AUTOMATIC MACHINE FOR WET UNDERWATER WELDING IN CONFINED SPACES*

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PWI developed technology and equipment allowing performance of automatic flux-cored wire wet underwater welding of structural elements, reliably insulating the lower part of heat exchanger column. The unique aspect of the work consists in development of an automatic welding machine, capable of operating when immersed into a pipe of 119 mm inner diameter into liquid heat carrier medium at 200 m depth. The semiautomatic machine was designed with application of special torque electric drives for electrode wire feed and welding displacement mechanisms. A special cable with welding and control wires was developed, capable of operating at a large distance from the arc power sources and control system. Cable uncoiler design was also developed, with digital recording of automatic machine position along the pipe length. Approbation results showed that application of special automatic machine allows increasing heat exchanger reliability, reducing time loss during performance of work on its sealing, rational use of site area and reducing financial expenses. 5 Ref., 8 Figures.

Keywords: *wet arc welding, geothermal heat exchangers, sealing, automatic machine, power source, cable uncoiler, control system*

Process of mechanized wet arc welding, equipment and flux-cored wire for its implementation were proposed at PWI [1] and are currently being developed in different spheres. This is repair of ships and vessels, underwater product lines, port underwater facilities, etc [2, 3].

One of the new objects of effective application of wet welding are complexes of Greenfield Energy Ltd Company — technology developer and operator of power efficient Geoscart™ complexes, combining such systems for satisfying production needs as closed-loop heating systems, systems of treatment of consumed hot water for production purposes, refrigeration units and air conditioning systems.

Geostart™ system was developed to control heat flows of public and commercial buildings and enterprises with continuous high-density energy consumption such as modern supermarkets, higher class hotel business enterprises, stationary hospital complexes, as well as satisfying production needs of food and pharmacological industry. One of the main functional features of Geoscart™ system is the ability to store excess thermal energy up to the moment of this energy deficit. Company uses geothermal heat exchangers of a special design for fast and efficient transfer of excess or deficit of low-grade thermal energy, using high density and heat capacity of formations located much lower the surface soils. Standard depths for the main transaction of heat-exchange process are the ranges down to 200 m from ground surface level.

At construction of heat exchangers, the quantity of which can reach several tens, depending on facility size, principles similar to methods applied in oil and gas well drilling, but with certain differences in construction technology, are used. In particular, closed-loop heat exchangers require guaranteed insulation of the lower part of insulation column, in order to avoid losses of expensive heat-conducting working liquid, produced from a composition of nonpolluting propylene glycols, extracted from the plant mass. Used for these purposes are plugs of a special design, made from organic uncured rubber. Operation experience of these heat exchangers, however, showed that natural ageing of plug material in service results in a change of its dimensions, and leakage of its working fluid. Mounting a new plug requires shutting down the complex. Considering that heat exchangers are usually located in the territory of vehicle parking areas near the serviced facility, this operation leads to significant financial losses, in addition to losses of op-

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Figure 1. Heat exchanger pipe neck and external conditions of work performance

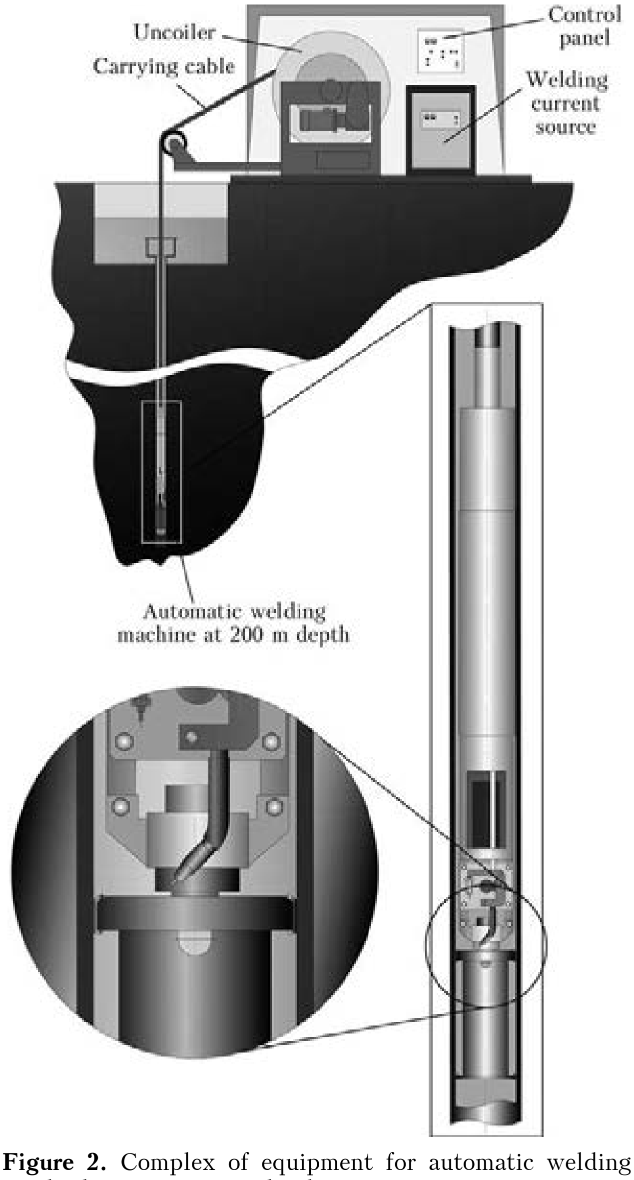

Figure 2. Complex of equipment for automatic welding inside the pipe at great depth

eration effectiveness at lowering of liquid level. As an alternative, PWI proposed a process of heat exchanger tube sealing by placing and welding-on a cap.

The objective of this work was development and introduction of a special automatic welding machine and its application technology for welding-on the plug-cap inside the pipe at down to 200 m depths, that will allow shortening time losses, lowering financial expenses, reducing loss of useful area, and improving heat exchanger reliability.

Pipe neck design and conditions of work performance are shown in Figure 1.

Conditions and environment of welding performance predetermine the complexity of the problem being addressed both in terms of equipment and technology. Development was based on PWI experience on designing mechanized equipment for wet welding with application of special flux-cored electrode wires. However, rather great welding depths, extremely confined conditions (pipe inner diameter is not more than 120 mm), as well as the medium (25 % water solution of polyethylene glycol) required a large scope of additional research both on individual components of welding equipment, and on welding technology and welding consumables, as experience of equipment design and its application in the automatic welding mode for these conditions is lacking either at PWI or in the world practice.

Development of the automatic machine proper for cap welding-on at great depth is just part of the complex, which should include welding current source of a special design (remoteness of welding site with inevitable voltage drop in the cable), special load-carrying cable with power conductors and control wires, as well as a device for automatic machine lowering and lifting. The entire equipment set and its application conditions are shown in Figure 2.

Algorithm of welding performance envisages that the cap of a special design to be welded on is placed into the automatic welding machine clamp before immersion, and is disengaged from it after welding and beginning of automatic machine lifting.

Considering that none of the complex components without exception could be selected from commercially manufactured equipment, features of their development and design are of interest.

Let us consider ADSP-200 automatic machine for wet welding at great depth in a confined space. The automatic machine is a tubular metal structure, combining the following main components: module of electrode wire feed, module of welding head rotation (of feed mechanism), module of contact components. Feed module and rotation module are based on gearless computerized DC electric drives incorporated into commutatorless electric motors with bevel drive to feed roller. Feed module consists of the device of electrode wire pressing down, nozzle with guide channel and current-conducting tip. Module further includes nozzle oscillator, as well as the assembly of cap fixing with fixation force regulator for guaranteed disengagement of the cap from the automatic machine after the welding cycle, as well as sliding contact component of welding voltage current transfer (return wire «–»). Addition of nozzle oscillator to the module is due to presence of quite large gaps between the cap being welded-on and pipe inner surface, on the one hand, and impossibility of essentially increasing the welding modes, because of the possible overheating of automatic machine components and pipe wall burn-through. The guide channel, accommodating the electrode wire stock required for a single welding cycle, is made of plastic with a low coefficient of friction. Channel length is 15–18 m. Considering the confined conditions, electrode wire is not wound on the spool, as it is usually done, but is in the straightened state. Two effects are achieved here: space saving for automatic machine systems, and essential reduction of feeding force. To provide protection from the liquid medium, feed mechanism electric motor is placed into a water-tight box filled with insulating-lubricating fluid and having a compensating diaphragm, as well as special sealed connector for control cable connection.

Main difficulties in development of automatic welding machine ADSP-200 consisted in selection of layout solutions in an extremely confined space, with performance of a large scope of experimental studies, with development of welding equipment mock-ups and simulation of welding conditions. This enabled effective solution of the problem of development of nozzle oscillator of an ingenious design, where the drive is combined with electrode wire feed drive and, as a result, increase of the required moment on drive electric motor shaft. The impossibility of mounting sensors of nozzle position relative to the butt being welded determined the search for engineering solutions in two directions. Before the automatic machine lifting the nozzle is oriented by the future gap relative to the cap fixed in the clamp. The start and end of welding is possible from any point and is pre-programmed by controller-based control system of rotation module, with analysis of path covered by nozzle, and then the operation of weld closing by automatic machine is performed by a similar algorithm.

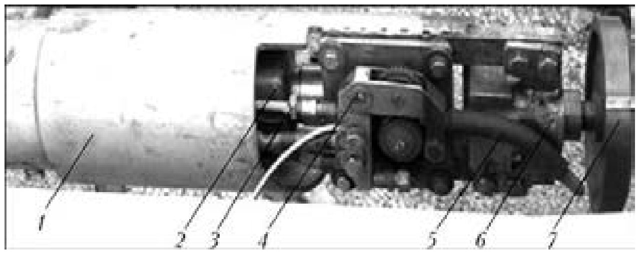

Figure 3. Automatic machine for welding in confined conditions at great depth: *1* — case; *2* — rotation mechanism; *3* — guide channel; *4* — feed mechanism with nozzle oscillator; *5* — nozzle; *6* — fixtures and elements of current transfer to the cap; *7* — cap

Figure 3 shows the ADSP-200 automatic welding machine in the position before immersion for welding.

The complexity of the task of connecting and sealing the welding cables and control wires should be noted. The great length predetermined the need to develop engineering solutions for their fast connection to automatic machine systems and sealing. This also involves special deep-water connectors, and couplings filled with low-melting dielectrics.

Welding current source of VDU 25-506 MP type. It is obviously impossible to implement the welding process with the required characteristics at considerable distance from the object of welding, by using traditional welding current sources with flat external volt-ampere characteristics (VAC). This follows from experimental investigations and conclusions of [4]. Source VAC in the arcing zone changes significantly because of great lengths of welding cables of a limited section (ohmic resistance of outer circuit rises and, hence, voltage drop in the cable becomes higher). Here, compensation of voltage drop in the outer circuit due to voltage rise, does not yield the required result. Inductance of source–arc system changes noticeably, that has a negative effect on the nature of arcing and electrode metal transfer. In order to solve these problems, specialized VDU 25-506 MP source for mechanized and automatic welding at large distance of feed mechanism (of automatic machine) from power source was designed and manufactured, in particular, for wet automatic welding at 200 m depth. Figure 4 shows the appearance of VDU 25-506 MP source.

To ensure high quality of welding at application of various kinds of electrode wire, the source enables adjustment of dynamic characteristics to establish the rate of current rise, required for a specific wire type. Ability to perform such additional adjustments is ensured through application

Figure 4. Source of welding current for working with remote objects

of Moller programmable logic controller (Germany). Application of the principle of proportional plus integral plus derivative control of welding contour dynamics to ensure the required power source characteristics at operation with long welding cables allows guaranteeing its stable performance in the entire adjustment range and repeatability of the selected adjustment parameters.

Cable. As shown by results of experiments on possibilities of transfer of welding current, control and adjustment signals, the only correct engineering solution for operation under confined conditions is combining all the electric circuits in one cable, which, in addition to that, should also be carrying, i.e. should be able to support the automatic machine weight, its own weight, as well as overcome the hydrostatic resistance of the environment at immersion and lifting stages.

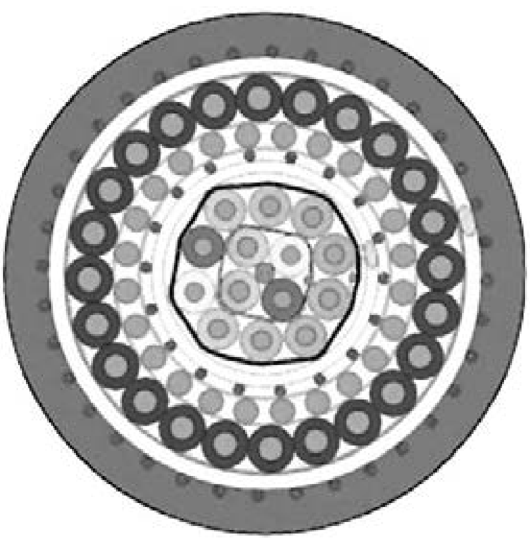

Figure 5. Section of cable for underwater automatic welding

Industry lacks cables, capable of satisfying such a set of requirements. It turned out to be possible to solve the above-defined problems at purposeful development of a cable, which was given the technical name «Cable flexible armored strengthened submersible for electric welding KGBUPES 2×95+(4×2.5)e+(10×2.5)e» [5].

Cable specification

Design weight of 1 km of cable, kg	3850
Cable outer diameter	47.5
Tensile force, N	not less than 20,000
Minimum radius of inner loop of cable bending in outer cable diameters	not less than 8

It should be noted that all the conductors with rational layout of cores and conductors to ensure reliable insulation and flexibility are made of copper. Power and control conductors are shielded. Measuring (with one meter spacing) marks are made on the cable for additional control of the length of its unwinding or winding. Figure 5 shows the cross-section of cable of complex design KGBUPES 2×95+(4×2.5)e+(10×2.5)e. Cable strength at considerable tensile force is ensured by additionally incorporated flexible enclosing steel elements, including flexible armour. Additional strengthening was provided by a large number of mylar filaments of different diameter. Insulation of each conductor and conductor layer was performed with application of reliable modern insulating materials, such as PET-E film, folsan, etc., with multiple (3–4 times) overlapping.

Cable uncoiler. Cable uncoiler is designed for storage, transportation, lifting and lowering of automatic welding machine into the pipe to 200 m depth and its subsequent removal, and is a drum of lattice-rod design, mounted on rotator drive shaft. On the other end the shaft is additionally supported by roller support adjustable by its position (backrest). Rotary motion of the shaft with drum with adjustable frequency is provided by variable frequency electric drive with asynchronous electric motor, connected to drum shaft through a reduction gear. Drum design envisages availability of a special cable box for fast connection of welding and control cables. The entire structure of the drum, rotator and roller support is mounted on a welded bed.

Uncoiler incorporates its own local system of control and adjustment, allowing control of both the direction of drum rotation, and its rotation

Figure 6. Appearance of cable uncoiler

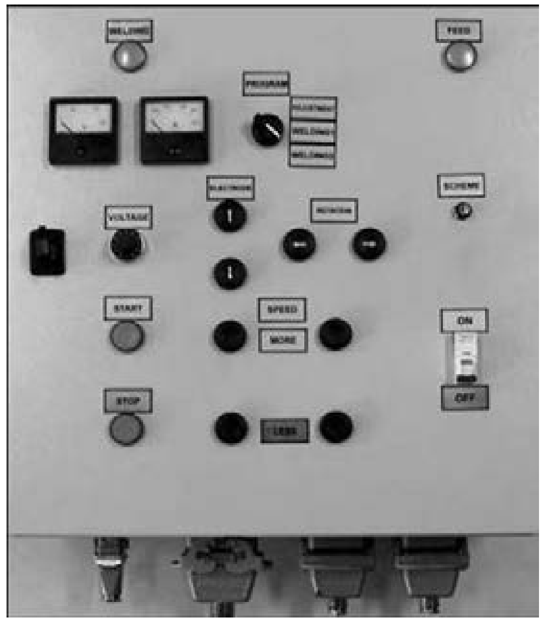

Figure 7. Appearance of control panel of ADSP-200 automatic machine

frequency. For convenience of automatic machine immersion or lifting, the uncoiler has a remote control panel. More over, uncoiler incorporates guide roller, ensuring stable advance of the cable into the pipe to the welding area. The roller is fitted with rubber-bonded bush, ensuring roller engagement with the cable at its uncoiling. The roller is also connected to incremental encoder (digital converter of cable movement), ensuring calculation of length of uncoiled cable (lowered to welding area) with result digitizing. Figure 6 shows the considered uncoiler in the position of automatic machine readiness for immersion.

Main technical characteristics of cable uncoiler

Minimum drum diameter, mm	100
Nominal rotation frequency, rpm	0.267
Range of rotation frequency adjustment	1:10
Nominal moment, N·m	40095

System of control and adjustment of automatic machine ADSP-200. The system is designed for adjustment control of direction of rotation of electric motors of electrode wire feed and rotation mechanisms, setting the rates of wire feed and welding displacement (feed mechanism rotation). System of control and adjustment is based on welding cycle control module, several of which can be used and which differ by the method of arc excitation and weld crater welding up. The model is based on a programmable controller. This system further includes modules of controllerized control of automatic machine electric motors with the possibility of setting and monitoring their shaft rotation frequencies, as well as welding cycle control. Each of the modules is fitted with its own power stabilizer block. All the above-mentioned is installed on a special control

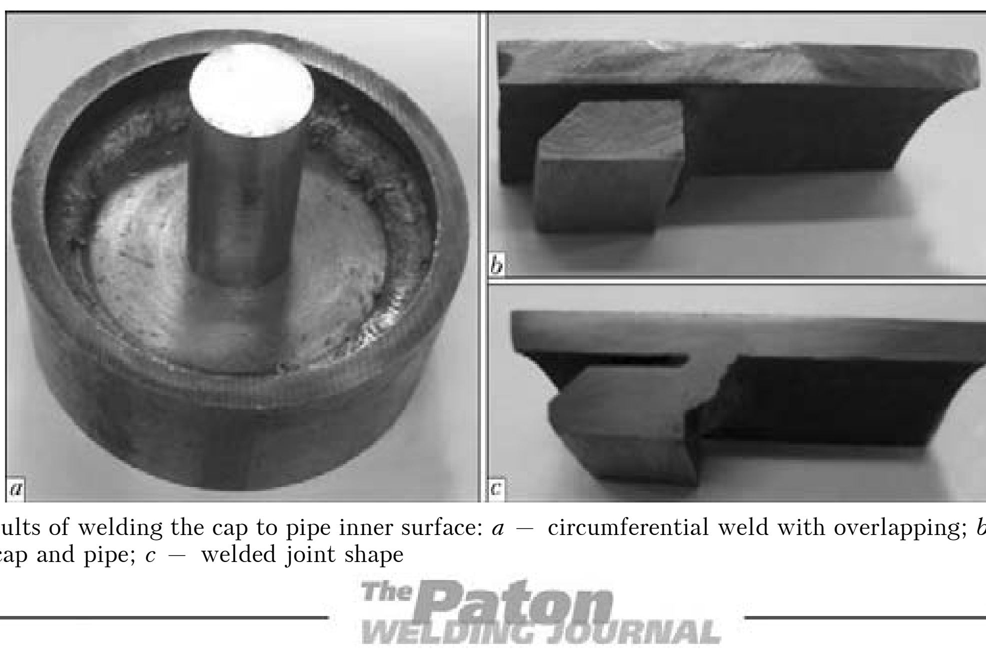

Figure 8. Results of welding the cap to pipe inner surface: *a* — circumferential weld with overlapping; *b* — actual gap between the cap and pipe; *c* — welded joint shape

panel with sealing elements (Figure 7). The same panel separately accommodates matching equipment, for instance, decoupling relays for remote control of welding current source. Front control panel carries signaling devices, elements for protection from overloads and short-circuit currents, control and adjustment elements, as well as dial monitoring instruments. Connection with the objects of control is provided through a number of connectors.

For testing and adjustment of both individual components of ADSP-200 automatic machine, and the complex as a whole, PWI developed a specialized facility, where basic technology was optimized. Deep-water technological experiments were performed in a special pressure chamber. Some test results are shown in Figure 8. Note that the welding cycle consists of two stages: cap fixing with application of the arc process preventing rotation of automatic machine with the cap relative to the pipe, and welding performance around the contour of the fixed cap with weld overlapping.

The complex has passed production trials at GFE facility (London). Obtained results showed that application of special automatic welding machine allows heat exchanger reliability to be increased, time losses for performance of work for its sealing to be reduced, site area to be rationally used and financial losses to be reduced.

Conclusions

1. Technology and equipment are proposed, allowing performance of flux-cored wire wet automatic arc welding of structural elements, reliably insulating the lower part of heat exchanger column.

2. Automatic welding machine has been designed, which is capable of operation when immersed into a pipe of 119 mm inner diameter into liquid heat carrier at 200 m depth.

1. Savich, I.M., Smolyarko, V.B., Kamyshev, M.A. (1976) Technology and equipment for semiautomatic underwater welding of metal structures. *Neftepromysl. Stroitelstvo*, **1**, 10–11.
2. Kononenko, V.Ya., Rybchenkov, A.G. (1994) Experience of wet mechanized welding with self-shielded flux-cored wires in underwater repair of gas-and-oil pipelines. *Avtomatich. Svarka*, **9/10**, 29–32.
3. Kononenko, V.Ya., Gritsaj, P.M. (1994) Mechanized wet welding in repair of ship hulls. *Morskoj Flot*, **11/12**, 21–22.
4. Lebedev, V.K., Uzilevsky, Yu.A., Savich, I.M. et al. (1980) Analysis of possibility of self-adjustment system compensating typical disturbances of arc length in mechanized underwater welding. In: *Underwater welding and cutting of metals*, 10–23. Kiev: PWI.
5. Martinovich, V.N., Martinovich, N.P., Lebedev, V.A. et al. (2010) High-quality hose packs for underwater welding and cutting. *The Paton Welding J.*, **9**, 33–35.

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