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TECHNOLOGY OF ROBOTIC TIG WELDING OF STRUCTURE ELEMENTS OF STAINLESS STEELS

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An approach was proposed to create the technology for TIG welding of structure elements of complex geometric shapes of stainless steel using a adaptive robotic system, which allows adapting to changes in the surface shape of workpieces during welding process and minimizing the probability of arising the defected welded joints and temper colors on the workpiece surface. The technology of robotic non-consumable electrode welding of fillet joint of thin-sheet structure elements of stainless steel of AiSi 304, 210, 430 grades with a thickness of joined sheets from 0.8 to 1.5 mm was developed. The results of welding experiments showed that the developed algorithms of interaction between technical means of adaptation can be used in automatic control systems for TIG welding process. 5 Ref., 2 Tables, 10 Figures.

Keywords: *TIG welding, stainless steel, complex geometric shape, adaptive robotic system, fillet joints, thin-sheet structure*

In this article an approach was proposed to create a technology for TIG welding of structure elements of complex geometric shape of stainless steel using a robotic adaptive system which allows adapting to changes in the shape of the surface of workpieces during welding and minimizing the probability of arising the defected welded joints and temper colors on the workpiece surface.

It is known that in order to provide a quality welded joint with the required geometric characteristics of the weld, it is necessary [1–3]:

- to provide constant height of the arc;
- to control the inclination of welding torch relative to the workpiece (angle of inclination) and position of welding torch when passing fillets and roundings;
- to provide constant welding parameters during welding process or their changes in case of specifying such requirements.

A promising direction for maintaining the abovementioned technological requirements is the use of adaptive robotic system. Such a system should provide scanning of welded butt, its state of assembly and should have a connection with the welding current source allowing the correction of welding mode at certain locations of the welded butt. This can be both adjustment of welding current, as well as the use of special welding modes (for example, pulse current), the ability of feeding the filler wire. Definitely, the adaptive robotic system can both realize a complicated algorithm for changing technological parameters of welding, as well as perform monitoring of trajectory of movements and position of welding torch.

The adaptive robotic system should include two subsystems: geometric adaptation and technological adaptation. The writing of the robot control program for realizing the problem of geometric adaptation consists of several stages:

- presetting the coordinate system of the tool «tool frame»;
- presetting the user's coordinate system (desktop) «user frame»;
- planning the trajectory of moving a welding torch along the joint of parts being welded;
- presetting welding mode parameters for different thicknesses of stainless steel plates being welded.

By default, the coordinate system of the tool is attached to the center of the flange on the last link of the robot (Figure 1). This position is called «tool center point» (TCP). To perform welding process, it is necessary to change the position of TCP in accordance with the configuration of a real model of the torch. TCP of welding torch for MIG welding is the tip of welding wire; for TIG welding it is the tip of tungsten electrode.

To preset the coordinate system of the tool, the method by 6 points is used. This method is based on the use of additional device in the form of a needle, fixed, for example, on the desktop. In the process of identification the operator moves the torch at different

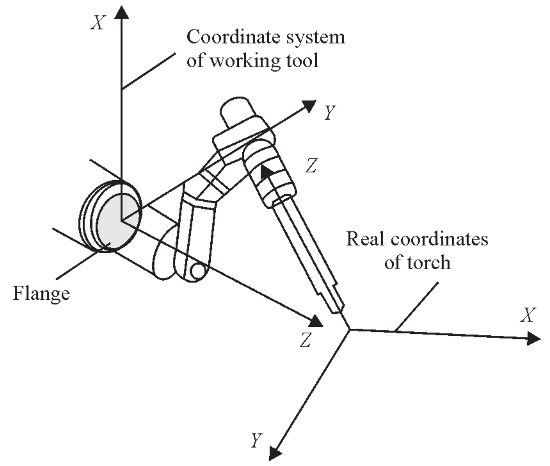


Figure 1. Coordinate system of working tool (welding torch)

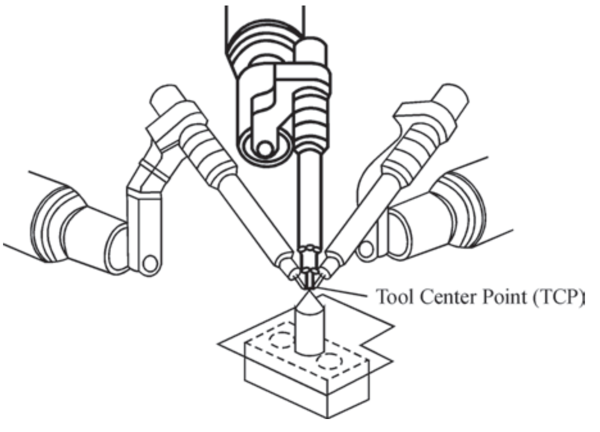


Figure 2. Orientation of torch in the process of identification of tool coordinate system

angles (Figure 2) to the tip of the needle and sequentially stores three configurations of the robot. Further, he moves the robot to the tip of the needle at such orientation of the torch, that its axis coincides with the axis of the needle and stores the 4th point. He moves it along the coordinate «*X*» and «*Z*» or «*Y*» and «*Z*» and stores the 5th and 6th points. As a result of subsequent calculations, we obtain the position of the electrode end and its orientation in 3D space.

We will perform all the measurements in the user's coordinate system. This means that the coordinates of the node points of welding trajectory will be counted down relative to the starting point of the desktop indicated during identification of the «user frame».

The planning of trajectory is performed either in the 3D-modeling package, or with the help of the «Teach Pendant» operator. The operator successively leads the welding torch to the welding start point, the intermediate points of the joint parts being welded, the welding end and stores the coordinates of these points in the robot program control code. In addition to the coordinates of the points of welding trajectory, additional information about the orientation of torch and configuration of the robot at each node point of the trajectory is stored.

The planned trajectory can be used without changes for a batch of products of one modification. However, at the end of welding process, the removal of workpiece from the rigging and fixing of a new workpiece, its position may change. To compensate the spatial position of the workpiece before starting the welding cycle it is necessary to perform the procedure of automatic search for a workpiece. Such procedure can be performed using touch sensor. Thus, for example, in the Fanuc Corporation this function is called «ARC START HEIGHT ADJUST». The algorithm of this function operation is shown in Figure 3.

After making the robot control program (planning of trajectory) and presetting the parameters of welding mode, the welding cycle can be started. However, the non-consumable electrode welding along a rigid trajectory without any means of adaptation during welding process does not guarantee the required weld quality. The disturbing factors are the errors in manufacture of rigging, which lead to changes in the butt position after performing the operation of changing the workpiece. Also the butt position can change during welding under the effect of thermal deformation.

To provide the required quality of welding, the additional sensors are applied, which adapt the trajectory of the robot to the butt trajectory (weld). One of

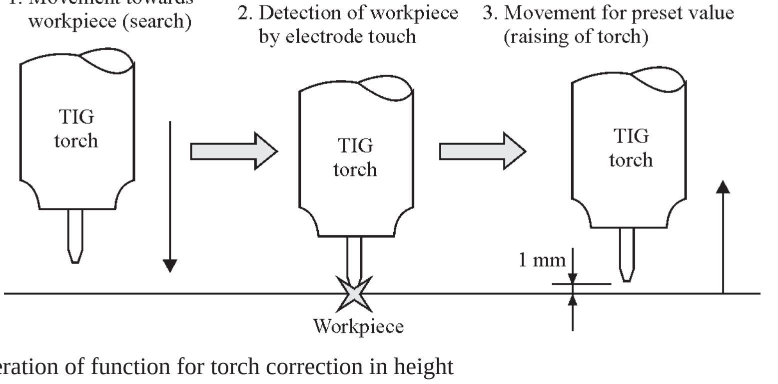


Figure 3. Algorithm of operation of function for torch correction in height

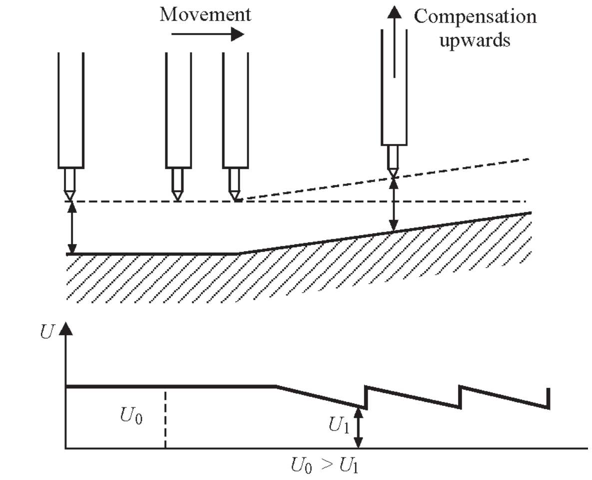


Figure 4. Method of automatic arc voltage control

such sensors, applied in the process of welding experiments, is the arc sensor and method «Automatic Voltage Control» (AVC) (Figure 4) to provide the constancy of power parameters of the welding mode.

AVC can be subjected to the effect of the following disturbing factors:

- change in type of electrode or its diameter;
- change in position of electrode relatively to weld pool as the result of action of welding thermal deformations;
- change in composition of shielding gas;
- change in parameters of oscillations (frequency, stop time in assemblies);
- surface condition of the products being welded.

AVC allows tracking the weld by monitoring the voltage. A typical application of AVC is the vertical tracking with the aim of stabilizing the arc voltage U_a by control the height of torch movement Z from the weld pool surface ($U_a = f(Z)$). The information, obtained with the help of AVC, allows correcting trajectory of the robot in accordance with the position of a real weld. If a weld is lowered relatively to the nozzle, then the arc voltage increases and the welding torch should be lowered. Otherwise, if a weld rises

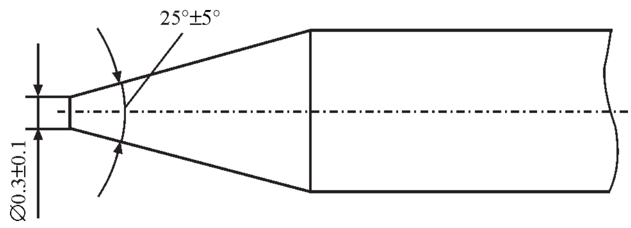


Figure 5. Shape of tungsten electrode sharpening

relatively to the nozzle, the arc voltage decreases and it is necessary to raise the welding torch.

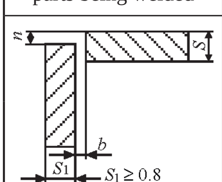
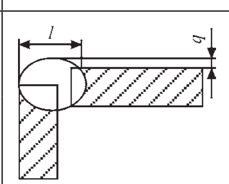
As a result, the preset value of arc length is maintained and, thus, the width of a weld is constant.

AVC can be used for welding with oscillations across the weld. In this case, adaptation to the position of a butt in the horizontal plane is realized. If it is necessary to apply oscillations, then their shape should be sinusoidal (SINE). AVC can be applied for moving welding torch both along the linear as well as circular trajectory.

The welding of products from stainless steel sheets of small thickness (up to 1.2 mm) is accompanied by several factors which significantly affect the weld quality and its appearance. Such factors are welding thermal deformations and formation of oxide film on the surface of structure being welded. The first factor leads to arising of defects in the form of burn-outs or lacks of penetration of a weld. The second factor leads to arising of temper colors on the metal surface. The oxide film deteriorates the appearance of the product and is also considered to be a rejection.

In this work AVC is used for the robotic process of TIG welding of structure elements of complex geometric shape. The structure of a product implies producing a fillet joint, the thickness of the joined elements of stainless steel AiSi 304, 210, 430 is 0.8–1.5 mm. To produce this type of joint with obtaining the required characteristics of weld, the TIG welding was performed using pulsed current by setting «+» on the electrode (reverse polarity) without filler wire.

Table 1. Welded fillet joint U4 according to GOST 14771–76

Structural elements		*s*	*b*		*n*	*e*		*g*	
of prepared edges of parts being welded	of joint weld		Nominal	Limited deviation		Nominal	Limited deviation	Nominal	Limited deviation
		0.8–1.4	0	+0.5	0–0.5	3	±1	0	+1
		1.5–2.0				5			

Note. Conditional symbol of welded joint — U4, welding method — pulsed heating.

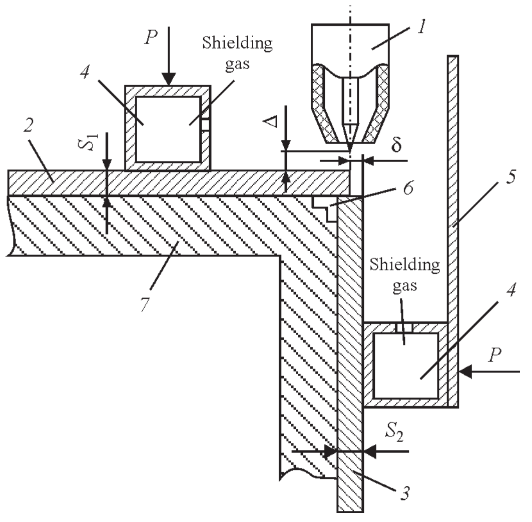


Figure 6. Scheme of assembly of structure elements before welding of fillet joint: *1* — welding torch; *2*, *3* — semi-products being welded; *4* — gas channel, for protection of outer side of the workpiece; *5* — protective screen; *6* — gas channel, for protect of back side of the workpiece weld; *7* — force part of rigging

As a non-consumable electrode, the tungsten electrodes of grade EVT-15, EVL-20 (GOST 23949) of 2.4 and 3.2 mm diameter were applied. To improve the stability of arc burning, the electrode was sharpened to a cone. The sharpening shape is presented in Figure 5. It is recommended to perform sharpening of tungsten electrodes using the specialized machine-tools.

As a shielding gas, argon of the highest grade was applied in accordance with GOST 10157 or its mixture with hydrogen: Ar + 2.5 % H, Ar + 5 % H.

Preheating and post-weld heat treatment are generally not required.

Applying this technology, the welding of fillet joint of the brake hammer of commercial equipment is performed. The geometric characteristics of the fillet joint U4 according to GOST 14771–76 are given in Table 1.

For automatic argon arc non-consumable electrode welding, the edges for welding are prepared mechanically, also using the specialized machine-tools for edge preparation. The angle of edges preparation is 90 ± 1°. In welding the joints of different thicknesses, the edge preparation for joined elements does not change, which is related to the thicknesses of semi-products being welded (0.8–1.5 mm).

Figure 7. Welded specimen of fillet joint without temper colors after argon arc welding in automatic mode

Before welding, the preparation of semi-products was performed: the burrs at the edges were eliminated by grinding. The mechanical treatment was carried out in a way to eliminate the arising of cavities on the edge of a semi-product being more than 30 % of its thickness. Also, before welding the metal surface was degreased with alcohol, acetone, aviation gasoline, white spirit or other solvents at a distance of at least 40 mm from the edges, to be welded.

The assembly of structure elements in the assembly and welding rigging was carried out in accordance with Figure 6. The superposition of the upper sheet *2* on the lower one *3* is carried out with overlapping the half of the thickness δ of second one. The fulfillment of this condition is necessary to produce a uniform weld as to its overlapping. It is also necessary to provide pressing of the workpieces to the assembly and welding rigging at the force which enables removing the gaps between sheets of semi-products and the assembly rigging (the value of pressing force is within the range P = 300–500 N, depending on thicknesses of metal being welded). To provide a tight abutment of semi-products to the rigging and to ensure the necessary heat removal, the pressing was performed by a uniform distribution of the force along the plane of clamping straps.

In case when it is impossible to provide the accuracy of fixing the semi-products, according to the scheme for making fillet joint the assembly of a workpiece should be performed by tacks using manual argon arc welding from the back side of fillet joint without a full penetration. Such arrangement of tacks will provide welding in automatic mode without disturbances of the process during welding arc passing through them.

The trajectory of movement of welding torch should be such that the tip of tungsten electrode was at the end of the edge of upper sheet, as is shown in Figure 6. The value of the arc gap between electrode and workpiece is set and maintained in the process of welding as equal to 1.5 mm applying AVC technology for all the types of materials and thicknesses being welded.

To produce welded joint without temper colors (Figure 7), the protection of welding zone and a part of the workpiece heated to the temperature of 200 °C, are provided. For this purpose zonal protection is per-

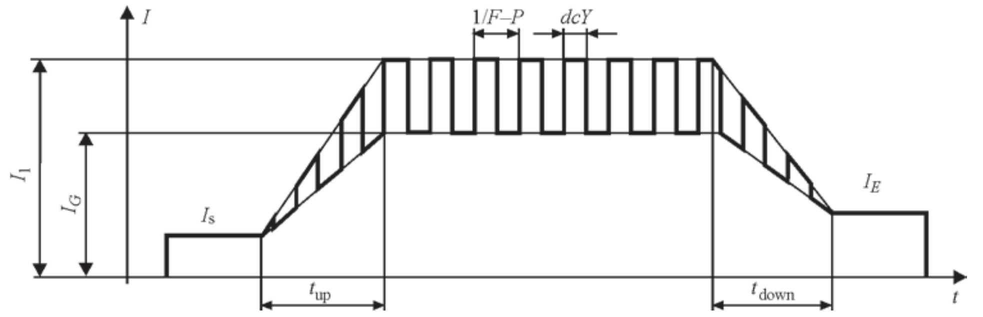


Figure 8. Cyclogram of pulsed welding current in TIG welding: TIG: I_s — starting current; I_e — end welding current; t_{up} — current increment; t_{down} — current drop; *F–P* pulse frequency (1/*F–P* — time interval between two pulses); *dcY* — working cycle; I_G — base current; I_1 — main current

formed, the shielding gas is supplied to the welding zone and to the area heated to 200 °C. Also, to protect the back side of the weld, the gas is supplied into the groove of rigging *6*, shown in Figure 7. The gas consumption is set in a flow meter in the amount, providing 6–8 l/min for protection of the back side of the weld, and 10–12 l/min for the outer side of the weld.

The use of pulsed arc makes it possible to expand the capabilities of welding by non-consumable electrode [1, 3–5]. Thus, the speed and quantity of heat introduced into the workpiece, are determined by the mode of arc pulsation, which, in its turn, is preset according to a certain program, depending on the properties of material being welded, its thickness, spatial position of the weld and so on. During welding by non-consumable electrode, the pulsed arc is intended for regulation of the process of base metal penetration and weld formation, while during welding by consumable electrode it is intended for regulation of the process of melting and electrode metal transfer [1, 3].

In this work, the welding was performed with pulsed arc at the frequency $F = 1$ kHz, the pulse and pause duration was 50 % of the total period. The main current was 10 % of the basic preset current. The duration of increment and drop of welding current t_{up}, $t_{down} = 1.5$ s. The cyclogram of pulsed welding current is shown in Figure 8.

The beginning and the end of automatic argon arc welding of fillet joint is performed on the run-in and run-out tabs to produce a defect-free welded joint on the main workpiece. The dimensions of run-in and run-out tabs should correspond to the duration of output for welding mode. The length of run-in and run-out tab is 30–40 mm.

The welding speed is preset in the control module of the robotic complex and should be 36 m/h (1 mm/s) for metal thicknesses being welded. Figure 9 shows the scheme of conducting the automatic welding of fillet joint. During welding process the welding torch should not deviate from the preset trajectory by more than ±0.2 mm.

Table 2. Modes of automatic argon arc welding of fillet joint of thin-sheet stainless steel

Thickness of semi-products to be joined $S_1 + S_2$, mm	Welding current I_w, A	Voltage U_a, V
0.8 + 0.8	100	9.0
0.8 + 1.0	105	9.2
0.8 + 1.2	115	9.5

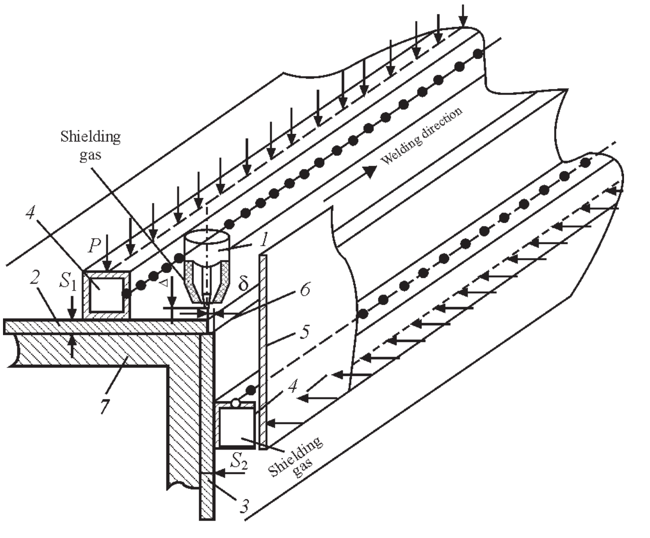


Figure 9. Scheme of moving welding torch along the butt: *1* — welding torch; *2*, *3* — semi-products to be welded; *4* — gas channel for protection of the outer side of the workpiece; *5* — protective screen; *6* — gas channel for protection of the back side of the workpiece weld; *7* — force part of rigging

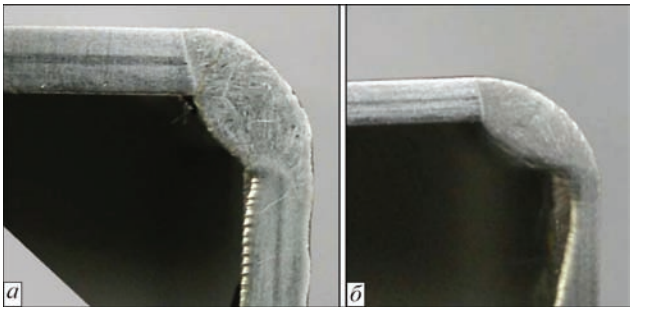


Figure 10. Macrostructure of fillet welded joint of stainless steel AiSi 304 of 1.2 mm thickness (*a*) and AiSi 201 of 0.8 mm thickness (*b*)

To reproduce the quality of welded joints, the robotic argon arc welding by non-consumable electrode should be performed in a premise with a controlled shop temperature. The given welding conditions (Table 2) were obtained at a room temperature of 18–22 °C. If there is a temperature difference by more than ±15 °C in the premice where the welding takes place, it is necessary to carry out correction of welding mode parameters.

In order to study the influence of technological welding modes on the structure of weld metal, a macro analysis of welded joint was carried out. The metallographic analysis of fillet welded joint of stainless steel AiSi 304, 210, 430 made on the basis of the developed technology of pulsed arc welding by non-consumable electrode with a full penetration, revealed certain features. As is shown in Figure 10, the weld has a solid cast structure with a smooth transition from horizontal plate to the vertical one without overlaps and also there are no visible defects such as pores, cracks or violation of weld integrity. Such results on the geometry of the weld allow concluding that the developed technology of robotic TIG welding of stainless steels of 0.8–1.5 mm thickness can be used in manufacture of workpieces made of stainless steel providing the quality weld with the required strength characteristics, appearance and color, similar to the color of base metal.

The results of welding experiments showed that the developed algorithms of interaction between technical means of adaptation can be used in the systems of automatic control for TIG welding process.

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