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### *Introduction*

Recently interest to development of new ecologically favorable methods of decontamination and treatment of waste (household, medical, biological, toxic, hazardous, etc.) all over the world has increased. Plasma treatment is one of the most promising directions. The method of plasma pyrolysis and gasification, where at waste processing at oxygen deficiency, it is possible to produce combustible syngas using as a raw material for power generation. A high-temperature mineralization is another modern method of toxic and hazardous waste treatment. Its basis is also the use of low-temperature plasma as an additional source of thermal energy [1-6]. High-current electric arcs or electric arc plasma torches are used practically in all plasma installations for waste treatment, as only they are capable to provide the required density of energy at sufficiently high power [7-11]. In the discharge chamber of a plasma torch the electrical energy input into the arc is transformed by means of heat exchange to the internal energy of the working gas. Use of plasma torches for the solution of the given problems has a lot of advantages. It is well known [1], that plasma ions are chemically active and capable to generate chemically reactive particles (radicals) at interaction with neutral molecules. It results in intensification of chemical processes. Use of air, heated in the plasma torch up to high temperatures, as an oxidative agent at incineration of low-calorie waste products in the furnace and specified temperature reduces the amount of flue gases, if necessary essentially increases an excess-air coefficient, reduces total amount of secondary gaseous waste generated at incineration of additional hydrocarbon fuel. Use of plasma torches in technological installations gives the possibility to provide the processes temperature above 1200°C, that allows practically to avoid formation of such especially hazardous emissions, as dioxins, cyanides and furans. (Temperature range of destruction processes at which especially hazardous emissions are most intensively formed - from 800 up to 1000°C.) In some cases the use of electric power is more profitable on cost parameters, for example, for stand-alone installations of small productivity the application of electric power eliminates problems of delivery, storages and fuel supply, increase safety of incineration process. Besides the obtained high temperature can be used for a high speed quenching, allowing to create metastable and non-equilibrium states. Application of plasma

generators simplifies temperature mode control at the expense of thermal power variation of the plasma jet.

It is necessary to stress, that plasma generators, interesting from the point of view of technological applications, first of all should have good operational and economic performances.

### *About Advantages of Alternating Current Use*

Existing electric arc plasma torches can be divided into two basic groups: DC plasma torches [10, 11] and AC plasma torches [8-10].

DC plasma torches are mainly linear circuit machines, which are characterized by a long chamber with rather small internal diameter.
Working gas, blasting the arc, flows on all depth of the chamber, thus the arc contracts and its surface temperature, as a rule, becomes higher (10000÷20000)К. Heat exchange between the arc and working gas is carried out mainly due to radiation, thus there is some energy loss caused by radiation flows into the chamber walls. In our opinion, multiphase single-chamber plasma torches are the most promising for technological applications. Several arcs can simultaneously burn in the discharge chamber of such plasma torch, filling disposable space, due to it and due to electron diffusion, the volumetric area  with sufficiently high concentration of charge carriers is formed.  It results in formation of the character of arc burning at which the temperature of the arc is much lower than at contracted mode. At a diffuse mode of arc burning  the heating of gas occurs due to two basic mechanisms: flowing part of  gas through the arc and  intensive convection. The energy spent for gas heating, flowing through the arc, is released at relaxation of excitation and recombination of atoms, distributing on the rest of gas. It promotes increasing of average mass temperatures. Losses due to radiation are small and, accordingly, the transfer ratio of the discharge energy to gas is high, the form of the chamber can be made close to spherical, that is optimum from the point of view of decreasing of energy loss to the chamber walls.

Diffuse character of arc burning provides smooth transition of current through zero, therefore oscillograms of currents are close to sinusoidal, changes of current values which can be caused by arc instability, are automatically suppressed by inductance of the power supply. From the reactive component of power, present at inductive load, it is simply get rid by capacitive neutralization.

## Background of Three-Phase Plasma Torches

On a boundary of 70 - 90th of the past century the representatives of different countries had been executed a considerable volume of the research and design work devoted to creation of

AC powerful plasma generators [4-8]. The leading firms: Institute of Problems of Electrophysics of the Russian Academy of Sciences (IPE RAS) - in Russia [7, 8], Westinghouse - in the USA [12], ONERA - in France [13].
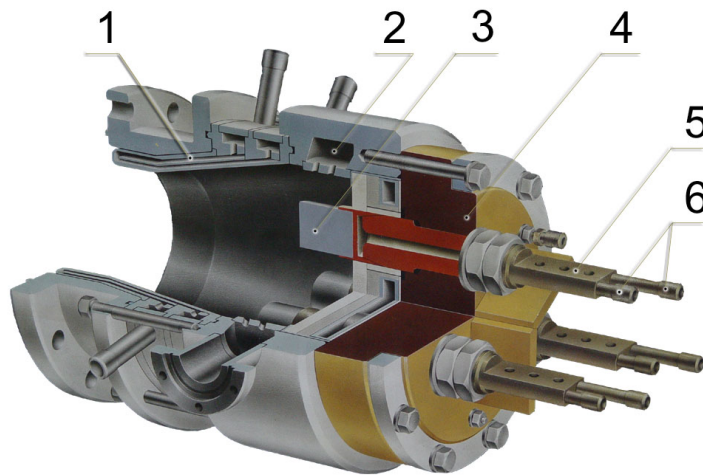


Fig.1. Three-phase plasma torch of EDP type [8]
*1 - chamber, 2 – gas supply loop, 3 – electrode tip, 4 – insulator, 5 - current lead, 6 – water supply.*

Presence of several simultaneously burning AC arcs in one chamber has allowed to create simple and reliable plasma torches transforming the electric current energy into thermal with high-efficiency (0.8÷0.9). Nevertheless, plasma torches designed earlier were mainly intended for operation on inert gases, nitrogen and hydrogen. However, for the modern technological applications it is required to work over the range of average and high powers (from tens kW up to several MW) on various media, including oxidative.

### *Description of the Experimental Devices*

AC three-phase plasma torches with power from 10 to 500 kW have been created in IPE RAS. They are able to operate stationary with different media, first of all with oxidizing ones. Plasma torch life time is more than 1000 hours, electrodes are replaced after hundreds of hours. Presently a plasma torch for 2 MW is developed.
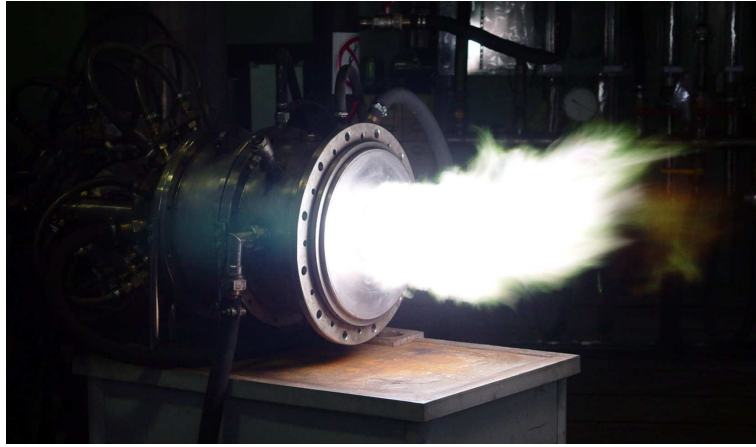
**Fig.2. Three-phase AC power torch**
Power 500 kW, working gas – air.

Operating powerful three-phase single-chamber plasma torch is shown in Fig.2. The principle of electrodynamic arc movement in the field of self-current (rail gun effect) is the basis of plasma torch operation. Fast movement of arc attachment point along the electrode under the action of electrodynamic and gasdynamic forces distributes the thermal load from the attachment along the electrode length, which allows to use water cooling electrodes from relatively easily melted material with high thermal conductivity and operating on oxidizing media. The diagram of the plasma torch is shown in Fig.3.
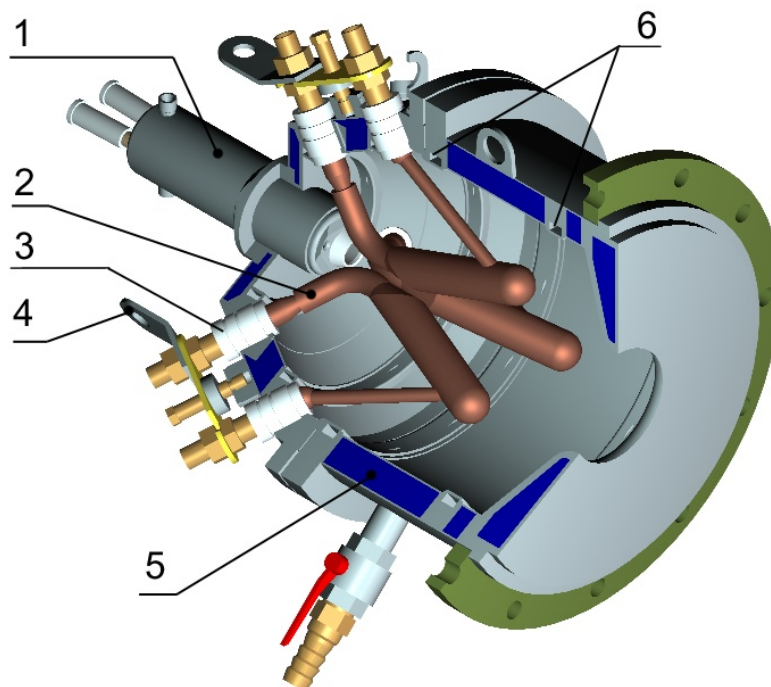


**Fig. 3. Diagram of a three-phase AC plasma torch**
1 – injector; 2 – electrode; 3 – insulator; 4 - terminal; 5 – cooling jacket; 6 – loop of working gas supply.

A single-phase high-voltage plasma torch of low power is used as an injector in the plasma torch. The injector creates a plasma stream in the interelectrode gap with electron concentration $n_e = (10^{13}\text{-}10^{14})$ cm$^{-3}$ sufficient for smooth ignition of basic arcs. Arcs are initiated between the basic electrodes in a zone of minimal interelectrode gap, then the arc attachments move along the surfaces of divergent electrodes.

Fig. 4 shows the characteristic oscillogram of phase currents and linear voltages. On duration of increase of amplitude of liner voltages curves (Uab, Ubc and Uca) it is possible to estimate the duration of extension of arc columns.
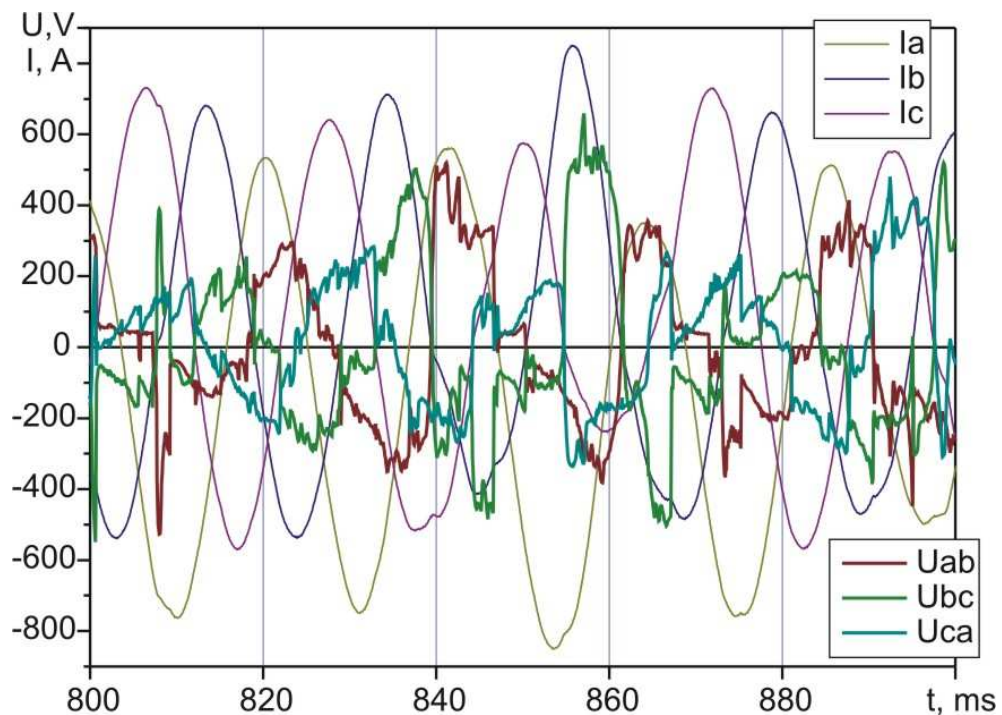
**Fig. 4. Characteristic oscillogram of currents and voltages: gas flow rate 30g/s (air) at atmospheric pressure, power - 130 kW.**

Two arcs burn simultaneously in the discharge chamber of single-chamber three-phase plasma torch with rail electrodes. The arcs fill the available area (Fig. 5(a)). Fig. 5(a) represents one frame from the videotape recording of the plasma torch operation, at the moment, when both arcs, sliding along the electrodes, can be completely seen through the nozzle (∅120mm). The image of arcs for shooting was projected on the flat screen, shooting was carried out using a high-speed digital video camera synchronously with recording of oscillograms of currents and voltages on the arcs. Such method of shooting allows to allocate the motion of the arc attachments on the electrode surface (near electrode jets) and character of arc movement in the discharge chamber volume. Joint studying of video data with oscillograms of currents and

voltages has shown, that the arc attachments move along the surfaces of divergent electrodes during several periods with velocity (2-20) m/s.
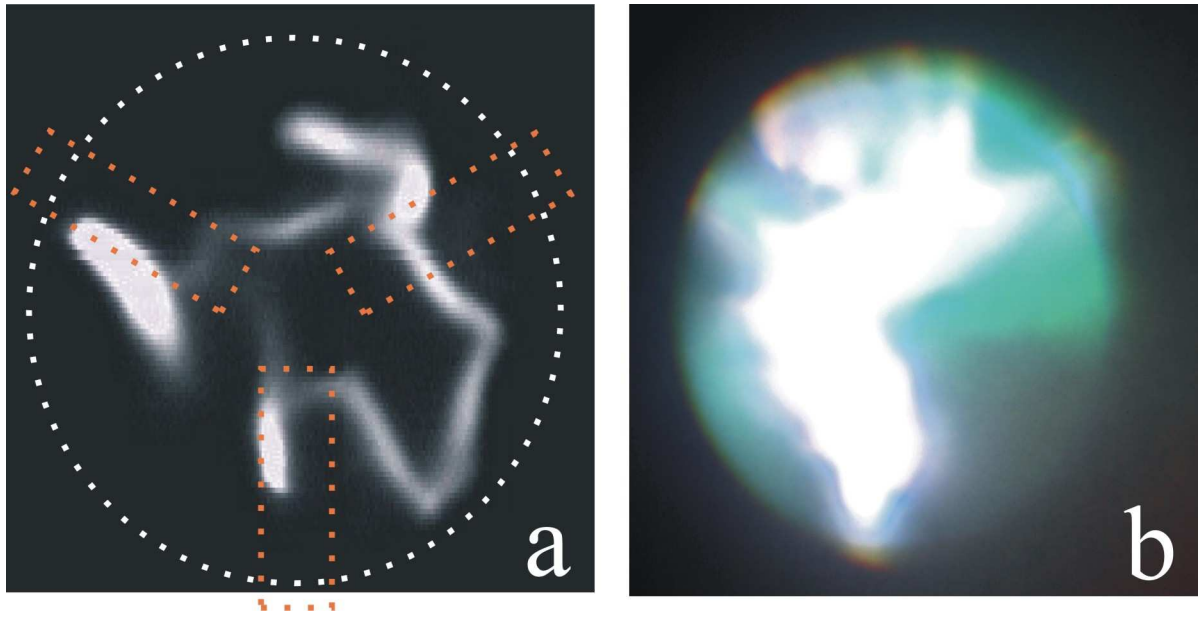


**Fig. 5. Arcs in the discharge chamber of the three-phase plasma torch (working gas - air).**

*a)* Frame of the high-speed digital video filming (camera HiSyS-2000, 2000 frame/s). Dash lines show the contours of the electrodes and boundary of the visible region of the discharge chamber. Power 130 kW. *(on the left)*
*b)* Diffuse mode of arc burning. Power 500 kW. *(on the right)*

In single-chamber plasma torches with rod electrodes made from tungsten alloys at the expense of ionization of electrode metal vapors and diffusion from the discharge zone, there was ion concentration $n_e \sim (10^{13}\text{-}10^{14})$ cm$^{-3}$ and diffuse mode of arc burning was achieved. In the case of rail electrodes made from easily melted materials the required concentration can be reached at the expense of the additional source of charge carriers. Furthermore, the density of the medium and speed of the working gas supply are essentially important. At diffuse mode of arc burning part of gas is blowing through the discharge zone, dissociation of gas molecules and atom ionization takes place. Then the energy is transferred from the heated gas to the remainder. At this the heat exchange is more efficient in the turbulent flow, where at whirl extinguishing the energy of dissociation was also released. The part of radiation heat exchange is insignificant. At set up of the contracted mode of arc burning the electron concentration $n_e$ in the discharge becomes $>10^{16}$ cm$^{-3}$, temperature $>>10^4$K, significant part of heat is transferred at the expense of radiation (50-99)%. Metal vapors of electrodes in the working gas significantly decrease radiant losses, because they absorb the most of radiation energy. Moreover, in spite of the comparatively small section area of the contracted arc column, the arcs intensively move in the discharge chamber volume, realizing the working gas blowing through the discharge area [7, 8].

The image presented in Fig. 5 (a), is typical for the contracted mode of arc burning, and the optical system has been tuned so that most obviously allocate evolution (motion) of area with the greatest radiant intensity.

In most cases the mode of arc burning of a single-chamber AC plasma torch has a diffuse character [7, 8]. The arcs fill the greater part of the discharge chamber, executing a motion in longitudinal and cross directions due to what for powerful plasma torches it is possible to receive a comparatively high thermal efficiency - (70-90) %. Fig. 5(b) shows the photo of the diffuse arc burning in the discharge chamber of the plasma torch. In a near wall zone, where the cold gas forming the insulating layer is fed, concentration of charged particles sharply decreases and that is why the arc does not touch the walls. The process described above is repeated continuously, therefore a jet of low-temperature plasma is formed at the outlet of the plasma torch nozzle. The average mass temperature of a jet can be controlled by adjustment of the power supply and change of the working gas flow-rate, so at use of air the control range makes from 2000 K up to 6000 K, which is optimum for some technological applications.

Photos of operating three-phase plasma torch of average power are shown in Fig. 6. It is a high-voltage plasma torch with rod electrodes in cylindrical channels. Power is supplied to electrodes $U_{xx}$=6kV, the arcs are initiated in the areas of minimal zone between the electrodes and body walls, they are blown by gas and close at the outlet of the channels. Three conducting plasma columns are formed. The value of voltage drop on the arcs in dependence of gas flow rate is about (0,8÷2) kV. The plasma torch operates stationary for hundred of hours, its body and electrodes are cooled by water, thermal efficiency is (80÷95)%, average mass temperature of gas at operation on air can be controlled in the range between 1500K and 6000K, that is sufficient for most technical applications.
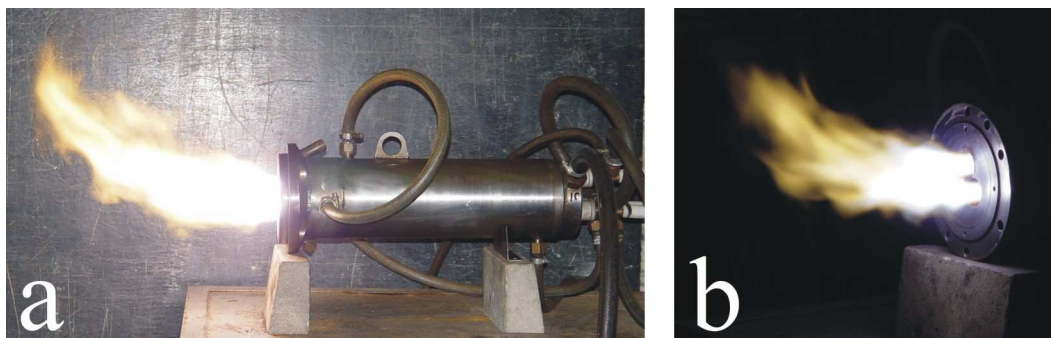


**Fig. 6. Three-phase AC plasma torch of average power**
а) operating plasma torch: power 30 kW, working gas  – air;
б) arc columns are closed at the channel outlets.

Fig.7 represents characteristic current and voltage oscillograms of such plasma torch. There is no variation of voltage amplitudes characteristic for plasma torches with rail electrodes.

The arcs burn in the channels with constant length, determining power of the plasma torch operation. The differences of the shape of the voltage curves of the adjacent periods in this case are stipulated by near electrode processes.
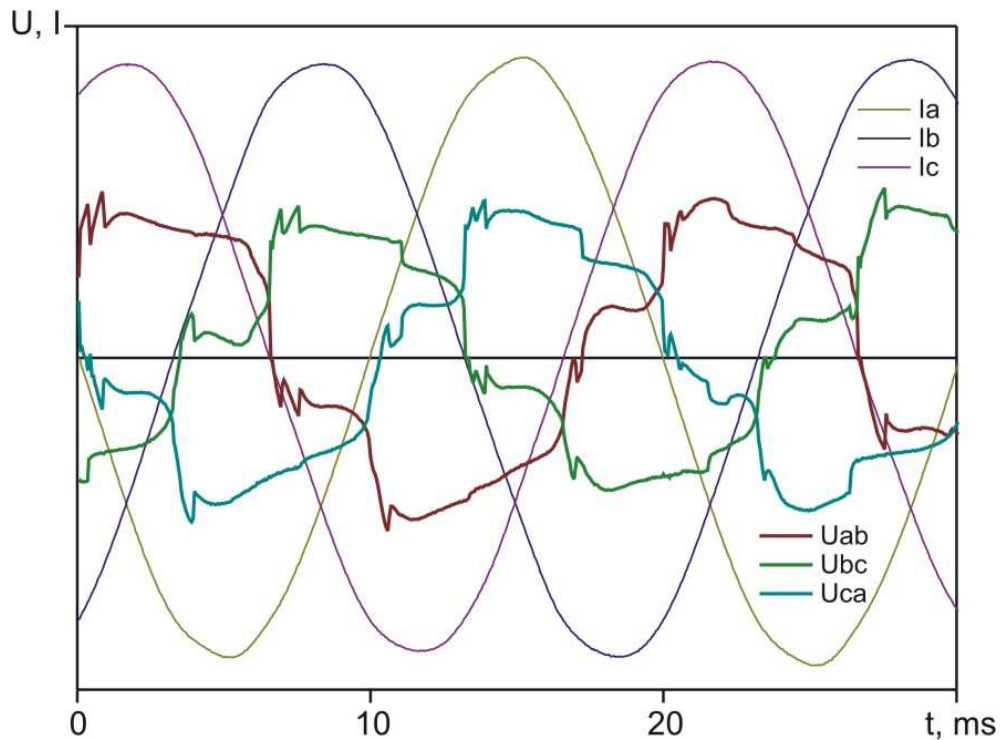


**Fig. 7. Characteristic voltage and current oscillogram of the three-phase high-voltage plasma torch (PTV). Active voltage value - 1.2 kV, gas flow rate - 5 g/s (at atmospheric pressure).**

## *Description of a Power Source of Power Three-Phase Plasma Torch*

In power supplies of AC plasma torches is designed the opportunity to change the injector power and power level of the basic arcs. Compensation of the reactive power occurs in an automatic mode.

Fig. 8 shows the photo of the power supply for three-phase plasma torches with rail electrodes with power (100÷500) kW. The electric circuit of such source is represented in Fig. 9. It reflects features of work of such type plasma torches and includes the following basic elements: current limiting reactors, reactive power compensators of the basic arcs and injector, transformer of the injector supply, and also automatic switches and contactors. Power of the source is adjusted in steps by switching of taps of the current limiting reactors.

In the power sources of AC plasma torches the voltage variations are suppressed by the energy of the magnetic field of the current limiting inductances, and the reactive power compensator allows to increase the power factor of the system (cosφ) practically to 1. The operation of such power source does not distort the curve form of the supply voltage.

**Fig. 8. Power supply source of the three-phase plasma torch (power up to 500 kW)**
1 – power cabinet; 2 – cabinet of current limiting reactors; 3 – cabinet of water and gas supply; 4 –control cabinet.
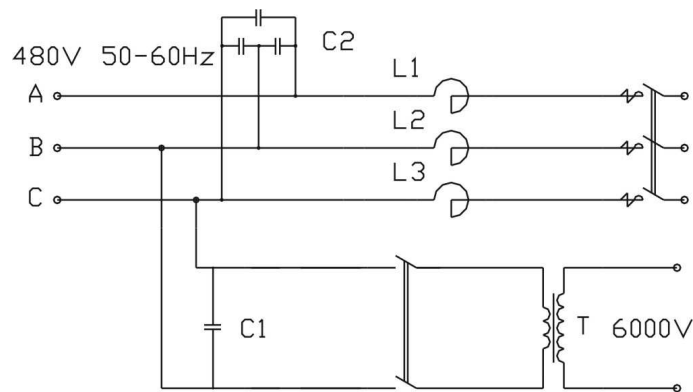


**Fig. 9. Diagram of the power source of the three-phase plasma torch On the left there are terminals of connection to the power network (A, B and C), on the right – to the current leads of plasma torch electrodes (at the top) and injector (at the bottom); L1 – L3 – current limiting reactors; T – transformer of the injector supply; C1 and C2 – reactive power compensator of the injector and the basic arcs correspondingly.**

## Test-Bench Description

A test-bench was equipped to carry out tests of AC plasma torches. It includes: power supply sources of the plasma torches with the reactive power compensation, gas supply system, cooling system, diagnostic collector, plasmachemical reactor and gas manifold, closed for the cleaning system and exhaust of spent gases.

Air is used as a working gas for tests of plasma torches and for insurance of thermal protection of the diagnostic chamber elements.

The diagnostic collector (Fig.10.) is a horizontal cylindrical chamber with cooling jacket. The plasma torch is mounted on one of its flanges, another flange of the diagnostic collector is connected with a vertical quencher, closed for manifold of exhaust gas removal. There are diagnostic peepholes in the sidewalls of the diagnostic chamber. These peepholes allow to study the character of movement of arcs and arc attachments, investigate the character of arc interaction with the surface in the end area of the electrodes, and also to carry out the optical diagnostic of the plasma parameters in the nozzle zone of the discharge chamber and in the plasma torch plume.
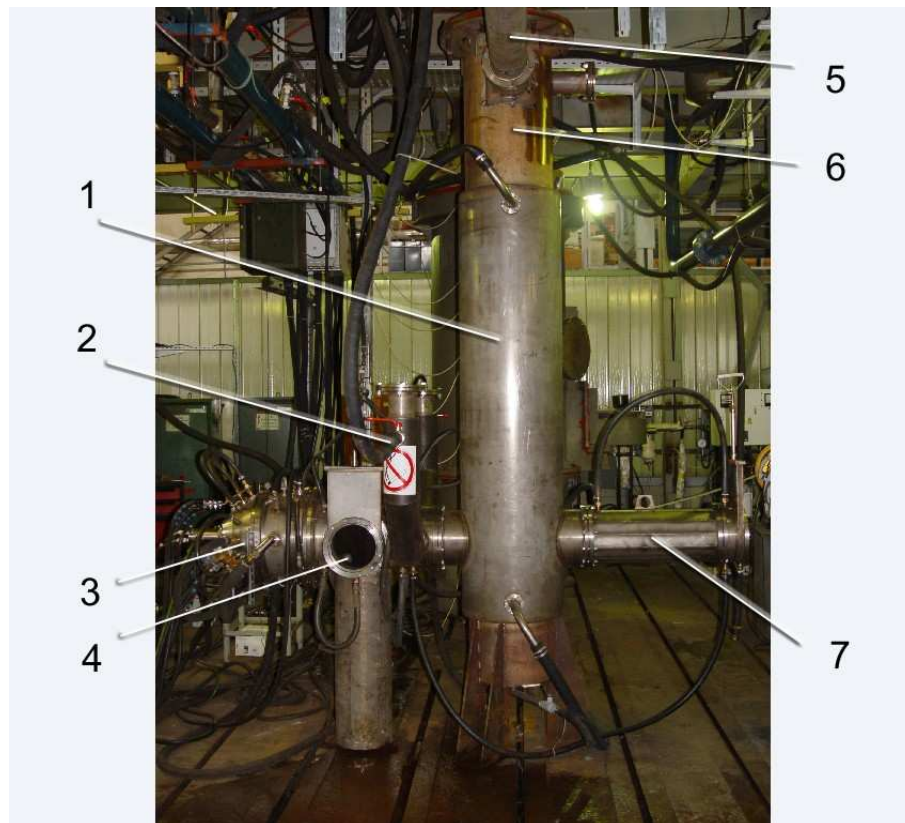


**Fig. 10. Diagnostic collector**
1 – quencher with the cooling jacket; 2 – water supply; 3 – plasma torch; 4 – diagnostic chamber; 5 – exhaust line; 6 – place for quencher injector mounting; 7 - extender of the diagnostic chamber.

To study the features of operation of AC plasma torches in technological installations on treatment of different materials at the test-bench is used a pre-production model of the plasmachemical reactor (PCR). It is a vertical cylindrical furnace, lined by high temperature ceramic and refractory breaks.

For collection, computation and registration of working parameters of the experiment are used measuring complexes on the basis of industrial computers with modules of computation of digital and analog signals.

## Investigation results

Investigation of external characteristics of the plasma torch operation is necessary for optimization of its working parameters and achievement of maximal life time of continuous operation in the conditions characteristic for corresponding technological applications. Fig.11 represents dependences of the power of the plasma torch with rail electrodes in dependence of working gas flow rate (air) for different settings of the power supply source corresponding to short circuit currents 500A, 700A, 1000A and 1500A. In the process of the plasma torch development it is important to design correctly the internal geometry of the discharge chamber and electrode system jointly with the method of the working gas supply and selection of the electrode material, in order to obtain the maximally optimal modes from the point of view of electrode erosion with opportunity of flexible control of relation power-flow rate (kW/g). In the result of the experiments it was developed a plasma torch with rail electrodes with the most favorable characteristics from the point of view of technological applications. The power of this plasma torch at the corresponding setting of the power supply source varies insignificantly in the whole operating range at variation of gas flow rate. That allows to organize regulation of temperature modes at realization of plasma technologies.
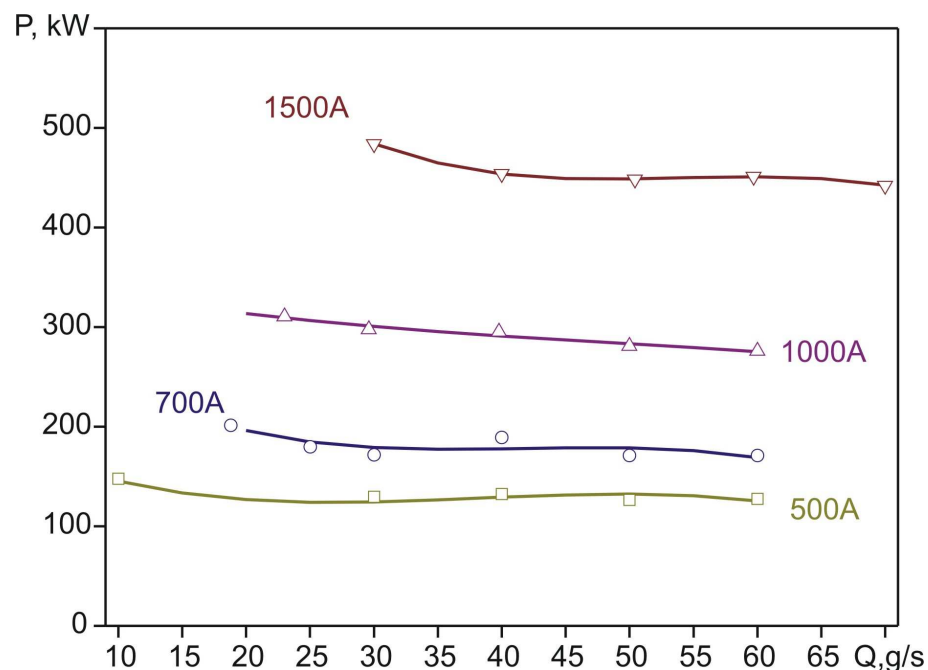


**Fig. 11. Dependences of power on working gas (air) flow rate for three-phase plasma torch with rail electrodes at atmospheric pressure. The curves are indicated in accordance with the settings of the power source on short-circuit currents.**

Measuring the electrical parameters of the plasma torch operation (currents, voltages, power in arcs) and determining losses for the cooling system it is possible to estimate the thermal efficiency of the plasma torch:

$$\eta = \frac{P-W}{P}, \qquad (1)$$

where $P$ – power in the arcs, $W$ – losses for the cooling system, $(P\text{-}W)$ – energy for the working gas heating .

A curve was built on the results of a number of experiments (Fig.12). So for air for flow rates in the range of (25-50)g/s the thermal efficiency is about 70%. At that its values at power of the plasma torch about 500 kW are underestimated, because the plasma torch was closed for the diagnostic collector.
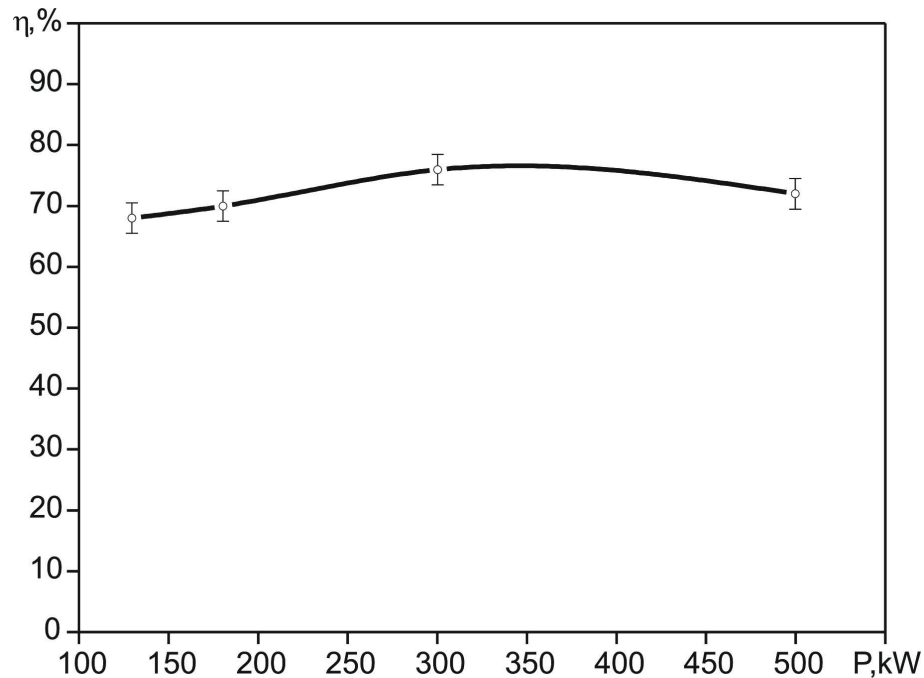


**Fig.12.** Thermal efficiency of the three-phase plasma torch with rail electrodes **within a range of flow rates (25-50)g/s at atmospheric pressure, working gas - air**

Fig.13 represents the curves of working gas enthalpy, corresponding to different settings of the power source on short-circuit current. Here enthalpy was determined taking into account the thermal efficiency:

$$H = \frac{P\eta}{Q} + H_{To}$$

where $P$ – power in the arcs, $\eta$ -thermal efficiency of the plasma torch, $Q$ – working gas flow rate, $H_{To}$ – initial enthalpy of the working gas

Using air as a working gas in the range of flow rates (25-50)g/s a three-phase plasma torch with rail electrodes can provide energy input about (1.5 - 12.5) MJ/kg, thus a long life time of continuous operation is ensured (without replacement of electrodes) more than hundred of hours.

Knowing the working gas enthalpy it is possible to estimate the average mass temperature of the jet at the plasma torch outlet (Fig.14).
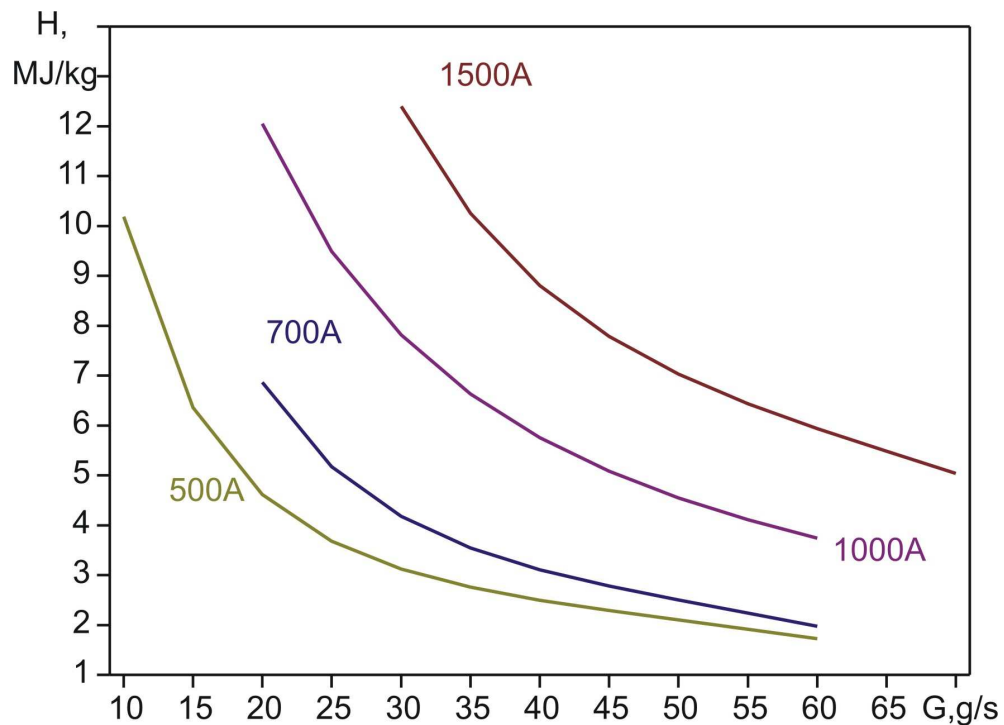


**Fig.13. Dependences of enthalpy of the working gas (air) of the three-phase plasma torch with rail electrodes at atmospheric pressure. The curves are indicated in accordance with the settings of the power source on short-circuit currents**
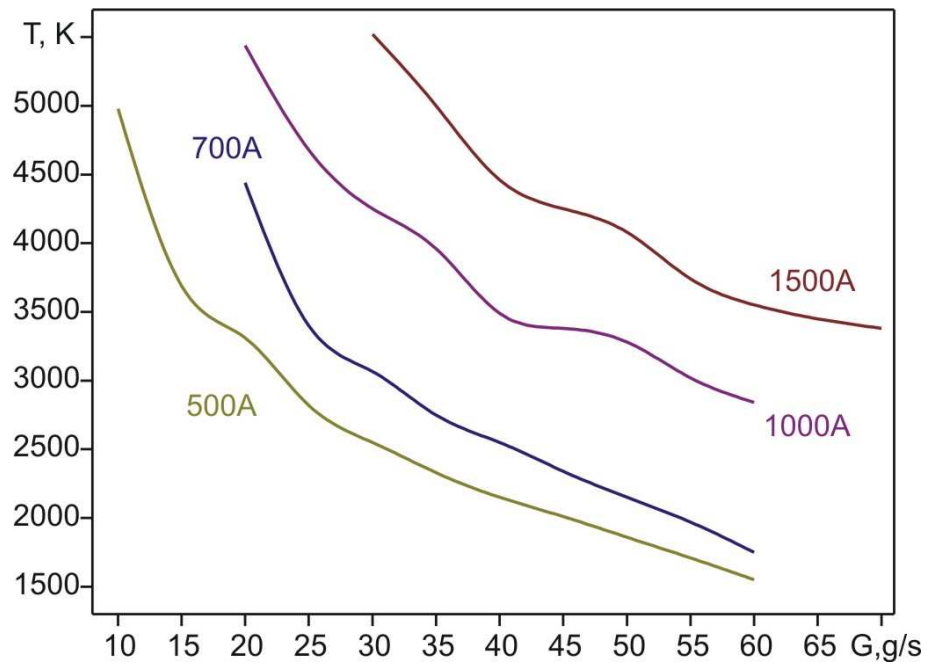
**Fig.14. Dependences of average mass temperature of the working gas (air) of the three-phase plasma torch with rail electrodes at atmospheric pressure. The curves are indicated in accordance with the settings of the power source on short-circuit currents**

Dependences of plasma torch power on arc current in the working range of flow rates (air) are shown in Fig. 15. They have the increasing character. Static volt-ampere characteristics (VAC), for various flow rates of the working gas (air) are shown in Fig.16. Characteristics are increasing. There is a change near 800A, stipulated by the character of processes in the discharge.
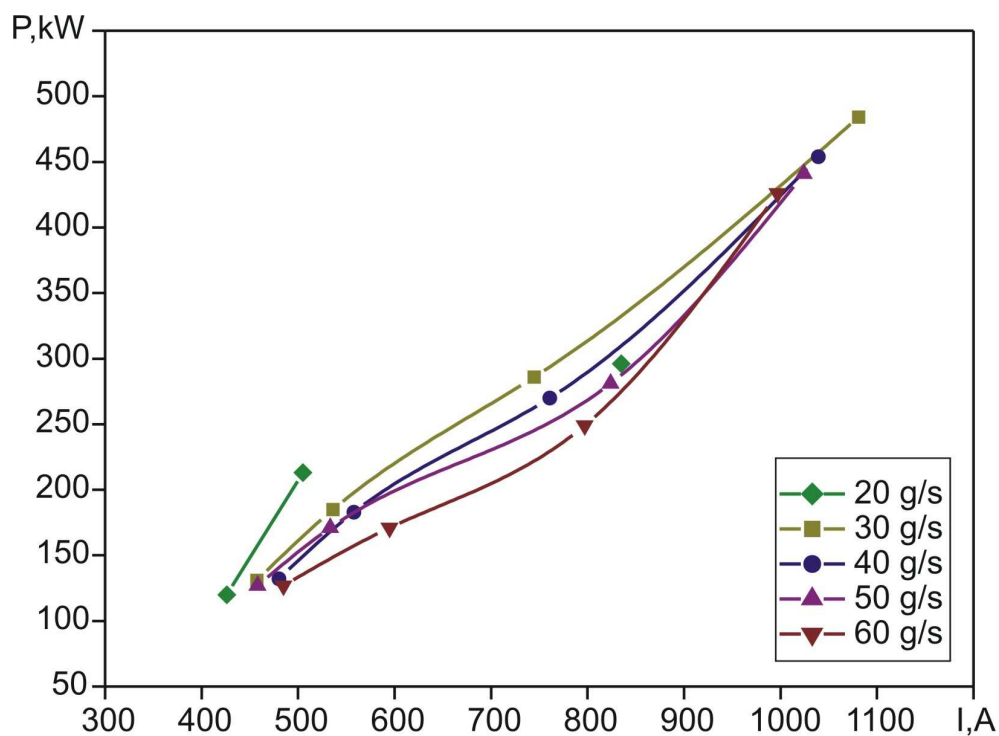
**Fig. 15. Dependence of power on current in the arcs of the three-phase plasma torch with rail electrodes for various flow rates of the working gas (air) at atmospheric pressure.**
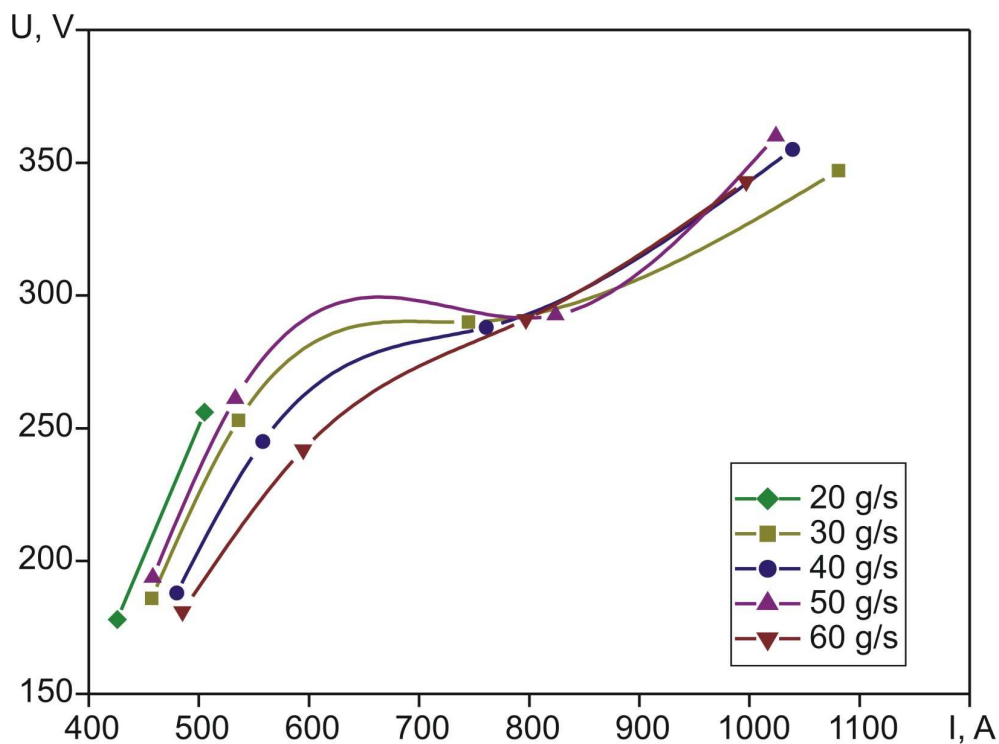


**Fig. 16. Static VAC of three-phase plasma torch with rail gun electrodes for various flow rates of working gas (air) at atmospheric pressure**

Dependence of power of high-voltage three-phase plasma torch with rod electrodes, placed in separate cylindrical channels is shown in Fig.17. It has an increasing character

stipulated by peculiarity of the operation principle of the plasma torch. Supporting arc currents at one level, stipulated by the design of the power source, at increase of the working gas flow rate the arc length increases, correspondingly the voltage on the arcs increases and therefore power increases. Approximating polynomial has the appearance:

$$P = 26.429 + 2.319Q - 0.135Q^2 + 0.003Q^3$$

where Q – gas flow rate (g/s), $P_{av}$ –plasma torch power (kW). Corresponding values of enthalpy and average mass temperature of gas at the outlet, taking into account thermal efficiency, determined in the examined range of flow rates on losses to the cooling system of the plasma torch. Thermal efficiency of such type of plasma torch is comparatively high and as evident from Fig.18, practically equal to 90% in the whole operating range.
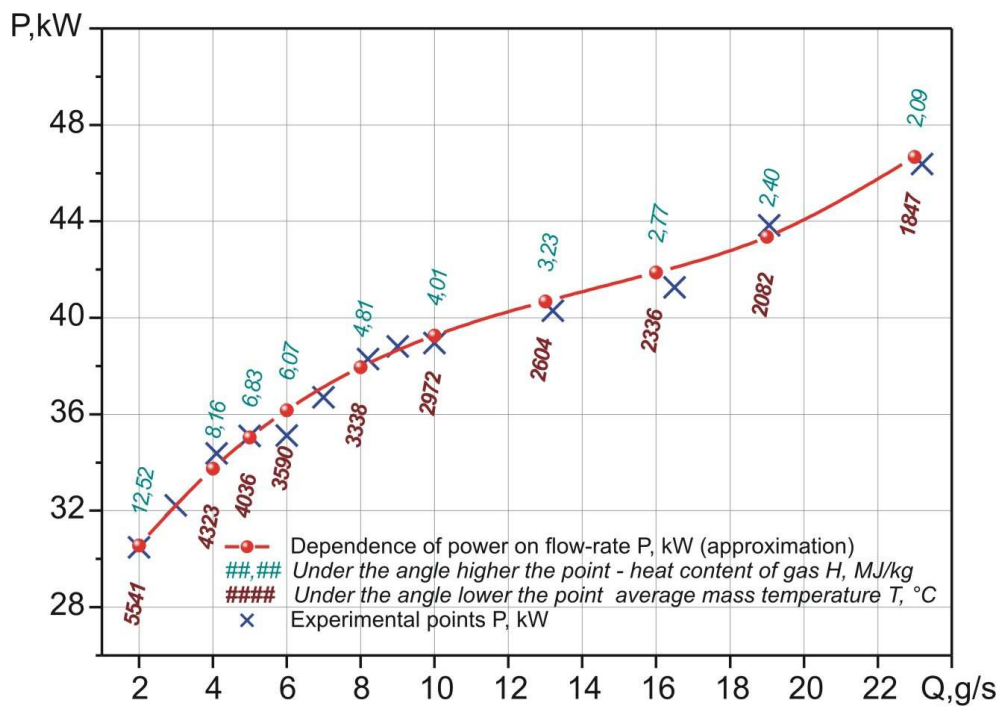


**Fig.17. Dependence of power the three-phase high-voltage plasma torch on gas flow rate (air) at atmospheric pressure.** The diagram also shows the corresponding values of enthalpy and average mass temperature of the working gas
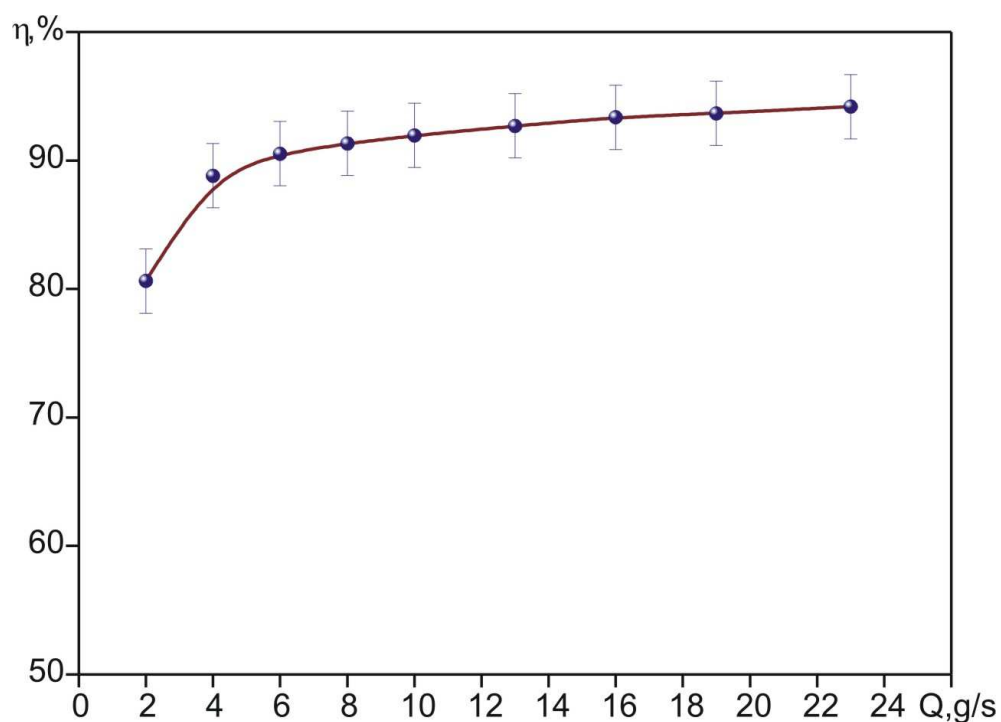
**Fig.18. Dependence of thermal efficiency of the three-phase high-voltage plasma torch on gas flow rate (air) at atmospheric pressure**

*Analysis of electrical processes in the power supply circuit of the plasma torches*

The analysis of electrical processes taking place inside the electric arc chamber was carried out using the experimental data obtained at testing of a single-chamber three-phase plasma with rail gun electrodes. Typical oscillograms of voltages at different flow rates of plasma forming gas are shown in Fig.19.
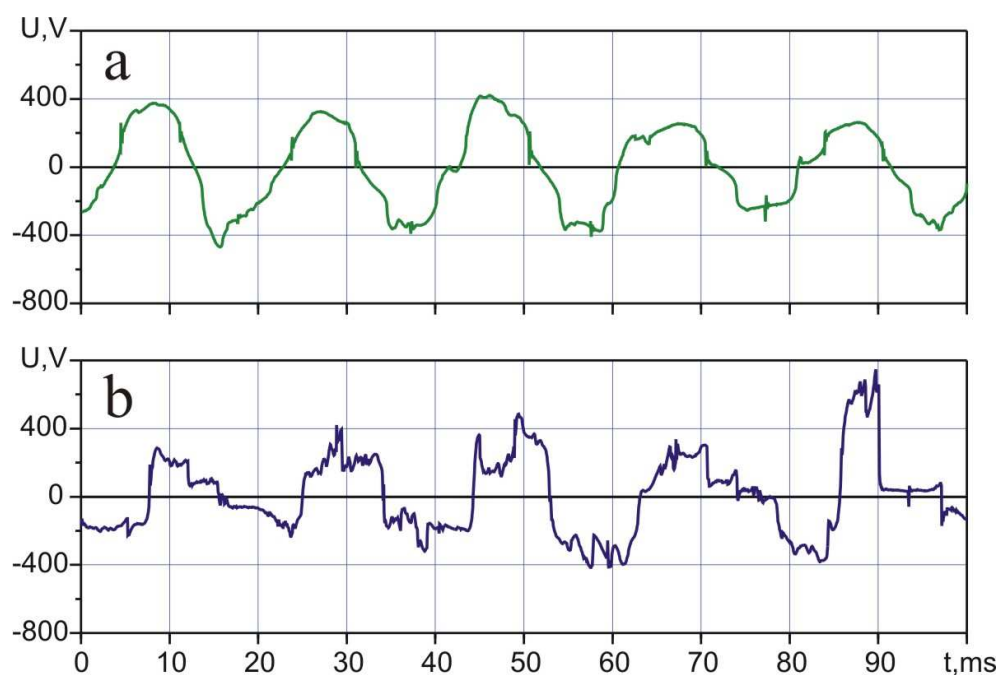


**Fig.19.** Characteristic voltage oscillograms on the arcs of plasma torch with

rail electrodes at operation on air**.** Upper – gas flow rate 10g/s, lower - 30 g/s.

As evident from the oscillograms the shapes of the current and voltage curves are strongly distorted and their forms are significantly differs from sinusoidal, and expansion of the oscillograms into Fourier series reveals a great spectrum of frequencies different from the first harmonic.

To understand the reasons of the current and voltage variations it is necessary to imagine the processes taking place inside the chamber of the plasma torch. A single-phase model is used to simplify the description of the processes inside the chamber of the three-phase plasma torch Fig. 20.
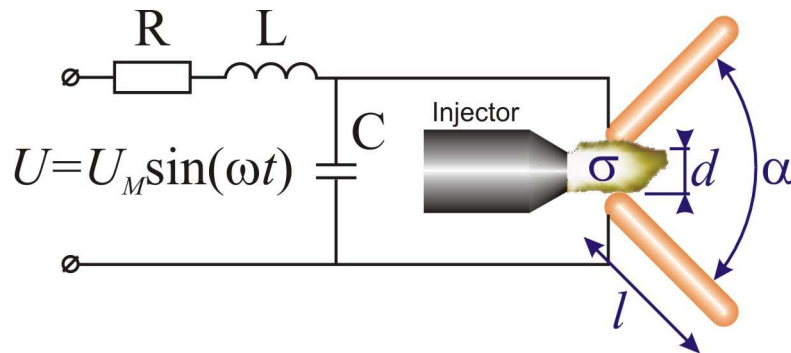


**Fig. 20 Schematic of single-phase model of a plasma torch with rail electrodes.** $U=U_M\sin(\omega t)$ – power source voltage; $R, L$- correspondingly active resistance inductivity of current limiting reactors; $C$- capacity between the lines; $\sigma$ - conductivity, created by the injector in the area of minimal interelectrode gap; $d$- minimal interelectrode gap; $l$- electrode length; $\alpha$- angle between the electrodes.

In the critical interelectrode gap the injector creates the area of the ionized gas with conductivity $\sigma$ and resistance $R_{gap}$, where after supply of voltage $U$ on the basic electrodes the arc ignites. The arc has time constant - $\tau$, resistance - $R_{arc}$ and residual arc resistance $R_{arc, res}$ during current transition through zero. As it was described above, the conductivity created by the injector in the critical interelectrode gap is sufficient for arc initiating between the basic electrodes. Under the action of the applied forces the arc extends, and its attachment moves along the electrodes. If during the next transition of current through zero the arc length does not achieve the length of foolproof extinction, and residual arc resistance will be lower the resistance of the ionized gas in the critical interelectrode gap, so the repeated ignition will take place and the arc moves farther.

Two arcs burn simultaneously in the chamber of the three-phase plasma torch that is why the processes in the chamber are more complicated. One electrode is common. Two arcs are attached to this electrode which can have attachment points in different places of the electrode.

Moreover the arc area moves rotating along the electrodes. It is determined that inter-phase arc commutation takes place with frequency 300 Hz.

At optimal mode the arcs distribute evenly along the whole surface of electrode. Arc attachment in its motion along the electrode surface go from the critical interelectrode gap up to the electrode ends, where it extinguishes, and ignites again in the critical interelectrode gap. This mode corresponds to the even wear of the working surfaces of the electrodes and maximal life time of the plasma torch operation.

Another characteristic mode, when arc attachment does not reach the ends of the electrodes. The mode corresponds to the uneven electrode wear in the middle part or in the area of minimal interelectrode gap. The basic reasons of this mode are high injector power and non-optimal working gas supply. Most often the reason is too high flow rate, which does not correspond to the divergence angle of electrodes, geometrical dimensions of the electrodes and chamber, and also power setting of the power supply.

And at last, the operation mode at which arcs, once initiated in the zone of the shortest interelectrode gap, go out to the electrode ends and work only in the end area. The basic reason of this mode is non-optimal gas supply.

So, operation of the plasma torch is nothing but constantly repeating ignition and extinction processes of electric arcs with simultaneous periodical movement along the divergent electrodes from the area of the minimal interelectrode gap to the ends.

The results of the harmonic analysis reveal a number of characteristic frequencies in oscillograms of currents and voltages.

Current oscillograms include:

- Direct component, near electrode processes are responsible for its appearance, the arc works as non-liner element (in the easiest case - semiconductor diode);

- Electric arc movement along the electrodes are responsible for oscillations with frequency less than 50 Hz. During the arc area movement from the critical interelectrode gap to arc exit on the ends, the arc length increases, and correspondingly increases the resistivity of the arc column, the arc current decreases, the voltage increases.

As oscillograms show the arc area in dependence of various conditions can move from the critical area to the ends during 2 - 11 frequency periods of the power network.

The harmonic analysis does not reveal the direct component in voltage oscillograms, but there are even harmonics with clearly expressed second harmonic. Availability of oscillations with frequency of 100 Гц can be explained by the influence of the injector operation – variation of medium conductivity in a critical interelectrode gap takes place with doubled frequency of the power network of the injector.

Fig. 21-23 represents the results of computation of oscillograms of the three-phase AC plasma torch with rail electrodes at one power setting with different flow rates of working gas. Shape factor of the curve (Fig. 21) reflects the difference of shape of the investigated curve from the sinusoidal (for the sinusoid the shape factor is equal to 1.11). The harmonic factor (Fig. 22) reflects the influence of the harmonic components different from oscillations of the basic frequency (for sinusoid the harmonic factor is equal to 0). Distortion coefficient (Fig.23) reflects the content of the direct component and harmonic components in the investigated curve (for sinusoid the harmonic distortion coefficient is equal to 1). As illustrates show there is the dependence between the variation of gas flow rate and variations of voltage and current of electric arcs.
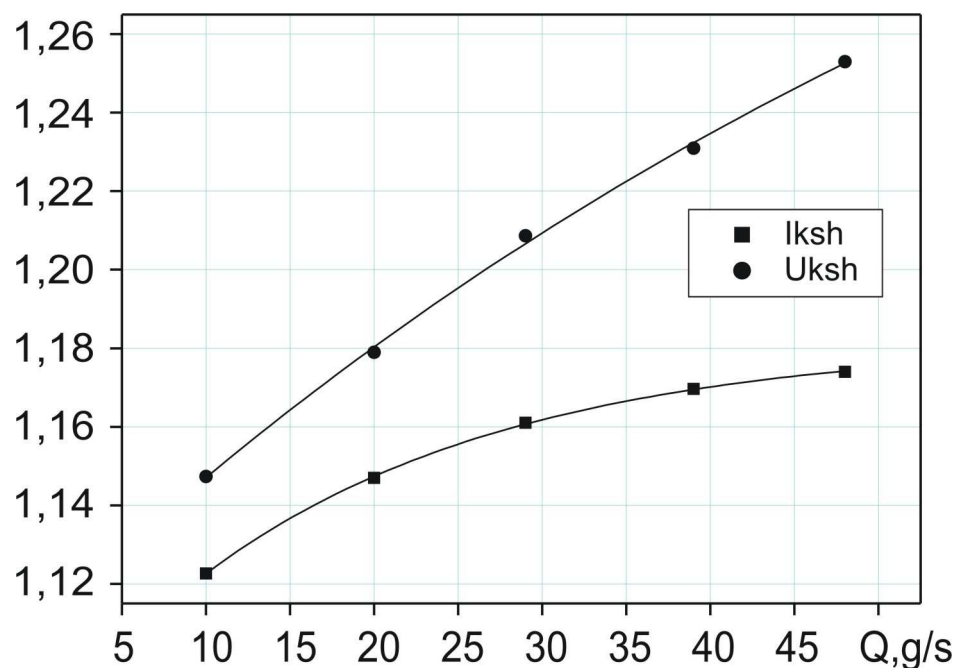
**Fig. 21.** Dependences of shape factor of current and voltage curves on the flow rate of working gas (air) for a three-phase plasma generator with rail electrodes at atmospheric pressure. Power - 130 kW.

**Fig. 22.** Dependences of harmonic factor of current and voltage curves on the flow rate of working gas (air) for a three-phase plasma generator with rail electrodes at atmospheric pressure. Power - 130 kW.
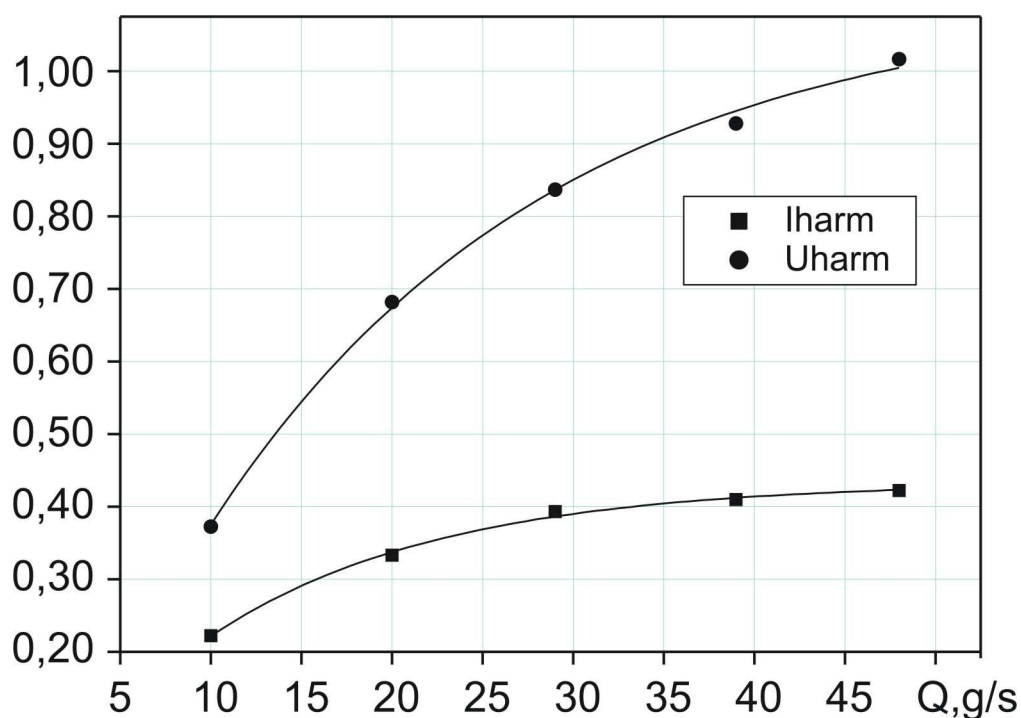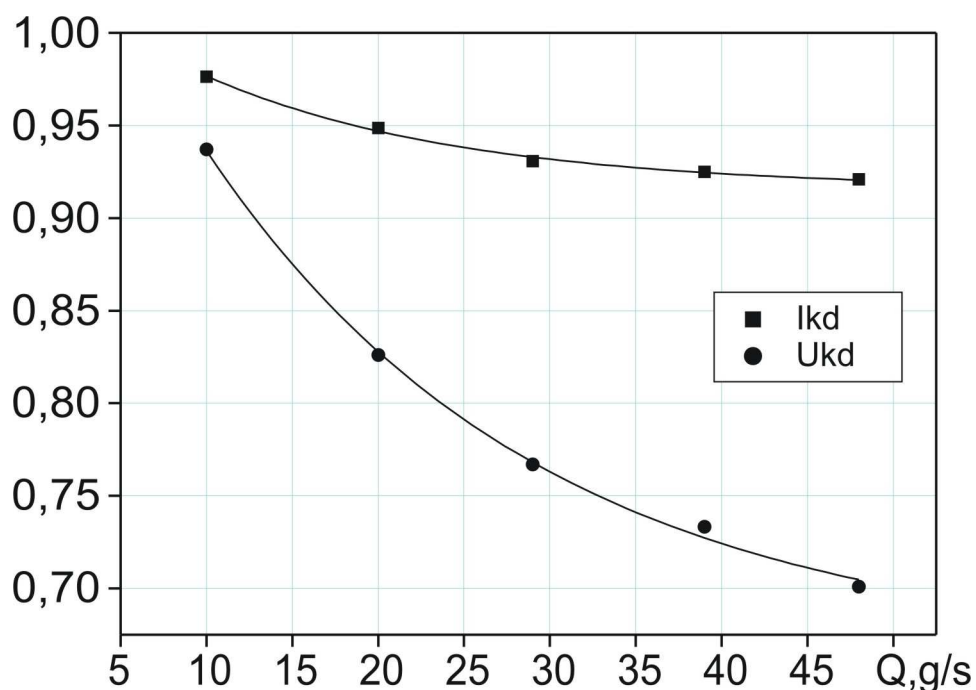


**Fig. 23.** Dependences of distortion coefficients of current and voltage curves on the flow rate of working gas (air) for a three- phase plasma torch with rail electrodes. Power - 130 kW.

From the above studied dependences it is clear that at operation of the plasma torch at low gas flow rate the influence of the harmonic components different from the first harmonic is

minimal. Apparently it is connected with the fact that inside the electric arc chamber it is formed a sufficiently big area of ionized gas with residual conductivity enough for repeated arc ignition. Mode of arc burning has a pronounced diffuse character, they mainly burn in the end area and variations of the injector power do not have the essential influence. Voltage curve on the arcs practically does not change. At low gas flow rates the gas-dynamic variations of cold gas are also not very important. The arc with some assumption (if do not take into account the waves forming at arc ignition and reflected from the walls of the electric arc chamber) can be considered free burning, pulsations of current and voltage on the arc are minimal in this mode.

## *Conclusion*

AC plasma torches operating on different, first of all oxidizing media, for a long period of time ($>10^3$ hours) in power ranges (1–800) kW.

The most important factor ensuring optimal operation of a number of the newest plasma technologies (treatment and pyrolysis of various types of waste) is relation of the plasma torch power to the gas flow rate (kW/g). Created systems allow to optimize this parameter within a range (1.5 to 12.5) kW/g.

Use of method of harmonic analysis allows to study in details processes taking part inside the electric discharge chamber. Obtained external characteristics of the plasma torches permit to optimize their modes and create more power systems – to (1.5-5)MW.

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