) and energy consumption in the process of maintaining necessary microclimate parameters. With the use of the energy utilization pattern reflecting share of each process in total amount of electric energy consumption at an enterprise, weighted averages of standard capacity and their changes for the long period being studied, have been determined. The diagram of changing of total weighted average of equipment specific capacity (standard capacity) in basic processes at animal breeding farms is shown at Fig. 1.

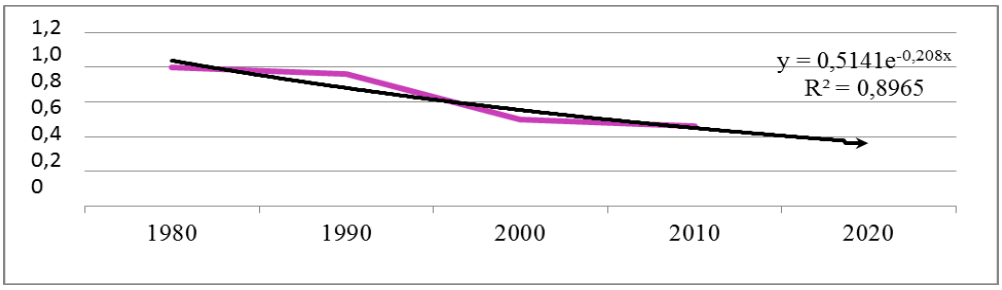

Fig. 1. Dynamics of weighted average of standard capacity of basic processes at a farm, kW/unit of work

The equation describing the time dynamics of weighted standards has the form of exponent and the factor of approximation certainty factor $R^2 = 0.8965$ is rather high. Conducted research and calculation of energy consumption indicators in separate processes in animal breeding in the past period demonstrated that the character of their changing in time (decreasing) is similar to the revealed regularities of changing (lowering) of indicators of equipment specific capacity (standard) at that period. This confirms the possibility of using of considered regularities for assessment (forecasting) of the amount of energy consumption in the long term, both for individual processes and averaged pattern in the industry in general [3]. Decrease of the standard of capacity of electric drives of equipment and plants in animal breeding is determined by improvement of technologies of livestock handling and of technological equipment, the introduction of automated systems, as well as of systems for control of electric drives and technological processes in general.

The analysis of energy-consuming equipment energy-intensive processes demonstrates that scientific and technological progress in technologies of livestock handling and the use of new advanced equipment reduces energy consumption and specific capacity per unit of work and, consequently, contributes to reduction of energy intensity of the production of agricultural goods.

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OPTIMIZATION OF HEAT-RECOVERY HEAT EXCHANGERS WITH THE USE OF THE METHOD OF GRAPH CONSTRUCTION

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Information on topological models and the analysis of exergy flow graphs are given. The fundamentals of matrix representation of graphs are outlined. The criterion of optimization of energy systems is formulated. The algorithm of determining the optimization criterion for optimization of energy-consuming systems is presented.

Keywords; *exergy; graph-theoretic methods; topological models; matrix; criterion of optimization; heat-exchanger; algorithm of thermoeconomic analysis.*

Nowadays one of the most urgent problems is saving of energy resources both in industrial production and in everyday life.

Efficient way of the solution of the above-mentioned problem is optimization of existing energy structures and their parameters with the aim of minimization of capital and operating costs, considering relevant technical and resource limitations.

Optimization of any energy-saving system involves varying structures and parameters with the aim of minimization of capital and operating costs, considering relevant technical and resource limitations with due account for environmental protection, availability of materials, and providing operational reliability and low repair cost.

It is reasonable to use the concept of exergy as maximal operability while considering the degree of perfection of various processes in terms of energy conversion [1, 2].

Any energy system may be represented as ordered set of physical components integrated by link ends. To each simple physical component some graph branch corresponds, that is termed terminal graph of this physical component [3].

To solve the tasks of mathematical simulation, analysis and optimization of energy systems, topological models of systems are used. They make it possible to determine dependence of interconnection of changes of technological topology and quantitative characteristics of a system being studied with input variables affecting the system [4]. Matrix representation of graphs make it possible to reflect structural peculiarities of graphs.

Goal of research is to develop the method of optimization of energy systems on the basis of the method of graph-theoretic construction; to give an example of heat-recovery heat exchangers.

Research method and materials. Optimization of the system being researched is determination of its best possibilities in terms of selected criterion of efficiency. Complex system optimization is aimed at the selection of such values of the system parameters (technological, design, etc.) which would provide optimal, or near optimal values of efficiency criterion

$$Z_{opt} = \underset{x_j \in R^n}{extr} \left\{ Z(x_j) \right\} \tag{1}$$

under constraints

$$f_i(x_j) > 0, \quad i = 1, 2, ..., m; \tag{2}$$

$$q_k(x_j) > 0, \quad k = 1, 2, ..., L, \tag{3}$$

where где R^n is n-dimensional vector space.

It is evident that the formulation of optimization condition is a multiextremal large-dimensional problem of discrete non-linear programming complicated by constraints (2) and (3) [1, 2].

This method relying on the well-developed mathematical apparatus of the graph theory, makes it possible to analyze and obtain optimal system layouts rather easily, being as good as other mathematical models both in terms of rigidity of mathematical approach and generality of results.

Below the algorithm of exergy and thermoeconomical analysis of energy system is given. The algorithm $A\Pi_\Sigma$ is the determination of exergy losses in an energy system. The algorithm comprises the following basic steps:

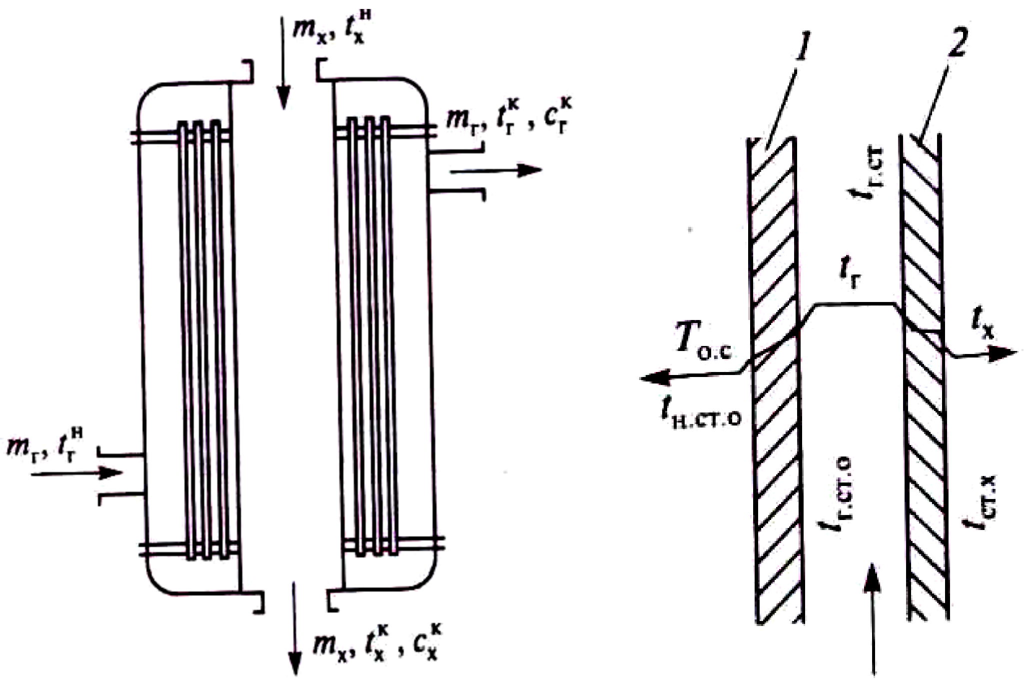
I. To construct the exergy flow graph $E = (A, U)$ corresponding to the given system, incidence matrix $\|M_{ij}\|$ and to calculate flows exergy through arcs E_j, $j = 1, 2, ..., n$.

II. To determine incoming (M_{ij} = 1) and outcoming $M_{ij} = -1$ flows for all components, to calculate the sums and $E_j^{вых}$ of flows exergy of *i*-th elements and the degree of their perfection.

III. To calculate total exergy losses

$$П_{\Sigma} = \sum_{i=1}^{m} П_i . \qquad (4)$$

Let us consider the tube and shell heat exchanger with in-line tube arrangement (Fig. 1). The provision below may in principle be applied to heat exchangers with shaft tube arrangement, as well as to plate heat exchangers. Process parameters presented at the diagram, are repeated later on. The structure graph of heat exchange process in heat exchangers is presented at Fig. 2.



a **b**

Fig. 1. Tube and shell heat exchanger:
a – general arrangement of the heat exchanger;
b – the heat exchanger component with heat-exchange circuit

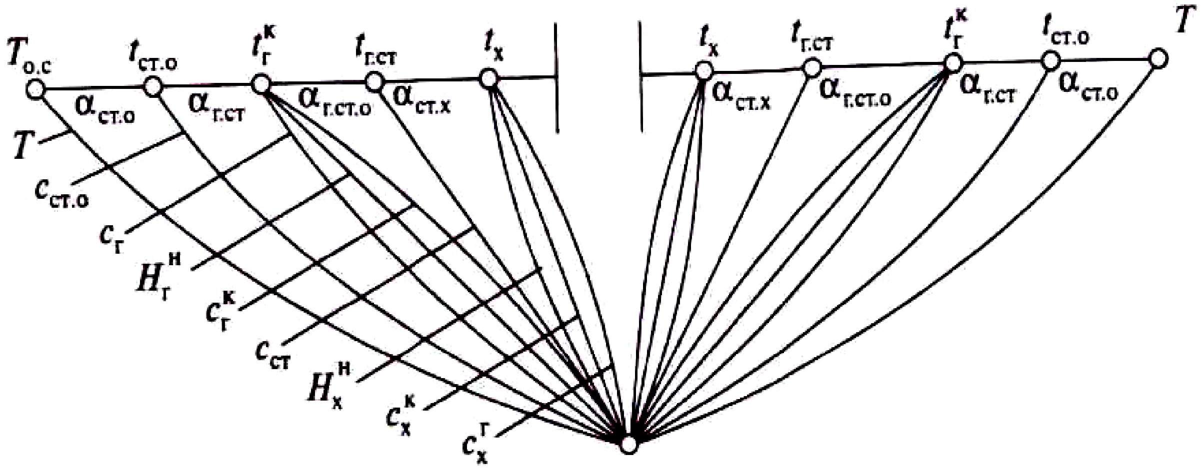


Fig. 2. Structure graph of heat exchange process in the heat exchanger

Let us use the following designations: $m_г$, $m_х$ – mass hot and cold flow rates; $t_г^н$, $t_х^н$ – initial temperatures of hot and cold flows; $t_г^к, t_х^к$ – final temperatures of hot and cold flows; $T_{о.с}$ – environmental temperature; $c_г^к, c_х^к$ – specific heat capacity of hot and cold flows at outlet of the heat exchanger; $t_{н.ст.о}$ – temperature of outer surface of the wall on the side of surrounding air; $t_{г.ст}$ – temperature of the tube surface on the side of hot flow; $\alpha_{г.ст}$ – heat exchange rate between hot flow and the shroud outer surface; $\alpha_{ст.т}$ – heat exchange rate between the tube interior wall and cold flow; $\alpha_{г.ст.о}$ – heat exchange rate between hot flow and the tube outer wall; $\alpha_{ст.о}$ – heat exchange rate between the outer wall and outer environment; $c_{ст.о}$ – heat capacity of the outer wall (of the shroud); $c_г^к$ – heat capacity of hot flow at outlet of the plant; $c_х^к$ – heat exchange capacity of cold flow at inlet; $c_г$, $c_х$ – heat capacity of cold and hot flows at inlet, $H_г^н, H_х^н$ – enthalpy of hot and cold flows at inlet to the heat plant.

Let us note that the values $T_о$ и $H_о$, referring to environment, are considered known.

In structure graph of heat exchange process the nodal point O corresponds to the reference temperature measurement point (O °C) [3]. Prior to presenting polar equations in matrix form, let us state initial conditions.

In the heat exchanger in each row there are *i* tubes, the number of rows being *j*. Let us assume that as hot flow moves from inlet section to outlet section, heat exchange rates on the side $\alpha_{г.ст.о}$ of outer tubes surface and on the side of interior tube surface $\alpha_{ст.т}$ are not changing. In cases when in heat exchange process aggregative state of one of flows changes, it is also assumed that heat exchange coefficients $\alpha_{г.ст.о}$ & and $\alpha_{ст.т}$ have constant value in the whole volume of the heat exchanger. They may be designated $\alpha_{г.ст.о}^{эф}$ and $\alpha_{ст.т}^{эф}$; they provide the same heat exchange conditions as their variable values.

Moreover, we shall not consider thermal resistance of the tube wall because of its low value in comparison with thermal resistance of heat convection processes.

Polar equations of components of heat exchange process in matrix form take the following form:

$$
\begin{bmatrix} H_г^н \\ H_х^н \\ H_г \\ H_х \\ H_г^г \\ H_х^к \\ H_{ст} \\ H_{ст.о} \\ H_{г.ст} \\ H_{ст.х} \\ H_{г.ст.о} \\ H_{ст.к} \\ H_{н.ст.о} \\ T_{о.с} \end{bmatrix}
=
\begin{bmatrix}
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & c_г & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & c_х & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & c_г^к & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & c_г^к & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & c_{ст} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & c_{ст.о} & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \alpha_{г.ст} & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \alpha_{ст.о} & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \alpha_{г.ст.о} & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \lambda_{ст.к} & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \alpha_{сг.о} & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1
\end{bmatrix}
\times
\begin{bmatrix} H_г^н \\ H_х^н \\ T_к \\ T_х \\ T_г^к \\ T_х^н \\ T_{ст} \\ T_{ст.о} \\ T_{г.ст} \\ T_{ст.л} \\ T_{к.ст.о} \\ T_{ст.к} \\ T_{н.ст.о} \\ T_{о.с} \end{bmatrix}
$$

The presented matrix is used for calculating heat exchange processes in heat exchangers. Analyzing various topological and technological versions, it is possible to choose the one optimal in energy terms. In [3, 4] the approximating hybrid algorithm of calculation of multiloop systems, in particular, heat exchangers, has been developed. Information bigraph of set of equations of the mathematical model of the heat-recovery is given at Fig 3 and 4.

For exergy evaluation of the heat exchange plant let us determine its energy efficiency:

$$\eta_{ex} = \frac{E_{вых}}{E_{вх}} = \frac{E_{вх} - E_{п}}{E_{вх}}, \tag{5}$$

where где $E_{вх}$ –is energy delivered to the heat exchanger; $E_{вых}$ – exergy extracted from the heat exchanger.

Exergy losses in the heat exchanger are determined by irreversible heat exchange because of finite temperature difference $E_т$; hydraulic resistance in the process of heat carrier medium E_ρ flowing; environmental heat losses [3] $E_с$, that is

$$E_п = E_т + E_\rho + E_с. \tag{6}$$

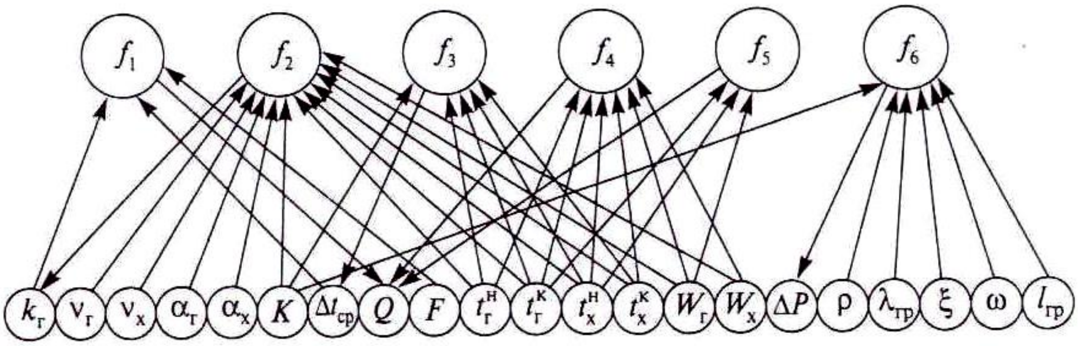


Fig. 3. Information bigraph of the set of equations of the heat exchanger mathematical model

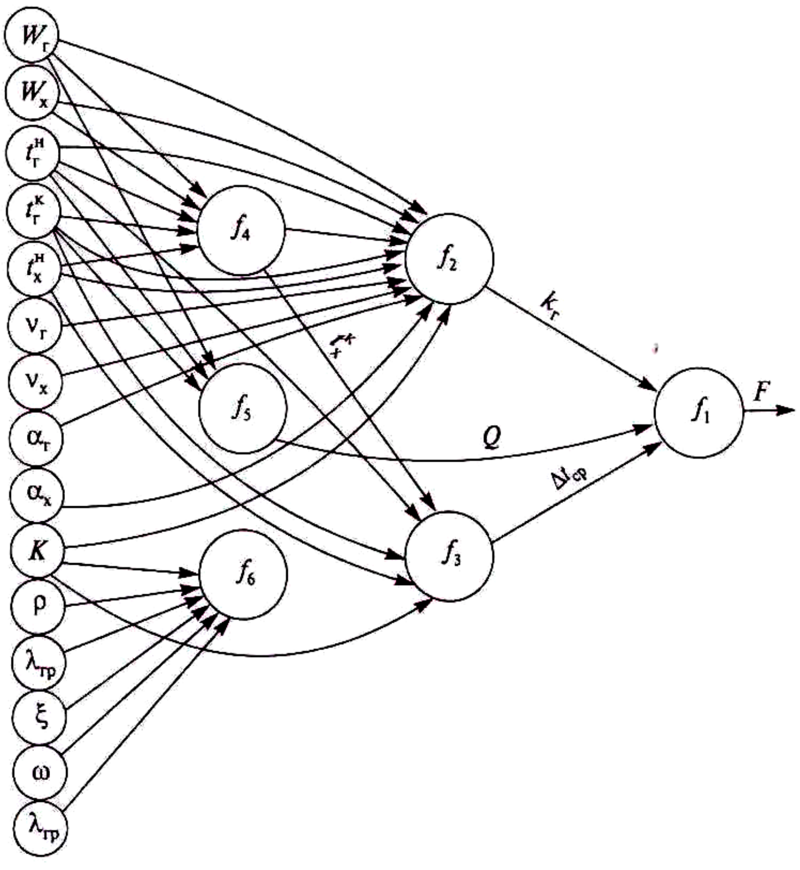


Fig. 4. Information bigraph of the set of equations of the heat exchanger mathematical model

We shall accept index ”o” for cooled flow of heat carrier and index “n” for flow being heated.

Total exergy losses due to finite temperature difference between heat carriers

$$E_T = E_q^o - E_q^н = Q\Delta\overline{\tau_e}, \quad (7)$$

where где $E_q^o, E_q^н$ – exergy of corresponding flows; Q – thermal load of the heat exchanger; $\Delta\overline{\tau_e}$ – average difference of exergy temperature functions of flows “o” and “n” in the process of the first flow cooling and the second flow heating.

Exergy temperature function

$$\overline{\tau_e} = 1 - T_{o.c}/T, \quad (8)$$

$$E_q^н = \Delta\overline{\tau_e}\,.$$

Exergy losses from finite temperature difference will be equal to

$$E_T = Q\left[\left(1 - T_{o.c}/T_н\right)\right] - \left(1 - T_{o.c}/T_o\right) = Q\left(\left(T_н - T_o\right)/T_н T_o\right). \quad (9)$$

Using the notion of water equivalent $W = m_r c_r \approx m_x c_x$, we shall obtain

$$E_T = T_{o.c} W \ln\frac{T_x^к T_Г^к}{T_x^н T_Г^н}. \quad (10)$$

Exergetic efficiency of heat exchange ($E_р = E_{о.с} = 0$):

$$\eta_{ex} = E_q^o / E_q^н = Q\tau_e^o / Q\tau_e^н = \tau_e^o / \tau_e^н =$$

$$= \Delta E_o / \Delta E_н, \quad (11)$$

where $\Delta E_о$, $\Delta E_н$ is change of exergy of cooled and heated flows.

Exergy losses from hydraulic resistance in heat exchangers are determined by the relation:

$$E_p = T_{o.c} R \ln\frac{p_{вых} + \Delta p}{p_{вых}}, \quad (12)$$

where $\Delta p = p_{вх} - p_{вых}$ – pressure drop in the system.

At $\Delta p / p_{вых} < 1$ exergy losses from hydraulic resistance are

$$E_p = mRT_{o.c}\Delta p / p_{вых}, \quad (13)$$

Exergy losses from heat exchange with environment

$$E_S = \Delta Q\overline{\tau_e} = E_{qo.c}^o + E_{qo.c}^н =$$

$$= m_н Q_н\left[1 - \frac{T_{o.c}}{T_{н.о}}\right] + m_o Q_o\left[1 - \frac{T_{o.c}}{T_{o.o}}\right], \quad (14)$$

where $T_{н.о}$ – average temperature of the outer surface of the heat exchanger on the side of the flow H; $T_{н.с}$ – average temperature of the outer surface of the heat exchanger on the side of cooled flow.

Exergy losses from heat exchange with environment E_S may be determined with the use of flows enthalpy values

$$E_S = m_н c_н\left(t_{н.о} - t_{o.c}\right) + m_o Q_o\left(t_{o.o} - t_{o.c}\right), \quad (15)$$

where $c_н$ and c_o – heat capacity of corresponding flows.

In the result, the expression for exergy efficiency of the heat exchanger can be written as:

$$\eta_{ex} = \frac{E_{вх} - E_T - E_p - E_S}{E_{вх}} =$$

$$= 1 - \frac{T_{o.c}\left[m_r R^г \frac{\Delta p_г}{p_{г.вых}} + m_x R_x \frac{\Delta p_х}{p_{х.вых}} + m_r c^г \ln\frac{T_г^к}{T_г^н} + m_x c_x \ln\frac{T_х^к}{T_х^н}\right] - Q\Delta\bar{\tau}_{es}}{Q\frac{T_г^н - T_{o.c}}{T_г^н}}, \quad (16)$$

where $\Delta\bar{\tau}_{es}$ – average exergy temperature of the heat exchanger insulation.

Technical and economical criteria of the heat exchanger efficiency are reduced and operating costs [2]. We believe that for heat exchangers it is reasonable to use reduced costs $П_э$ through energy spent on the process

$$П_э = E_н K_э N + \frac{N C_q \tau_г}{\eta_t}, \quad (17)$$

where $E_н$ – norm profit to investment ratio, 1/year; $K_э$ – relative capital investment referred to consumed energy, hryvnia/(kW·hour); N – amount of energy spent in the process, kW·hour; C_q – cost of thermal unit, hryvnia/kW·hour; $\tau_г$ – number of hours of the heat exchanger work per year, hours/year; η_t – thermodynamic efficiency of the process.

From the equation (17) computed dependence for reduced energy costs $П_{э.пр}$ is as follows:

$$П_{э.пр} = \frac{E_н K_э}{\tau_г} + \frac{C_q}{\eta_t}, \quad (18)$$

Operating costs can be determined in proportion to energy costs [5]

$$П_э = E_н K_F F + \Delta E C_E \tau_г, \quad (19)$$

where K_F – relative capital investments referred to unit heat exchange area of the heat exchanger, hryvnia/m^2; F – heat exchange area, m^2; $\Delta E = E_{вх} - E_{вых}$ amount of energy spent on heat exchange process, kW; C_E – cost of energy unit, hryvnia/(kW·hour).

Reduced operating costs are determined by the following dependence:

$$П_{E.пр} = \frac{П_E}{Q} = \frac{E_н K_F}{K \Delta T} + \left(1 - \frac{T_{o.c}}{T_x + \Delta T}\right) C_E \tau_г, \quad (20)$$

where $T_x = \dfrac{T_x^к - T_x^н}{\ln\left(T_x^к / T_x^н\right)}$.

As exergy E is lower than the amount of heat Q, $П_{э.пр} < П_{E.пр}$. This implies that $П_{э.пр}$ can be considered as lower bound of the value $П_{E.пр}$.

Conclusions

Optimization of any energy system means the search for design (primarily, structural modification) and corresponding parameters with the aim of minimizing existing constraints and requirements in the field of energy use (environmental protection, operation reliability and stability, reliability of working mode control in operation process).

The exergy system has definite structure, that is, comprises a number of interconnected elements, is characterized by specified parameters and interacts with environment.

The method of graph-theoretic construction has the advantage of presenting used structures in visual form, making it easy to select among possible solutions. The algorithms of solving such problems have been developed.

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VIETA'S FORMULAS FOR PSEUDO-ALGEBRAIC EQUATIONS

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We extend the classical Vieta's formulas over the principal and secondary lianit roots of pseudo-algebraic equations. This generalization allows a broader interpretation of the Vieta relations for an arbitrary level pseudo-polynomial.

***Keywords**: pseudo-algebraic equations, lianit roots, associated polynomials, Vieta's formulas.*

Introduction

The very fact of existence of non-numeric roots (lianit roots)[1]-[4]for pseudo-algebraic equations compels us to generalize the classic Vieta's Formulas for algebraic equations [5].The number of principal and secondary lianit roots in the general case does not coincide with the degree of the polynomial and depends on the specific properties of the chosen lianit algebra. Consider the n-element lianit ($N = n$) algebra:

$$\begin{cases} \sigma_1 + \sigma_2 = (x_1, x_2, \dots, x_n) + (y_1, y_2, \dots, y_n) = (x_1 + y_1, x_2 + y_2, \dots, x_n + y_n) = \sigma_2 + \sigma_1, \\ \sigma_1 \cdot \sigma_2 = (x_1, x_2, \dots, x_n) \cdot (y_1, y_2, \dots, y_n) = \\ \qquad = [x_1 (y_1 + y_2), x_2 (y_1 + y_3), \dots, x_{n-1} (y_1 + y_n), x_n y_1] \neq \sigma_2 \sigma_1. \end{cases} \quad (1)$$

Algebra (1) is not commutative and associative. It is only distributive with respect to multiplication law: $\sigma_1(\sigma_2 + \dots + \sigma_n) = \sigma_1\sigma_2 + \dots + \sigma_1\sigma_n$. At $k = (k, 0, \dots, 0)$ acting as the lianit analogue of complex number k, the lianit$e = (1, 0, \dots, 0)$ is the right identity element: $\sigma \cdot e \equiv \sigma$. Any algebraic polynomial with non-zero coefficients and degree $1 \le n_0 \le n$, has over (1) a single principal lianit root [1]-[3],

$$\begin{aligned} &f^n(x) = x^n + a_1 x^{n-1} + \dots + a_{n-1}x + a_n\,; \sigma_1 = \left(-a_1, \frac{a_2}{a_1}, \frac{a_3}{a_2}, \dots, \frac{a_n}{a_{n-1}}\right);\ a_i \neq 0 \\ &f^{n-1}(x) = x^{n-1} + b_1 x^{n-2} + \dots + b_{n-2}x + b_{n-1}\,; \sigma_2 = \left(-b_1, \frac{b_2}{b_1}, \frac{b_3}{b_2}, \dots, \frac{b_{n-1}}{b_{n-2}}, 0\right);\ b_i \neq 0 \\ &f^{n-2}(x) = x^{n-2} + c_1 x^{n-3} + \dots + c_{n-3}x + c_{n-2}; \sigma_3 = \left(-c_1, \frac{c_2}{c_1}, \frac{c_3}{c_2}, \dots, \frac{c_{n-2}}{c_{n-3}}, 0, 0\right);\ c_i \neq 0 \\ &\dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \\ &f^1(x) = x + a_0; \quad \sigma = (-a_0, 0, \dots, 0);\ a_0 \neq 0\,. \end{aligned} \quad (2)$$

Over the same set (1) any polynomial of degree $1 < n_0 \le n$, has also some secondary lianit roots [1-3]. However, given the lianit analogue of complex number as $k = (0, 0, \dots, 0, k)$, it is solely $f^n(x) = x^n + a_1x^{n-1} + a_2x^{n-2} + \dots + a_{n-1}x + a_n$ that has a single principal root, that is: $\sigma_1 = (x_1, x_2, \dots, x_n) = \left(-a_1, \frac{a_2}{a_1}, \frac{a_3}{a_2}, \dots, \frac{a_n}{a_{n-1}}\right)$. Mean while, all polynomials of degree less than$n$, do not have any secondary or principal lianit roots over the set (1).

Let $f^n(x) = x^n + a_1x^{n-1} + a_2x^{n-2} + \dots + a_{n-1}x + a_n$, with numeric roots $x_{01}, x_{02}, \dots, x_{0n}$, is defined over an arbitrary set of N-element lianits ($N > 1$), within a commutative algebra with respect to addition, and in general case, only distributive with respect to multiplication. From the definitions of principal and secondary roots follows that the principal roots are of structure $\{x_{01}, x_{02}, \dots, x_{0n-1}, x_n\}$, ($C_n^n = 1$). All other combinations $\{x_{0i}\}$, $\{x_{0i}, x_{0j}\}$, $\{x_{0i}, x_{0j}, x_{0\ell}\}$, ..., $C_1^n, C_2^n, \dots, C_{n-1}^n$, correspond to secondary roots[1]. Let $n_1, n_2, \dots, n_n$ are the number of possible principal roots for polynomials of degrees $1, 2, 3, \dots, n-1, n$ accordingly. Some of n_i may be zero. This implies that the corresponding polynomial of degree$i$ ($1 \le i \le n$), at a given lianit analogue of complex number k, N-element lianits, does not have any single principal

[1] When $n > N$, all the roots are secondary.

lianit root. If $n_i = 1$, then the elements of the principal root of the polynomial of degree$i$, are obviously, some rational functions of the numeric coefficients of the same polynomial. Then, in the general system of non-linear equations $f^n(\sigma) = (0, 0, \dots, 0)$ on principal and secondary roots, the degree of the corresponding associated polynomial with respect to at least one of the elements of lianit roots $\sigma = (x_1, x_2, \dots, x_N)$, must be $n_0 = C_n^n \cdot n_n + C_{n-1}^n \cdot n_{n-1} + \dots + +C_3^n \cdot n_3 + C_2^n \cdot n_2 + C_1^n \cdot n_1$. Given the fact that all the required elements of primary and secondary lianit roots are numeric roots of corresponding associated polynomials, obviously, the set of all possible sums $\sum \sigma_i$, $\sum \sigma_i \cdot \sigma_j$, $\sum \sigma_i \cdot \sigma_j \cdot \sigma_\ell$, ..., compiled for various dispositions $C_n^n, C_{n-1}^n, C_{n-2}^n, \dots, C_3^n, C_2^n, C_1^n$, are lianits whose elements are rational functions of the coefficients $a_1, a_2, \dots, a_{n-1}, a_n$ of the original polynomial $f^n(x) = x^n + a_1 x^{n-1} + a_2 x^{n-2} + \dots + a_{n-1} x + a_n$. In this aspect it becomes possible to extend the Vieta's Formulas over the principal and secondary roots of the given pseudo-polynomial within the fixed lianit algebra. In preparing the symmetric expressions $\sum \sigma_i \cdot \sigma_j$, $\sum \sigma_i \cdot \sigma_j \cdot \sigma_\ell$, ..., one should take into account the commutativity and associativity under multiplication. If multiplication is non-commutative and non-associative, for every single $\sigma_i\sigma_j$one should also take $\sigma_j\sigma_i$, and in the case of every$\sigma_i\sigma_j\sigma_\ell$, one should also apply $\sigma_i\sigma_\ell\sigma_j$, $\sigma_j\sigma_i\sigma_\ell$, $\sigma_j\sigma_\ell\sigma_i$, $\sigma_\ell\sigma_i\sigma_j$, $\sigma_\ell\sigma_j\sigma_i$ and so on.

Vieta relations in two-element lianit algebras

In this section we show how the Vieta relations can be obtained within the two-element lianit algebras. Consider the set of two-element lianits within the algebra,

$$\begin{aligned} &\sigma_1 + \sigma_2 = (x_1, x_2) + (y_1, y_2) = (x_1 + y_1, x_2 + y_2), \\ &\sigma_1 \cdot \sigma_2 = (x_1, x_2) \cdot (y_1, y_2) = [x_1(y_1 + y_2) + x_2 y_1, x_2 y_2 - x_1 y_1] = \sigma_2\sigma_1;\ k = (0, k) \end{aligned} \tag{3}$$

Algebra (3) is commutative, associative and distributive with respect to multiplication, $e = (0, 1)$ is the identity element. Linear and quadratic equations are solvable over this set, therefore, any $f^n(x) = x^n + a_1 x^{n-1} + a_2 x^{n-2} + \dots + a_{n-1} x + a_n$, $(n > 2)$ can have only secondary roots [since (3) is a two-element set]. In particular, for $f^3(x) = x^3 + bx + c$, the condition $f^3(\sigma) = \sigma^3 + b\sigma + c = (0, 0)$ leads to,

$$\begin{cases} 3x_2^2 x_1 + 3x_1^2 x_2 + b x_1 = 0,\ \ x_1 \neq 0,\ \ x_1 = -\left(\dfrac{b + 3x_2^2}{3x_2}\right) \\ x_2^3 + b x_2 - c - (x_1^3 + 3x_1^2 x_2) = 0, \quad x_2 \neq 0. \end{cases} \tag{4}$$

Inserting $x_1 = -\left(\frac{b+3x_2^2}{3x_2}\right)$ into the second equation of the system (4), we obtain the general associated polynomial of the system $f^3(\sigma) = (0, 0)$, that is: $z^6(x_2) = -27x_2^6 + 27c x_2^3 + b^3$. Hence,

$$x_2 = \sqrt[3]{\frac{c}{2} \pm \sqrt{\frac{c^2}{4} + \frac{b^3}{27}}} \tag{5}$$

Thus there are exactly six secondary lianit roots $\sigma_\ell = (x_1^\ell, x_2^\ell) = \left[-\left(\frac{b+3x_2^2}{3x_2}\right), x_2\right]$, each of which, over the set of complex numbers, corresponds to a polynomial $f_\ell^2(x) = x^2 + p_\ell x + q_\ell$ $(\ell = 1, 2, \dots, 6)$. The numeric roots of these polynomials are also the roots of $f^3(x)$. Indeed, for an arbitrary $f^2(x) = x^2 + px + q$, operating over the set (3), the condition $f^2(\sigma) = \sigma^2 + \sigma \cdot p + +q = (0, 0)$ yields,

$$\begin{cases} x_1^2 + 2x_1 x_2 + p x_1 = 0,\ \ x_1 \neq 0,\ \ x_1 + 2x_2 + p = 0, \\ x_2^2 - x_1^2 + p x_2 + q = 0. \end{cases} \tag{6}$$

From (6) it follows that within the set (3), any $f^2(x) = x^2 + px + q$ has two principal lianit roots $\sigma = (x_1, x_2) = [-(p + 2x_2), x_2]$. Therefore, the associated polynomial $z(x_2)$ of the system of equations $f^3(\sigma) = (0, 0)$, is indeed of degree $C_2^3 \cdot 2 = 6$, as it follows from (4)[2]. As is known, the values of p coincide with the numeric roots of $f^3(x) = x^3 + bx + c$. Therefore the reisnoneed to recover the explicit expressions

[2] We essentially exclude the secondary roots $\sigma = (x_1, x_2) = (0, x_2)$, which are equivalent to the numeric roots by the condition $x_1 \neq 0$.

for the required binomials $f_\ell^2(x) = x^2 + p_\ell x + q_\ell$ using (5) - (6). From (6), in view of (4), we write: $p = -x_1 - 2x_2 = \frac{b+3x_2^2}{3x_2} - 2x_2 = \frac{b}{3x_2} - x_2$. Taking any value of x_2 from (5), we obtain Cardano's formula with one cubic radical. From (5) we have exactly six x_2, namely: $x_{21} = \sqrt[3]{\frac{c}{2} + \sqrt{\frac{c^2}{4} + \frac{b^3}{27}}}$, Bx_{21}, Dx_{21}, $x_{22} = \sqrt[3]{\frac{c}{2} - \sqrt{\frac{c^2}{4} + \frac{b^3}{27}}}$, Bx_{22}, Dx_{22}, where B and D are the primitive roots to $x^3 - 1 = 0$; $B, D = \frac{-1 \pm i\sqrt{3}}{2}$; $B^2 = D$, $D^2 = B$, $i = \sqrt{-1}$. Thus the secondary lianit roots of $f^3(x) = x^3 + bx + c$ [which are simultaneously principal roots for $f_\ell^2(x) = x^2 + p_\ell x + q_\ell$, $\ell = 1, 2, \dots, 6$] are,

$$\begin{gathered} \sigma_1 = \left(-\frac{b + 3x_{21}^2}{3x_{21}}, x_{21}\right);\ \sigma_2 = \left(-\frac{b + 3Dx_{21}^2}{3Bx_{21}}, Bx_{21}\right);\ \sigma_3 = \left(-\frac{b + 3Bx_{21}^2}{3Dx_{21}}, Dx_{21}\right); \\ \sigma_4 = \left(-\frac{b + 3x_{22}^2}{3x_{22}}, x_{22}\right);\ \sigma_5 = \left(-\frac{b + 3Dx_{22}^2}{3Bx_{22}}, Bx_{22}\right);\ \sigma_6 = \left(-\frac{b + 3Bx_{22}^2}{3Dx_{22}}, Dx_{22}\right). \end{gathered} \tag{7}$$

The subsets σ_1, σ_2, σ_3 and σ_4, σ_5, σ_6, constitute a system of classical Vieta's relations, namely: $\sigma_1 + \sigma_2 + \sigma_3 = (0, 0)$, $\sigma_1\sigma_2 + \sigma_1\sigma_3 + \sigma_2\sigma_3 = (0, b)$, $\sigma_1\sigma_2\sigma_3 = (0, -c)$, while the whole set (7) constitute an analogous system for$f^6(x) = (x^3 + bx + c)^2$. This verify esourinitial conjecture on the possibility of generalizing the Vieta's relations over the lianit roots of pseudo-algebraic equations.

We will see however, that the Vieta's relations for pseudo-algebraic polynomials deserve a much broader interpretation than in the case of the classical numeric polynomials. To this end, we consider the set of two-element lianits,

$$\begin{gathered} \sigma_1 + \sigma_2 = (x_1, x_2) + (y_1, y_2) = (x_1 + y_1, x_2 + y_2); \\ \sigma_1\sigma_2 = (x_1, x_2)(y_1, y_2) = [x_1(y_1 + y_2), x_2 y_1]. \end{gathered} \tag{8}$$

As we know, at$k = (0, k)$, $f^1(x) = x + a_0$ ($a_0 \neq 0$) cannot be resolved over the set (8), i.e. $n_1 = 0$ for the dispositions $\{x_{0i}\}$. The equation $f^2(x) = x^2 + px + q$ has a single principal root: $\sigma = (x_1, x_2) = \left(-p, \frac{q}{p}\right)$, $p \neq 0$,which implies that for dispositions $\{x_{0i}, x_{0j}\}$we have $n_2 = 1$. The trinomial $f^3(x) = x^3 + ax^2 + bx + c$ will hold only secondary roots, since the two-element lianit set (8) does not derive the disposition $\{x_{01}, x_{02}, x_{03}\}$. The degree of the associated polynomial of the system $f^3(\sigma) = \sigma^3 \cdot 1 + \sigma^2 \cdot a + \sigma \cdot b + c = (0, 0)$ calculates as $C_1^3 \cdot n_1 + C_2^3 \cdot n_2 == 3 \cdot 0 + 3 \cdot 1 = 3$. If the degree of the associated polynomial is less, then $f^3(x)$, obviously, has a pair of numeric roots $\pm x_{0i}$. Since $\sigma = (x_1, x_2) = \left(-p, \frac{q}{p}\right)$ $(p \neq 0)$, we have,

$$\begin{gathered} \sigma_1 = \left(x_{01} + x_{02}, -\frac{x_{01} \cdot x_{02}}{x_{01} + x_{02}}\right);\ \sigma_2 = \left(x_{01} + x_{03}, -\frac{x_{01} \cdot x_{03}}{x_{01} + x_{03}}\right); \\ \sigma_3 = \left(x_{02} + x_{03}, -\frac{x_{02} \cdot x_{03}}{x_{02} + x_{03}}\right). \end{gathered} \tag{9}$$

Given the Vieta's formulas for the numeric rootsx_{01}, x_{02}, $x_{03}$of the polynomial $f^3(x) == x^3 + ax^2 + bx + c$, it is easy to see that the sums $\sum \sigma_i$, $\sum \sigma_i \cdot \sigma_j = \sigma_1\sigma_2 + \sigma_2\sigma_1 + \sigma_1\sigma_3 + +\sigma_3\sigma_1 + \sigma_2\sigma_3 + \sigma_3\sigma_2$ и $\sum \sigma_i \cdot \sigma_j \cdot \sigma_\ell$ are lianits whose elements are rational functions of the coefficients a, b, c of the original trinomial $f^3(x) = x^3 + ax^2 + bx + c$ e.g. $\sigma_1 + \sigma_2 + \sigma_3 = \left(-2a, \frac{b^2 + ac}{ab - c}\right)$. Consider now the problem of finding the numeric roots of the quartic function $f^4(x) = x^4 + b_0 x^2 + c_0 x + d_0$ utilizing the set of two-element lianits (8). The condition $f^4(\sigma) = \sigma^4 \cdot 1 + \sigma^2 \cdot b_0 + \sigma \cdot c_0 + d_0 = (0, 0)$ yields,

$$\begin{cases} x_1^4 + 2x_1^3 x_2 + b_0 x_1^2 + c_0 x_1 = 0,\ x_1 \neq 0,\ x_2 = -\left(\frac{x_1^3 + b_0 x_1 + c_0}{2x_1^2}\right), \\ x_1^3 x_2 + x_1^2 x_2^2 + b_0 x_1 x_2 + d_0 = 0. \end{cases} \tag{10}$$

Inserting x_2 in to the second equation of the system (10), leads, with respect to x_1, associated polynomial of the form: $z^6(x_1) = x_1^6 + 2b_0x_1^4 + (b_0^2 - 4d_0)x_1^2 - c_0^2$ [over the set (8), the binomial $f_\ell^2(x) = x^2 + p_\ell \cdot x + q_\ell$, has a single principal root $\sigma_\ell = (x_1^\ell, x_2^\ell) = \left(-p_\ell, \frac{q_\ell}{p_\ell}\right)$, $p_\ell \neq 0$, therefore, the degree of $z(x_1)$ is indeed $C_2^4 \cdot 1 = 6$]. Denoting $x_1^2 = y$, we arrive at,

$$y^3 + 2b_0y^2 + (b_0^2 - 4d_0)y - C_0^2 = 0. \quad (11)$$

The equation (11) coincides with the well-known Lagrange's resolvent. Each of the six second ary roots $\sigma = (x_1, x_2) = \left(x_1, -\frac{x_1^3 + b_0x_1 + c_0}{2x_1^2}\right) = \left(x_{0i} + x_{0j}, -\frac{x_{0i} \cdot x_{0j}}{x_{0i} + x_{0j}}\right)$ matches a binomial $f_\ell^2(x) = x^2 - x_1 \cdot x - x_1 \cdot x_2 = x^2 - x_1 \cdot x + \frac{x_1^3 + b_0x_1 + c_0}{2x_1}$, the numeric roots x_{0i}, x_{0j} $(i \neq j)$ of which coincide with the numeric roots of the quartic function $f^4(x) = x^4 + b_0x^2 + c_0x + d_0$[3].

Vieta relations in three-element lianit algebras

In this section we show how the Vieta relations can be obtained within the three-element lianit algebras. The three-element algebras will show vividly the gap between the classical and the lianit nature of Vieta's formulas. Consider the set of three-element lianits,

$$\begin{gathered} \sigma_1 \cdot \sigma_2 = (x_1, x_2, x_3) \cdot (y_1, y_2, y_3) = (x_1y_2 + x_2y_1, x_2y_2 - x_3y_3, x_2y_3 + x_3y_2 + x_1y_1); \\ k = (0, k, 0) \end{gathered} \quad (12)$$

Algebra (12) is commutative and distributive with respect to multiplication but is not associative, $e = (0, 1, 0)$ is the right identity element (addition is commutative). The polynomial $f^3(x) = x^3 + ax^2 + bx + c$, in addition to secondary roots has also a principal root. As summing $x_1 \neq 0$, $x_3 \neq 0$, the condition $f^3(\sigma) = \sigma^3 + \sigma^2 \cdot a + \sigma \cdot b + c = (0, 0, 0)$, yields:

$$x_1^2 = \pm\left(\frac{2a^3 - 9ab + 27c}{27\sqrt{b - \frac{a^2}{3}}}\right); \quad x_3^2 = b - \frac{a^2}{3}; \quad x_2 = -\frac{a}{3}. \quad (13)$$

In particular, at $a = 0$, we obtain:

$$\begin{gathered} \sigma_1 = \left(\sqrt{\frac{c}{\sqrt{b}}}, 0, \sqrt{b}\right); \sigma_2 = \left(-\sqrt{\frac{c}{\sqrt{b}}}, 0, \sqrt{b}\right); \\ \sigma_3 = \left(\sqrt{-\frac{c}{\sqrt{b}}}, 0, -\sqrt{b}\right); \sigma_4 = \left(-\sqrt{-\frac{c}{\sqrt{b}}}, 0, -\sqrt{b}\right). \end{gathered} \quad (14)$$

Since the lianits in (14) are commutative but not associative, out of 24 possible products $\sigma_i\sigma_j\sigma_\ell$ one should take the half as $\sigma_i(\sigma_j\sigma_\ell) = \sigma_i(\sigma_\ell\sigma_j)$. The same applies to $\sigma_i\sigma_j\sigma_\ell\sigma_k$. Explicitly we have,

$$\begin{gathered} \sigma_1 + \sigma_2 + \sigma_3 + \sigma_4 = (0, 0, 0); \quad a = 0, \\ \sigma_1\sigma_2 + \sigma_1\sigma_3 + \sigma_1\sigma_4 + \sigma_2\sigma_3 + \sigma_3\sigma_4 + \sigma_2\sigma_4 = (0, 2b, 0), \\ \sigma_1(\sigma_2\sigma_3 + \sigma_2\sigma_4 + \sigma_3\sigma_4) + \sigma_2(\sigma_3\sigma_4 + \sigma_1\sigma_3 + \sigma_1\sigma_4) + \sigma_3(\sigma_1\sigma_4 + \sigma_2\sigma_4 + \sigma_1\sigma_2) \\ + \sigma_4(\sigma_1\sigma_2 + \sigma_1\sigma_3 + \sigma_2\sigma_3) = (0, -4c, 0), \\ \sigma_1(\sigma_2\sigma_3\sigma_4 + \sigma_3\sigma_2\sigma_4 + \sigma_4\sigma_2\sigma_3) + \sigma_2(\sigma_1\sigma_3\sigma_4 + \sigma_3\sigma_1\sigma_4 + \sigma_4\sigma_1\sigma_3) + \\ + \sigma_3(\sigma_1\sigma_2\sigma_4 + \sigma_2\sigma_1\sigma_4 + \sigma_4\sigma_1\sigma_2) + \sigma_4(\sigma_1\sigma_2\sigma_3 + \sigma_2\sigma_1\sigma_3 + \sigma_3\sigma_1\sigma_2) = (0, 12b^2, 0). \end{gathered} \quad (15)$$

Thus, in a more general (non-numeric) setting, the Vieta's relations are not a simple consequence of the expansion of the original polynomial by its numeric roots: $x - x_{0i}$ $(i = 1, 2, \dots, n)$.

[3] $x_1^2 = y$ are the numeric roots of the resolvent (11).

Consider now the set of three-element lianits defined over a commutative, associative and distributive (with respect to multiplication) algebra (addition is commutative),

$$ {}_1 \cdot {}_2 = (x_1, x_2, x_3) \cdot (y_1, y_2, y_3) = (x_1y_1 + x_2y_3 + x_3y_2, x_3y_3 + x_1y_2 + \\ + x_2y_1, x_2y_2 + x_1y_3 + x_3y_1); k = (k, 0, 0). \qquad (16)$$

From $f^3(\sigma) = {}^3 + {}^2 \cdot a + \cdot b + c = (0, 0, 0)$, we arrive at [$e = (1, 0, 0)$ is the identity element]:

$$\begin{cases} x_1^3 + x_2^3 + x_3^3 + a(x_1^2 + 2x_2x_3) + 6x_1x_2x_3 + bx_1 + c = 0, \\ 3x_2^2x_3 + 3x_3^2x_1 + 3x_1^2x_2 + a(x_3^2 + 2x_1x_2) + bx_2 = 0, \\ 3x_3^2x_2 + 3x_2^2x_1 + 3x_1^2x_3 + a(x_2^2 + 2x_1x_3) + bx_3 = 0. \end{cases} \qquad (17)$$

The principal lianit roots (there are exactly six of them) are obtained from the conditions,

$$x_1 = -\frac{a}{3}; \quad x_2 \neq x_3; \quad x_2x_3 = \frac{a^2 - 3b}{9}; \quad x_2^3 + x_3^3 = \frac{9ab - 2a^3 - 27c}{27}; \qquad (18)$$

In the case, when $x_2 = x_3 \neq 0$, we obtain secondary roots corresponding to dispositions $\{x_{0i}, x_{0j}\}$, and for the case $x_2 = x_3 = 0$, $x_1 \neq 0$, the resulting secondary roots $\sigma_i = (x_1^i, 0, 0)$ are equivalent to the numeric solutions fitting the dispositions $\{x_{0i}\}$. Combining the equations of the system (17), we have: $(x_1 + x_2 + x_3)^3 + a(x_1 + x_2 + x_3)^2 + b(x_1 + x_2 + x_3) + c = 0$. The complex number $x_{0\ell} = x_1 + x_2 + x_3$ exist sand is the numeric solution of the polynomial $f^3(x) = x^3 + ax^2 + bx + c$, since the system of equations $f^3(\sigma) = (0, 0, 0)$ is always compatible based on the condition (18). From (18), follows the Cardano's solution in the general case. Curiously Cardano's solution is obtained through the principal roots of $f^3(x) = x^3 + ax^2 + bx + c$without having to reduce to the depressed cubic $f^3(y) = y^3 + b_0y + c_0$.

At $a = 0$ $(x_1 = -\frac{a}{3} = 0)$, we have $x_3 = -\frac{b}{3x_2}$, $x_2^6 + cx_2^3 - \frac{b^3}{27} = 0$. Denoting $x_{21} = \sqrt[3]{-\frac{c}{2} + \sqrt{\frac{c^2}{4} + \frac{b^3}{27}}}$, $x_{22} = \sqrt[3]{-\frac{c}{2} - \sqrt{\frac{c^2}{4} + \frac{b^3}{27}}}$, we obtain the explicit expressions for all six principal lianit solutions of the original polynomial $f^3(x)$, at $a = 0$.

$$ {}_1 = \left(0, x_{21}, -\frac{b}{3x_{21}}\right); \ \sigma_2 = \left(0, Bx_{21}, -\frac{b}{3Bx_{21}}\right); \ {}_3 = \left(0, Dx_{21}, -\frac{b}{3Dx_{21}}\right); \\ {}_4 = \left(0, x_{22}, -\frac{b}{3x_{22}}\right); \ \sigma_5 = \left(0, Bx_{22}, -\frac{b}{3Bx_{22}}\right); \ {}_6 = \left(0, Dx_{22}, -\frac{b}{3Dx_{22}}\right). \qquad (19)$$

In (19), B and D primitive roots to $x^3 - 1 = 0$. The subsets σ_1, σ_2, ${}_3$ and σ_4, σ_5, σ_6, constitute a system of classical Vieta's relations.

Summary

To conclude we summarize the results of our work. We have successfully extended the classical Vieta relations between numeric roots of a polynomial over the lianit roots of pseudo-polynomials operating within a given lianit algebra. We have shown that the sums and products of lianit roots are rational functions of the complex coefficients of the original numeric polynomial. Thus, in a more general (non-numeric) setting, the Vieta's relations are not a simple consequence of the expansion of the original polynomial by its numeric roots. The Vieta's relations are intrinsic property of the lianit roots even in the case when such an expansion is not possible. We have also shown how the knowledge of the Vieta relations between the lianit roots can be practically used to compute the numeric roots of polynomials in the cubic and the quartic functions.

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