

EXPERIENCE OF KHERSON SHIP-BUILDING PLANT IN APPLICATION OF PLASMA CUTTING

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The peculiarities of application of plasma cutting in manufacture of ship-hull parts were considered. The positive and negative phenomena were mentioned. The influence of composition of plasma-forming medium on the main technological characteristics of cutting process was analyzed. Aim of the work is to present the experience of the Kherson Ship-Building Plant (Kherson Shipyard) on application of plasma cutting using plasma-forming medium with addition of a small amount of water. The design of plasmatron PMR 74M was described. The addition of water results in increase of cleanness and decrease of roughness of the cut surface. The explanation to the observed effect was given. The replacement of acetylene-oxygen cutting by plasma one in the plasma-forming media, such as air + water, allows 3–5 times improving the efficiency of cutting, decreasing thermal deformations and increasing accuracy of the parts being cut, providing simplicity of control of cutting process, possibility of automation with application of flexible industrial systems. This technology was realized at the automated area of the enterprise in the production lines by using the machines of the type «Kristall», NPC devices 2R32T on the basis of microcomputer. 7 Ref., 1 Table, 8 Figures.

Keywords: *plasma cutting, ship-hull parts, design of plasmatron, purity of cut surface, addition of water, efficiency, thermal deformations, automation, production lines*

The prospects of development of ship building in Ukraine are connected with modernization of technologies. The first stage of ship building is the manufacture of hull parts, the number of which amounts to tens of thousands per one hull. One of the main technological operations defining the quality of welding of parts and welding of a ship as a whole is thermal cutting, which is used to treat about 80 % of applied metal in ship building. As to the labor consumption, these works amount up to 20 % of the whole volume of works of hull-treated workshop [1].

The main method of thermal cutting is plasma cutting, which considerably surpasses the gas-oxygen one according to its efficiency and quality. According to the regulations of the Russian Maritime Register it is necessary during manufacture of parts to be sure that there is no excessive saturation of cut surface with gases (nitrogen, hydrogen) to avoid deterioration of quality of welds. The appropriate quality of cut surface along the free edges should be provided [2].

The wide practice of industrial application of plasma cutting in manufacture of ship-hull parts showed that use of high-enthalpy gases (hydrogen, helium, oxygen, etc.) for plasma forma-

tion results in considerable change in the whole process of plasma cutting. On one hand its high efficiency is achieved, on the other — the service life of electrodes of plasmatron is decreased and stability of arc burning is violated.

The elimination of undesired factors is achieved due to application of high-enthalpy gases not in the pure form, but in the mixtures with heavier gases, i.e. the transition from single- to multicomponent gas media.

Plasma-forming medium has a direct effect on all the main assemblies of the equipment for plasma cutting. Change in quality composition of the plasma-forming medium allows considerable changing in the main technological characteristics of the process and, in the first turn, the quality of cutting. The role of the composition of plasma-forming medium in the cutting technology is determined as follows [3]:

- composition of plasma-forming medium at the preset geometry of a nozzle and current of cutting determines the intensity of arc column field both inside as well as outside the nozzle. Therefore, due to the change of composition of a medium the amount of heat energy evolving in the arc can be regulated within the wide ranges;

- composition of plasma-forming medium significantly influences the maximum permissible value I/d , which allows controlling the density of current in arc, heat flow in the cut cavity and, as a result, the cut width and speed of cutting.

As a result of change in composition of a medium the most favorable conditions for re-



removal of molten metal from the cut cavity can be created, preventing the formation of a flash on the lower edges of a sheet being cut and making it easy to remove.

In some cases the considerable addition of heat energy due to chemical interaction of plasma-forming medium with a metal being cut should be also considered. The additional input of chemical reaction into the general heat balance can reach the value commensurable with electric power of arc.

The composition of plasma-forming medium influences also the physical and chemical processes on the walls of a cut, the degree of saturation of cut walls with different gases, and also the depth of gas-saturated layer depend on it. Great influence on the selection of plasma-forming medium have the composition of metals being cut, and thickness of sheets have a great influence on the selection of plasma-forming medium. The higher the heat conductivity of a material and the larger the thickness of a sheet, the more rigid are the requirements to the composition of plasma-forming medium and, moreover, the range of used mixtures becomes more narrow.

In cutting of steels the compressed air as the most widely applied and economically efficient gas found the widest application as a plasma-forming medium [4–6].

The application of cheap and acceptable compressed air as plasma-forming medium in combination with high efficiency and flexibility of the process, suitable for cutting of almost all metals, provides considerable advantages as compared to other plasma-forming media. However, some disadvantages of plasma cutting in plasma-forming medium of air, where increase of hardness of metal of cut edges relates, do not provide perpendicularity of cut edges. Non-perpendicularity of 1.5–2.5 mm for each side increases with reduction of thickness of a metal being cut out. The change in chemical and structural composition and also increase of porosity of welds, produced along the edges after plasma cutting, narrow the area of its application. The reason of pores formation in welding of parts, sections and ship hulls of low-carbon and low-alloyed steels is nitrogen, located in the cut of edges in the state of oversaturated solution. The efficient method to decrease nitrogen concentration in the metal of edges is its bonding into thermodynamically stable compounds in air-plasma cutting.

The character of metallurgical processes running in the cut cavity is mainly determined by chemical properties of plasma gas. It is rationally to investigate the plasma jet with addition of

gases possessing reduction properties. First of all hydrogen, being a strong reducer, and water-containing mixtures are related to such gases. The use of the latter is more preferable in many cases on the reasons of safety and availability. The advantages of application of water-air mixtures for plasma cutting are low cost, availability, easy achievement of reduction or oxidation properties of plasma gas, possibility of change in character of metallurgical processes running in the cut cavity.

The peculiar place in plasma-forming media is occupied by water, composition of which includes hydrogen and oxygen. The power parameters of arc allow referring water to water-containing mixtures and quality of cutting indicates that oxygen, released as a result of dissociation of water, actively interacts with the metal being melted. In particular, during cutting of low-carbon steels the speed of cutting during use of water is the same as in water-containing mixtures, and quality of cutting is the same as in oxygen-containing ones.

Water can be used as plasma-forming medium independently in a form of vapor or as addition to plasma gas. High intensity of arc column, high penetration ability of arc, high efficiency of use of electric power of arc are achieved by adding of hydrogen.

The use of water as plasma-forming medium did not receive a wide industrial application. During water-electric cutting the complications with arc exciting arise. Besides, applied graphite electrodes are consumed quickly and an additional device is required for vertical movement of graphite electrode in the direction of the nozzle unit during the process of cutting, making the design of plasmatrone more complicated [3]. All these factors make the process of cutting during use of water as a plasma-forming medium not reliable and not sufficiently technological.

Such foreign companies as ESAB (Sweden), Messer (Germany) and other apply the process of plasma cutting under the layer of water. During this process the plasma jet falls directly into the water pool, the formation of smoke is absent, deformation of parts, levels of light radiation and noise reduce considerably. Under these conditions water sufficiently improves the sanitary-hygienic characteristics of the process, provides improvement of quality of edges of the parts being cut.

The application of plasma cutting under the layer of water requires special layout tables with the system for water level control. Water should be softened to increase the life of nozzles. The water preparation should be performed to avoid oxidation of cut edges and remove products of

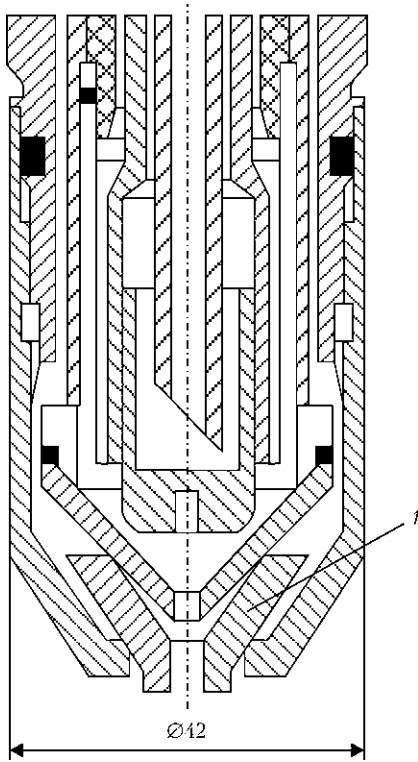


Figure 1. Scheme of plasmatron PMR 74M

plasma-chemical reactions running in the water. During cutting under water the operator can not observe the position of plasmatron and quality of cut edges. The application of special stabilizers of height and system of emergency stop of the process during casual throwing down of tiny parts are required. At the modern lines of thermal cutting with application of moving layout frames the application of the mentioned method of cutting is practically impossible.

At present, at the Kherson Shipyard the plasma-forming media for plasma-cutting of ship-

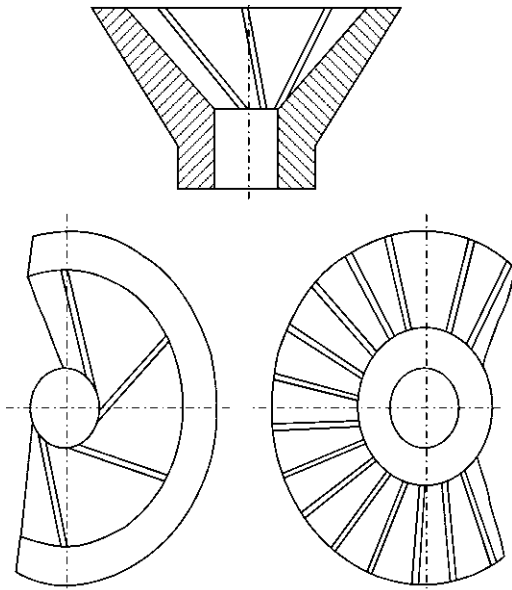


Figure 2. Scheme of nozzle unit for water supply

hull steels are used with addition of small amount of water to plasma gas. A part of water is supplied from the cooling system from modernized plasmatron PMR 74M (Figure 1) to the nozzle composed of two separate conic nozzles, included one into another (Figure 2). The outer nozzle of smaller sizes has six tangential grooves from the inside (0.15×0.93 mm), and 24 radial grooves (0.1×0.3 mm) from the outside for water supply. A part of water is supplied along the tangential grooves to the nozzle channel (into the plasma jet), and along the radial ones around the nozzle. To provide injection of water into the plasma jet the diameters of outer and inner nozzles are not equal between each other.

The water is supplied inside the channel clockwise with swirling, i.e. in the same direction as swirling of gas, squeezing additionally the plasma jet.

During adding of water into plasma the system is formed composed of nitrogen, oxygen and hydrogen. In this system plasma chemical reactions of bonding nitrogen with simultaneous obtaining of such products as NH_3 , N_2H_4 , NO , NO_2 and also other insoluble compounds of nitrogen in the cut edges [7]. The water is supplied along the radial grooves to the outside around the nozzle forming the air-water shower.

In the process of cutting the use of the considered design of a nozzle creates a double effect. The water supplied inside of the nozzle channel is partially evaporated, dissociates into hydrogen and oxygen, which during mixing create combined plasma-forming medium. Besides water squeezes and compacts the plasma jet in the nozzle channel, providing higher power characteristics.

Water, which is supplied concentrically to plasma column, is also partially evaporated and creates water-steam screen, limiting the access of air to the cutting zone. The gases being formed in the process of cutting are partially precipitated by water. The appearance of operating plasmatron with addition of water to air is shown in Figures 3 and 4.

The addition of small amount of water to plasma gas increases the quality of cut edges. Power parameters of arc allow attributing water to water-containing media, and quality of cutting indicates that oxygen, releasing as a result of dissociation of water, actively interacts with the metal being melted. During cutting of low-carbon steels the speed of cutting at adding of water is the same as in water-containing media and quality of cutting is the same as that of oxygen-containing ones.



Figure 3. Plasmatron PMR 74M for cutting (plasma-forming medium – air + water)

The power of arc during plasma cutting in plasma-forming media with addition of water is increased due to the growth of voltage U_a , whereas the current I_a (in use of vertical external characteristics of the power source) almost does not change. Such effect of water adding can be explained by thermal-physical properties of hydrogen. During dissociation of hydrogen the considerable amount of energy is absorbed, the losses of which are compensated by growth in arc voltage; as a result of recombination of atomic gas at the surface of metal this power is transferred to the anode. At comparatively low values of voltage (130–150 V) in air-plasma cutting the cut acquires a significant conicity due to its width in the upper part of the sheet being cut out. As a result of this fact the amount of molten metal increases as compared to the cut, the edges of which are close to the parallel ones. The increase in U_a (170–180 V) during plasma cutting de-



Figure 4. Process of cutting (plasma-forming medium – air + water)

creases the width of cut and volume of molten metal per unit of a cut length in the air + water plasma-forming medium. The flame of plasma is elongated, reaching 200 mm. During experimental verification the non-perpendicularity of edges amounted to not more than 1.0–1.2 mm on the side, which corresponds to the second grade according to the GOST 14792–80 for the thickness of 5–12 mm.

One of the characteristics defining the quality class of the parts being cut out is roughness of cut surface according to the GOST 14792–80. The character and depth of grooves, formed on the surface of a cut, characterize the fitness of parts to service having free edges under the conditions of dynamic loads.

The addition of water into plasma-forming medium results in increase of cleanness of cut surface of structural steel. The cut surface is smooth, has a silver color, projections and cavities have smooth transitions, drop of height values amounts to 10–20 μm (Table; Figure 5).

The roughness of cut surface is decreased from 120–90 μm at usual methods of cutting to 20–

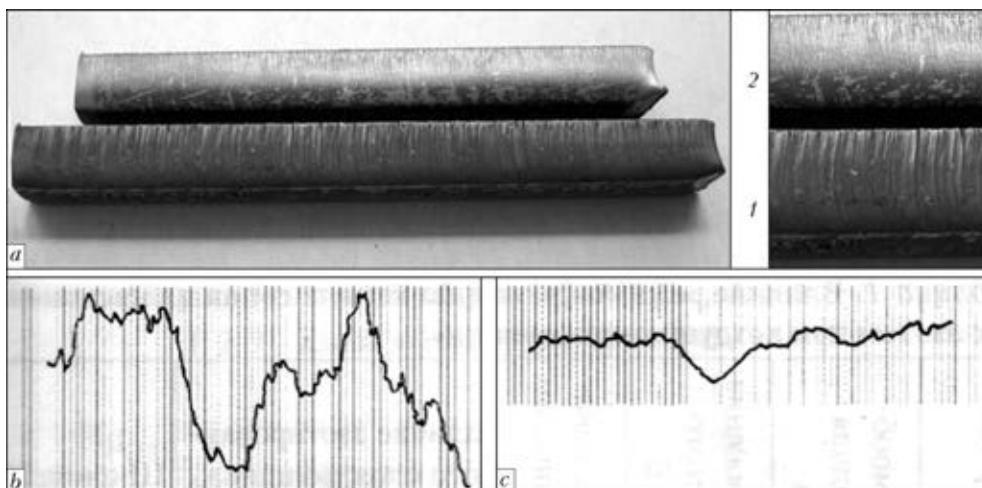


Figure 5. Appearance (a) and profilograms (b, c) of the surface of plasma cut in plasma-forming media: 1, b – air; 2, c – air + water

Dependence of roughness and microhardness of the cut surface on the cutting method

Cutting method	Microhardness, MPa	Width of HAZ, mm	Roughness, μm	Quality class	Speed of cutting, mm/s
Acetylene-oxygen	270	1.2–2.0	100–120	3	7.5
Plasma (plasma-forming medium – air)	620	0.6	80–100	2	33.3
Plasma (plasma-forming medium – air + water)	366	0.46	10–20	1	33.3
Machining (polishing)	150	–	5–10	–	–

10 μm during cutting with addition of water which corresponds to the first class of the surface according to the GOST 14792–80.

The parts, manufactured using thermal cutting, should be subjected to additional operations of treatment, straightening, lining. At present, in practice a number of technological procedures is applied to prevent and decrease thermal deformations: at the technological cards of layout the beginning and direction of cutting is indicated; succession of cutting out of parts; places where transition pieces were left; fixation of a sheet to the layout table, etc.

However application of mentioned procedures to prevent thermal deformations does not provide the production of parts according to the requirements RD 5.9091–80 «Manufacture of steel parts of hulls of metal ships». At the same time these procedures of struggling against deformations negatively influence the efficiency and quality of manufacture of parts.

During plasma cutting in plasma-forming media a part of water from the cooling system of plasmatron is supplied along the radial grooves outside around the nozzle forming air-water shower for localization of place of heating and reducing the thermal deformations. This cooling influences also the structure and mechanical properties of HAZ metal.

The presence of water prevents distribution of heat beyond the limits of water shower curtain surrounding the plasma jet and directly cooling

the cut edges during movement of plasmatron. The concurrent cooling of cut edges provides minimal deformations from the plain and on the rib. The straightening of parts according to the RD 5.9091–88 is not required. The replacement of acetylene-oxygen cutting by plasma one in the air + water plasma-forming media allowed increasing efficiency of cutting (on the thickness of up to 14 mm) by 3–5 times; decreasing thermal deformations and increasing accuracy of the parts being cut out; providing simplicity in control of cutting process, possibility of automation with application of flexible industrial systems. The system includes complex of correlated technical, software, information and organization means, providing designing of geometry of flat parts; layout of parts on customer sheets; designing of technology of cutting out of parts; automatic cutting out of parts; automatic transportation of billets and parts; control of process using computer.

The flexible automated area (FAA) at the Kherson Shipyard has two production lines with machines of the type «Kristall» equipped with the NPC devices 2R32T on the basis of micro-computer. The control system of FAA including local computational network is realized on the basis of domestic computer technologies (Figure 6).

Using optimal modes of plasma cutting applying the offered plasma-forming media it is



Figure 6. FAA with machines of the «Kristall» type (for thermal cutting)

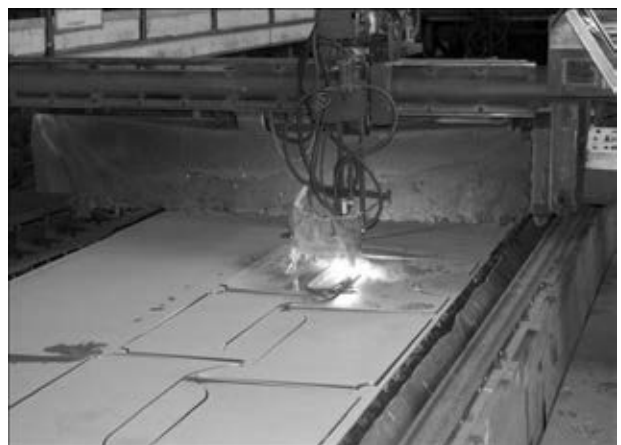


Figure 7. Plasma cutting in plasma-forming media with addition of water



Figure 8. Appearance of billets after plasma cutting

possible to obtain high quality characteristics of cutting (Figures 7 and 8).

As to the accuracy they are comparable with oxygen cutting excluding somewhat higher non-perpendicularity of cut edges. At the same time the depth of HAZ and deformations of the parts being cut out are smaller than during other methods of cutting. The developed modes of plasma cutting with addition of water provide elimination of pores in the weld metal during welding and allow reducing the thickness of the metal being cut out to 3 mm.

The roughness of the cut surface (see Figure 8) corresponds to the 1st grade according to the GOST 14792–80, free edges according to the regulations of the Russian Maritime Register do not require additional mechanical treatment.

Conclusions

1. The use of two-component plasma-forming mixtures is based on the fact that by selection of corresponding components and their correlations in the mixture the most optimal parameters of arc both from the power point of view, as well as from the point of view of stability of arcing, are provided.

2. In all mixtures containing hydrogen, the speed and quality of cutting depends mainly on the consumption of hydrogen and to the less degree on the consumption of the second component

of mixture. Arc voltage depends also mainly on the volume of hydrogen in the mixture and practically does not depend on the fact, in what composition of mixture the hydrogen is included. Therefore, both thermal physical and electro-physical parameters of arc are determined by the presence of hydrogen in the mixture.

3. When using the oxygen in mixtures, the efficiency of plasma-forming mixture depends considerably on the character of chemical interaction of oxygen with the metal being cut out. The application of oxygen-containing plasma-forming mixtures allows using both electric as well as chemical energy. In this case cutting is partially the process of melting and partially the process of burning out of metal from the cut cavity.

4. The application of water-air mixtures in plasma cutting will allow decreasing the concentration of gases dissolved in the cut edges, changing electric and thermal characteristics due to H_2 dissociation accompanied by the consumptions of power, the losses of which are compensated by the growth of intensity of arc column during simultaneous redistribution of heat and density of current as compared to the arc stabilized by air.

1. Golovchenko, V.S., Dobrolensky, V.P., Misyurov, I.P. (1975) *Thermal cutting of metals in shipbuilding*. Leningrad: Sudostroenie.
2. (2004) *Rules for supervision of shipbuilding construction and manufacturing of materials and products for shipbuilding*. Vol. 3. Saint-Petersburg: RMRS.
3. Bykhovskiy, D.G. (1972) *Plasma cutting*. Leningrad: Mashinostroenie.
4. Vasiliev, K.V. (1974) *Plasma-arc cutting*. Moscow: Mashinostroenie.
5. Esibyan, E.M. (2000) Air-plasma cutting: state-of-the-art and prospects. *The Paton Welding J.*, **12**, 4–15.
6. Lashchenko, G.I. (2012) Quality of cutter in plasma-arc cutting. *Svarshchik*, **4**, 34–39.
7. Goloborodko, Zh.G., Kvasnitsky, V.V. (2002) Investigations of plasma cutting in plasma-forming media with addition of water. *Zbirnyk Nauk. Prats UDMTU*, **5**, 37–46.

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