Arc Discharge, Plasma Torch (different approaches)

Contribution of M. Guivan to TeReGeo intermediate report

An electric arc, invented by Russian scientist V. Petrov, is an electrical breakdown of a gas which produces an ongoing plasma discharge, resulting from a current flowing through normally nonconductive media such as air or gas. An arc discharge is characterized by a lower voltage than a glow discharge, and relies on thermionic emission of electrons from the electrodes supporting the arc. The electric arc is influenced by different factors: the gas flow, inner and outer magnetic fields, construction elements of the chamber which confine the arc, the elements being often under electric voltage, differing from that of the arc. Thus, there is a strong need for deep understanding of a wide spectrum of the processes taking place in the discharge chamber in order to develop highly effective plasma torches that we have proposed to use as a source of the thermal plasma [1-3].

Let us analyse the classification of only linear plasma torches, which represent a wide range of plasma generators regading the consumed power, variations of applied working gases and pressure ranges. Knowledge of fundamental physical processes, taking place in the discharge chamber of a plasma torch, helps to suggest a simple classification and to reduce multiple constructive solutions to three principal classes. The first class (Fig. 1a) consists of the plasma torch with a tubular exit electrode and self-aligning arc length. This type of torch is used widely in the industry and scientific research work.

The average arc length l is a function of current value, chamber diameter, gas flow rate, pressure and it depends on the working gas and on the polarity of the exit electrode. The large-scale shunting, taking place in the transient zone of the discharge channel, forms the mechanism for arc length changes.

The second class of the plasma torches is characterised by the fact that the average arc length l is constant in a relatively wide range of current changes, while the other parameters, mentioned above, are constant, and this length is always less than that for the self-aligning arc $l_a < l_{sa}$. There are several technical solutions, providing the constant average arc length. One is a peculiarity of a broken gas flow behind a step, formed by the step construction of the exit electrode, that consists of two cylinders with different diameters, the diameter of the exit part of the electrode d_3, being larger than d_2. This forms the basis of one of technical solutions, which draws the greatest attention of the engineers (Fig. 1b). These plasma torches are working in a stable manner without additional resistance in the circuit on the rising branch of the arc VAC. Recently, special attention has been paid to the third type of linear plasma torches, in which the average arc length in non-changeable, but longer than that of the self-aligning arc (Fig. 1c). The increase of the average arc length is achieved by introduction of the interelectrode insert (IEI) between the anode and the cathode, the length of which is larger than l_{sa}. The insert may be solid, porous, with any gas injection through porous structure or sectional with/without gas injection into intersection gaps. The development of a block-module plasma torch with the IEI, which maintains power from 1 to 3–5 MW at moderate arc current, was a good engineering solution. Each plasma torch block is produced as an element of a separate sectional plasma torch. A plasma torch with a gas-vortex IEI can be regarded as an interesting and promising solution. In this plasma torch, a heat flux on the discharge chamber wall is determined by the radial heat transfer from the arc.

In contrast to the major part of the plasma torches which use gaseous mixture as a working medium, we suggest to use so called auto plasma torches [4]. This is the steam vortex plasma torch with a steam generator, embedded into the wall, which produces a plasma-forming water vapor due to heat loss (Fig. 2a). Using a vortex keeps all the advantages of plasma torches of a linear design, namely, high efficiency of axial stabilization of the arc, the durability of the initial part of the walls, ease of ignition of the arc and adds to them a tangible increase in thermal efficiency. Practically all the heat, absorbed by the wall of the arc chamber of plasma torch can be recovered by a little of water spending because of its anomalously high values of specific heat and latent heat of vaporization (Fig. 2, 3).

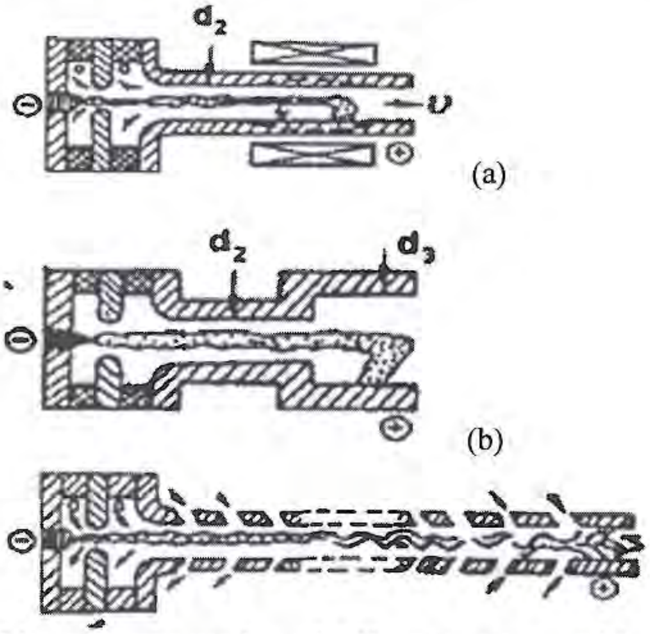
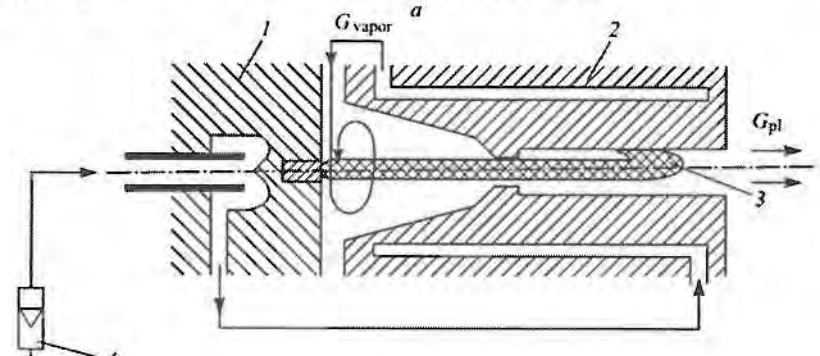
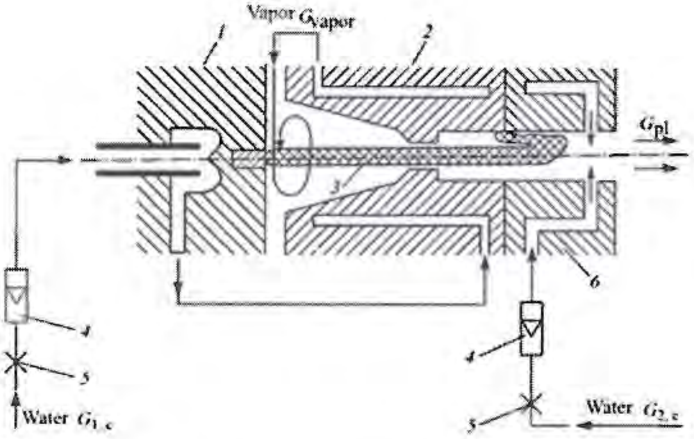


Fig. 1. Linear plasma torches of different types: a – with a tubular exit electrode, b – with a 'step' electrode, c - plasma torch with an interelectrode insert.



(a)



(b)

Fig. 2. Stechiometric scheme of water supplying of the plasma torch with a complete heat recovery.

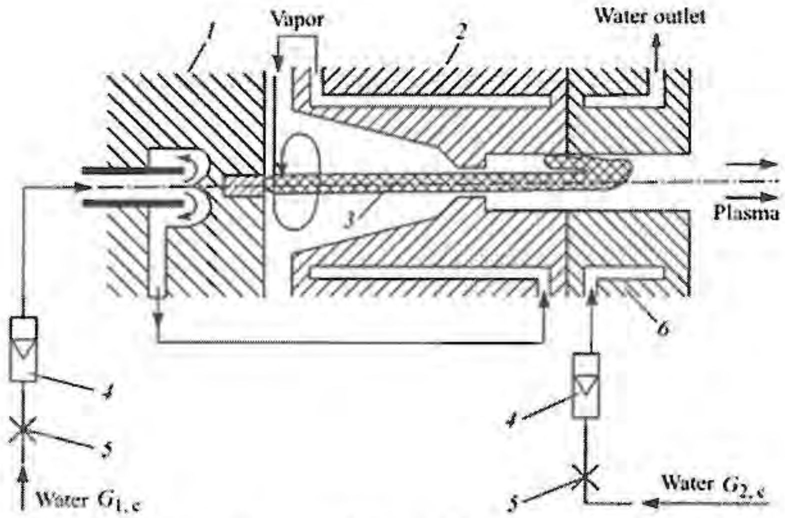


Fig. 3. Stechiometric scheme of water supplying of the plasma torch with a non-complete heat recovery.

Currently, the majority of plasma torches work under DC excitation. This situation is due to the factor that the DC arc, in principle, burning more stable compared with the AC arc. Actually, the current flowing through the AC arc crosses zero. In other words, we can assume that the arc is extinguished and periodically ignited and reignited again. Therefore, for sustainable AC arc is necessary to ensure the conditions for its reignition after the zero current. At the same time, the idea of the arc powered by alternating current looks very attractive for the following reasons:

- DC power supplies for the high-power plasma torches (~MW) become very complex and most important, expensive facilities, which cost far exceeds the cost of plasma torches themselves. Plasma torches driven by AC power do not require any special devices, they could be connected to the industrial three-phase AC through the inductor. The switches in three-phase electric power are simple and reliable.

- In DC plasma torches the cathode lifetime normally several times shorter than the anode lifetime. In AC plasma torches cathode and anode are reversed with frequency (~50 Hz), so electrodes lifetime is approximately two times larger compared to DC plasma torches (at the same other conditions).

From this viewpoint the plasma torches of "Zvezda" ("Star") type are very attractive (Fig. 4). The main characteristic peculiarity of the "Zvezda" type plasma torch is fact that all three arcs are connected to each other in the center of the mixing chamber by means of a star schema (Y-connection), forming a zero point on plasma. Thus, in this plasma torch three arcs burning, but it contains only three electrodes instead of six.

The main advantages of "Zvezda" plasma torches are as follows:

- Homogeneous distribution of temperature and pressure at the exit of jet.
- Symmetrical loading of three-phase electric power.
- Modular design allows increasing the plasma torch power due to an increase in the number of modules.

The schemes of the electric power supplies, adopted from [5], are presented in fig. 5.

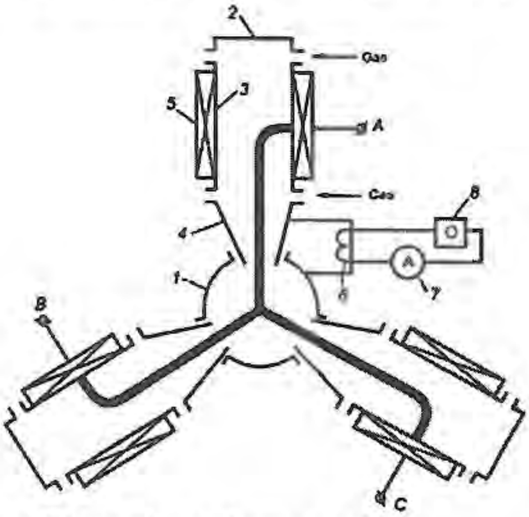


Fig. 4 Three-phase plasma torch.

In our research the optical emission spectroscopy is widely used for the determination of the plasma parameters, as well as for the control of electrodes erosion. The spectra emitted by plasma are registered by the registration system (400 μm quartz optical fiber, HR2000+ spectrometer (Ocean Optics), Spectra Suite software).

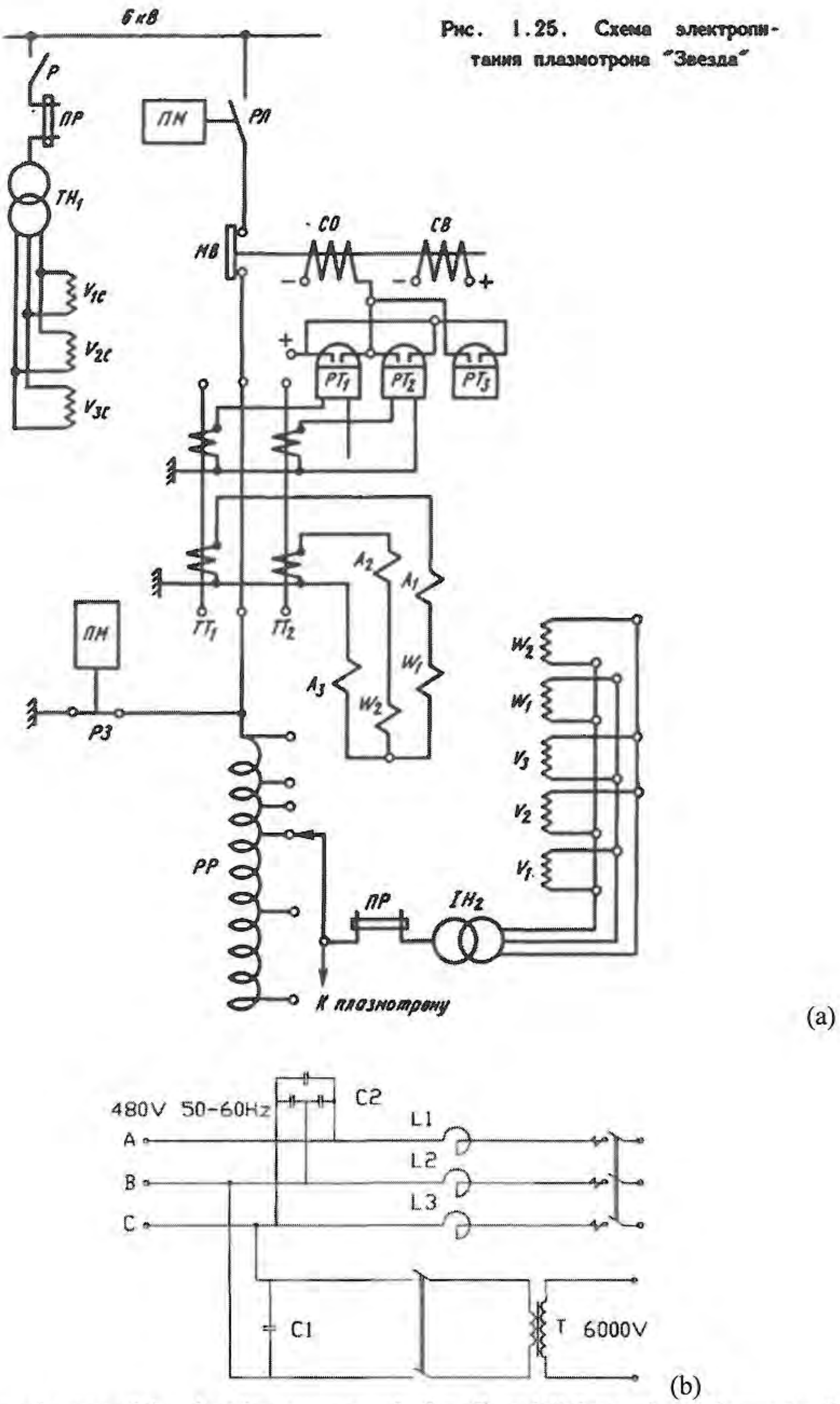


Fig. 5. The schemes of the electric power supply for „Zvezda“ three-phase plasma torch: (a) one-line schema; (b) schema with the step-up transformer.

References

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