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EQUIPMENT FOR PREPARING THE PIPELINE POSITION BUTTS FOR WELDING

The results of R&D works of the Paton Electric Welding Institute and its specialized departments have been presented. These works mainly concern designing the Ukrainian-made equipment for preparation of the edges and butt ends of pipeline position butts with diameter from 14 mm up to 159 mm, for the assembly, repair, and modernization of power engineering facilities, including the power units of nuclear and heat electric stations, in chemical, machine-building, petroleum and other industries.

Keywords: position welded pipe joints, automatic orbital welding, mechanical treatment, pneumatic drives, machining tools, pipe cutters, supports, and cutters.

During installation, repair or modernization of power engineering, petroleum, and chemical facilities the most complicated, time consuming, and labor intensive process is fixed-butt welding of pipeline joints. Moreover, in most cases, the welding works are done under conditions of limited access to pipelines.

A characteristic feature of the industrial pipelines is complicated conditions of their operation and maintenance. The pipelines of Nuclear Power Plants (NPP) are simultaneously exposed to high temperature, high pressure, corrosion and radiation caused by coolants and other media. Given the fact that the reliability and safety of NPP and other potentially dangerous objects are largely determined by the condition and service life of industrial pipelines, the demands for quality, operational properties, and corrosion resistance of welds are constantly getting more and more stringent [1—4].

An important factor that affects the quality of welds is welding technique.

Today, for welding the pipeline joints the following methods are used: manual argon arc welding (tungsten-inert gas (TIG)-welding) with or without filler metal wire; manual arc welding with coated consumable electrode (manual metal arc welding (MMA)-welding); and automatic orbital welding with non-consumable electrode in inert gas environment (gas tungsten arc welding (GTAW)-welding), with the manual welding still remaining the predominant technique [5, 6, 8]. A similar situation is reported not only for the power engineering sector, but also for other industries where industrial pipelines are applicable.

The manual methods of welding are characterized by flexibility and low sensitivity to the precision of pretreatment of pipe ends or edges. However, these methods provide neither required efficiency (e.g., in the case of manual TIG-welding the machine time does not exceed 20%) nor sustainable reproducibility of required quality of welded joints (the share of defects at the first presentation varies from 15 to 45%). In addition, the manual welding requires the involvement of many skilled welders.

As compared with the manual welding, the GTAW technique is capable of not only increasing, at least, 4 times the performance of welding works, but also of providing a high quality of pipeline welds. For the GTAW technique without filler metal wire the share of defects at the first presentation does not exceed 4%; for that with filler metal wire, the defect percentage accounts for 7%. The duration of training of automatic welding operators is several months, while the training of qualified manual welders lasts several years [5-8].

The experience shows that labor costs of fixed-butt welding of pipelines make up 40% of all labor costs for the installation of nuclear power plants and up to 60% of the total labor costs of welding works for the installation of NPP units. The welding of pipeline joints with a diameter less that 159 mm has the lion's share in the works (80%), with near 60% of all joints being the joints of pipelines made of austenitic steels [5, 6].

There is no alternative to GTAW-welding in the view of the above mentioned facts and quantities of welding works to be done to extend the residual service life of pipelines in potentially hazardous industries, as well as the scale of nuclear energy development through the modernization and extension of existing NPP units and construction of new ones with WWR type reactors (water-to-water reactors which require more than 120 000 welds per one NPP unit) [5-8]. However, there are still a lot of factors that keep the level of automation of pipeline joints welding at power engineering facilities and other industrial objects extremely low.

For a long time, among the major obstacles to widespread use of automated fixed-butt welding of pipeline joints there was the fact that equipment for GTAW-welding was not designed and industrially manufactured in Ukraine. The existing foreign equipment is very expensive in terms of OPEX and markedly underperforms even the orbital machines manufactured in 1970—1990s in the former Soviet Union both in productive time, maintainability, adaptability to the size and tube space of domestic pipelines and in capacity to use effective methods for welding joints of thin-walled tubes by automated compression molding or weld penetration techniques which have been successfully used for a long while in Ukraine and Russia [7-9]. Therefore, an important engineering challenge is the design of domestic technology and the creation and development of industrial production of advanced domestic equipment for GTAW-welding of pipe joints, especially for small diameter pipelines (up to 219 mm).

Mostly, this problem was solved in 2008 by the Paton Electric Welding Institute (EWI) and its specialized unit, Research and Engineering Center for Welding and Control in the Sphere of Nuclear Energy in Ukraine (REC WCNE) when they designed equipment for GTAW-welding without filler metal wire (the orbital machines ADC 627 U3.1, ADC 625 U3.1, and ADC 626 U3.1) to be used for pipe joints having a diameter from 7 to 76 mm with a wall thickness up to 4.0 mm (material of walls: austenitic or pearlitic steels and high alloys) [10]. Since that time, in Ukraine, the NPP units and repair departments started to be equipped with these machines. This process has been going on nowadays. Examples of their successful use are given in [11, 12].

Another important contribution to the solution of the mentioned problem was elaboration domestic pro-cesses in 2011—2012 and simultaneous design by EWI and REC WCNE of prototype hardware and soft-ware for GTAW fixed-butt welding (with filler metal wire and vibrating non-consumable electrode) of pipes having a diameter of 76 mm to 219 mm with a wall thickness of up to 12.0 mm (material of walls: austenitic and pearlitic steels) — the orbital machines ADC 628 UHL4, ADC 629 UHL4, and ADC 630 UHL4 [13]. In 2014, REC WCNE designed the orbital machine ADC 626P U3.1 for GTAW with filler metal wire and vibrating non-consumable electrode designed for fixed-butt welding of pipes having a diameter from 42 to 76 mm with a wall thickness of up to 7.0 mm. It should be noted that the processes and equipment for GTAW-welding are based on unique technical solutions, at the innovation level [14—16].

Both research and practice have showed that the quality of welds in pipelines largely (and in some cases, crucially) depends on the quality of pre-welding treatment of ends or edges of pipes, as well as on the quality of assembly of pipeline parts directly before welding [5—7, 9, 17]. Moreover, GTAW-welding is possible only in the case of proper preparation of pipe butts and compliance of the profiles with requirements of standards applicable in nuclear power engineering. Therefore, a very influential factor that hinders the au-tomation of welding during installation and repair of NPP units in Ukraine is the lack of advanced domestic equipment for preparing the pipe butts for GTAW-welding. That is why, the NPPs and other industries of Ukraine have to apply similar imported equipment whose properties can satisfy them only partially. The main disadvantages of this equipment are as follows:

- It is mainly based inside, which complicates the implementation of the mandatory operational control of geometrical dimensions of pipe ends and fixed butts and significantly increases the amount and duration of the preparatory and final operations, and consequently, the duration of personnel stay in the zone of radio-active pollution;
- The lack of some important options needed to meet the applicable requirements of Regulations for Harmonization and Safe Operation of Equipment and Pipelines of Nuclear Power Plants and other standards (e.g. the end facers of foreign origin are unable to provide the internal bore of pipes);
- High costs and significant operating expenses.

Obviously, considering the above mentioned facts, the design of domestic technology and the creation and development of industrial production of advanced domestic equipment for the preparation of fixed butts for welding are fairly urgent tasks.

In order to address this problem, in 2013—2014, the EWI and REC WCNE carried out studies and R&D works in the following areas:

- Experimental research on the preparation of fixed butts and edges of steel pipes;
- Identification and optimization of requirements for the preparation of fixed butts of NPP pipelines having a diameter of 14 — 159 mm for welding, the methods and means of operational control of geometrical dimensions of the ends of pipes with a diameter of 14—76 mm and edges of pipes having a diameter 76—159 mm, as well as for the equipment for pre-welding treatment of the fixed butts of pipes having a diameter of 14—159 mm;
- Development and testing of design solutions for the equipment for pre-welding treatment of fixed butts of pipes having a diameter of 14—159 mm; development and testing of technical documentation for the prototype Ukrainian-made equipment for the preparation of fixed butts of pipes of a diameter of 14—159 mm for GTAW-welding; elaboration of technical documentation on the bench equipment and non-standard test equipment for checking and testing the prototypes;
- Development of methods for testing the prototype equipment for pre-welding treatment of fixed butts of pipes having a diameter of 14—159 mm; determination of optimal process parameters and modes of machining of the ends of pipes with a wall thickness up to 4.0 mm and the V- and U-shaped edges of pipes with a wall thickness of up to 12.0 mm; pre-production, production, installation, commissioning, and testing of prototype equipment for pre-welding treatment of fixed butts of pipes having a diameter of 14—159 mm.

While carrying out experimental and R&D works, the researchers studied how the weld quality depends on the precision of pre-welding treatment of edges of pipeline elements that meet requirements of PNAE G-7-009-89 and OST 24.125.02-89 and on deviation of the inner diameters of elements to be welded from the

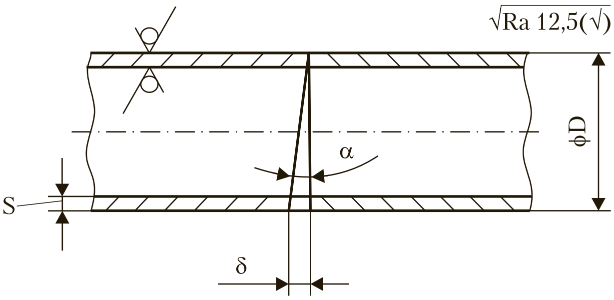

Fig. 1. Butt joint preparation of pipes having a wall thickness up to 4.0 mm for simulating the deviation of the end face plane from the perpendicular to the pipe axis for weld type C-39

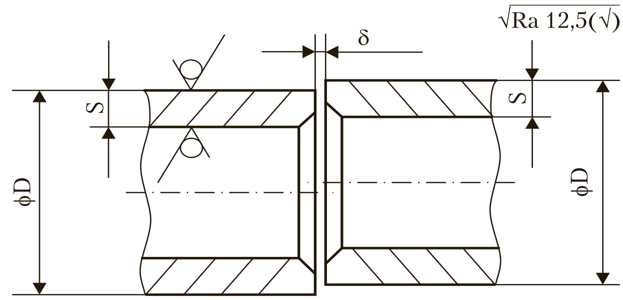

Fig. 2. Butt joint preparation of pipes having a wall thickness up to 4.0 mm for simulating the deviation of inner diameters of elements to be welded from the standard values (welding of pipes having different wall thickness) for weld type C-39

standard values (connection of pipe elements with different wall thickness).

The ends of 08H18N10T steel pipeline sample elements were treated to simulate the deviation of the end plane from the perpendicular to the pipe axis, i.e., conditions of irregular gap while performing C-39 type weld (Fig. 1 and Table 1).

The treated samples of pipe elements having a diameter of 18 mm and a wall thickness of 2.5 mm, and well as those having a diameter of 38 mm and a wall thickness of 3.5 mm underwent automated orbital welding with the use of non-fusing electrode in argon environment (GTAW) by compression molding technique, with the help of ADC 625 U3.1 machine for GTAW-welding of fixed butts of pipelines having a diameter of 18—42 mm. For welding the elements of pipelines having a diameter of 57 mm and a wall thickness of 4.0 mm by the weld penetration technique, the ADC 626 U3.1 machine for GTAW fixed-butt welding of pipelines having a diameter of 42—76 mm was used [10].

For simulating the deviation of the inner diameters of elements to be welded from the standard values (connection of pipe elements with different wall thickness) while performing C-39 type weld, the ends of pipe element samples made of 08X18H10T steels were treated as showed in Fig. 2 and Table 2. For simulating the conditions of welding the pipe elements with different wall thickness the samples to be welded were treated in such a way as to ensure that they had different inner diameters d_1 and d_2.

$$d_1 = D_1 - 2{,}25\, S_1, \quad (1)$$

$$d_2 = D_2 - 2{,}25\, S_2, \quad (2)$$

where D_1 and D_2 are outer diameters of pipe elements to be welded, S_1 and S_2 are wall thicknesses of these elements, respectively.

Table 1

Linear and Angular Size of Samples of 08X18H10T Steel Pipes for Simulation of Conditions of Irregular Gap for Welding C39 Type Joints

Pipe dimension, (D×S), mm	Gap (δ), mm		
	0.3	0.5	0.7
	Angle of deviation from the perpendicular to the pipe longitudinal axis (α), degree		
18 × 2,5	1.23°	1.72°	2.88°
38 × 3,5	0.55°	0.92°	1.29°
57 × 4,0	0.36°	0.60°	0.84°

Table 2

Linear Dimension of 08X18H10T Steel Pipeline Elements for Simulating the Conditions of Welding of Elements Having Different Wall Thickness

Nominal size of pipe ($D_{HOM} \times S_{HOM}$), mm	Δd, mm		
	0,010 D_{HOM}	0,015 D_{HOM}	0,020 D_{HOM}
18 × 2,5	0.18	0.27	0.36
38 × 3,5	0.38	0.57	0.76
57 × 4,0	0.57	0.86	1.14

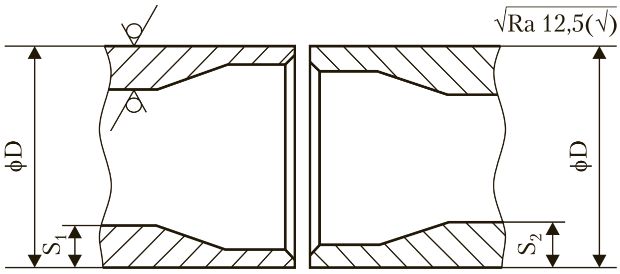

Fig. 3. Butt joint preparation of steel 20 pipes having a wall thickness from 5.0 to 12.0 mm for simulating the deviation of linear or angular size of elements to be welded from the standard values (asymmetry of angles of butt joints and welding of pipe elements with different root faces) for weld type C-42

According to (1), (2), and Fig. 2 the difference of inner diameters Δd of pipe elements to be welded can be written as

$$\Delta d = d_1 - d_2 = (D_1 - 2{,}25S_2) - (D_2 - 2{,}25S_1), \quad (3)$$

In the case if $D = D_1 = D_2$ i $S_2 > S_1$

$$\Delta d = 2{,}25\,(S_2 - S_1). \quad (4)$$

The several series of welding tests have showed that:

- The sections of welds where the gap between the ends varies from 0.45 to 0.75 mm feature many defects, the most serious of which are subsidence, lack of penetration, lack of side fusion, and undercuts;
- The sections of welds where the gap between the ends varies from 0.35 to 0.05 mm feature many defects, the most serious of which are subsidence, lack of side fusion, and undercuts;
- The sections of welds where the gap ranges from 0 to 35 mm have no defects or feature few minor defects, with the weld quality complying with the requirements of PNAE G-7-009-89;
- The welds of pipe elements with Δd ranging from 0.014 D_{HOM} to 0.020 D_{HOM} have such defects as misshape of weld, undercuts, lack of penetration, lack of side fusion, and concave root surface;
- The welds of pipe elements with Δd less than 0.010 D_{HOM}, are perfect or feature few minor defects, with the weld quality complying with the requirements of PNAE G-7-009-89.

Also, for simulating deviations from linear and angular dimensions established by PNAE G-7-009-89 and OST 24.125.02-89 for C-42 type welds, the edges of pipe elements made of steel 20 were treated according to Tables 3, 4 and Fig. 3 and welded.

The results of welding tests have showed:

- The welds of pipe elements with asymmetrical bevel angles $\Delta\alpha$ ranging from 8 to 12 degrees have continuous inacceptable defects such as misshape of weld, lack of side fusion and fusion between heads, lack of penetration, bending deflection near the edge with high bevel angle, undercuts in the face weld;
- The welds of pipe elements with asymmetrical bevel angles $\Delta\alpha$ ranging from 4.5 to 8 degrees feature similar defects, but in slightly smaller amount;
- The welds of pipe elements with asymmetrical bevel angles $\Delta\alpha$ not exceeding 4 degrees have no defects or feature minor flaws, with the weld quality complying with requirements of PNAE G-7-009-89;
- The welds of pipe elements with the root face (S_1—M_1) of the one of the edges differing from the root face (S_2—M_2) of the other edge by more than 0.5 mm are prone to such defects of root weld as misshape of weld, lack of penetration, settlement of weld, concave root surface or lack of side fusion;

Table 3

Asymmetry of Bevel Angles of Pipe Elements Made of Steel 20 for Simulating Deviations from Re-quirements of PNAE G-7-009-89 and OST 24.125.02-89 for C-42 Type Welds

Nominal size of pipe ($D_{HOM} \times S_{HOM}$), mm	Asymmetry of bevel angles $\Delta\alpha = \alpha_1 - \alpha_2$ (при $\alpha_1 > \alpha_2$), degree		
108 × 5,0 159 × 6,5 219 × 12,0	4	8	12

- In the case of welding with modulated current, even with the difference between the root faces up to 0.75 mm, the root welds have much lesser defects; some of them are flawless;
- The welds of pipe elements with the root face of the one of the edges differing from the root face (S_1—M_1) of the other edge by less than 0.5 mm feature no defects, with the weld quality complying with requirements of PNAE G-7-009-89.

In addition to the effect of precision of edge treatment on the quality of welds, the optimal regimes of treatment (cutting) have been studied to ensure proper treatment of edges and surfaces of pipe elements before welding and depositing in compliance with requirements of PNAE G-7-009-89 and other standards applicable in the power engineering industry of Ukraine.

These studies are necessary because of specific features of austenitic steels and their machining. Among the important characteristics of these steels (like most stainless steels and alloys) there is the fact that they are basically structured as a solid solution with face-centered cubic lattice [18, 19]. The austenitic steels lend themselves to machining most difficultly. This is due to several factors, one of which is work hardening capacity of steels: small deformation causes severe hardening of metal. High metal toughness causes the formation of long chips, which also affects the processing conditions [18]. The chips with large work hardening capacity have high strength causing the resistance to movement of the tool and necessitating careful sharpening of tool working edge for cutting metal without crumb formation. Low thermal conductivity of the material processed causes an increase in temperature in the cutting zone, stimulates adhesion and diffusion, enhances hardening of contact surfaces and leads to the destruction of the working parts of machine. Machining is inevitably accompanied by conversion of work into heat, at least, 80% of which is taken away with chips, with the remainder being distributed between the cutting tool, the blank, and the environment. Under the influence of heat, the structure and hardness of the surface layers of cutting tool and its ability to cut change and so do the properties of the surface layers of blank. Any type of machining is known to be characterized by the following parameters: cutting speed, rate of feed, and depth of cut. The cutting forces applied to the elements of flexible technological system *the machine—the cutting tool—the blank*, cause its deformation, with the precision of treatment being affected by those system deformations that change the distance between the working edge of the tool and the surface processed.

One of the main factors affecting the tool stability and, consequently, the precision of treatment is the vibrations that inevitably occur during the cutting process and lead to varying power and heat loads on the working surface of tool, and respec-

Table 4

Linear Dimensions of Edges of Pipe Elements Made of Steel 20 for Simulating Deviations from Re-quirements of PNAE G-7-009-89 and OST 24.125.02-89 for C-42 Type Welds

Nominal size of pipe ($D_{НОМ} \times S_{НОМ}$), mm	Angle of vee						
	Diameter of bore $d_р$, mm		Wall thickness in the place of bore, at least	Root face ($S - M$) at $S_1 = S_2$, mm			
	Nominal	Maximum permissible deviation		$S_1 - M_1$	$S_2 - M_2$		
					$M_2 = M_1$	$M_2 = M_1 + 1$	$M_2 = M_1 + 1{,}5$
108 × 5,0	100	+0.23	2.7	$2.3^{+0,4}$	$2.3^{+0,4}$	$3.3^{+0,4}$	$3.8^{+0,4}$
159 × 6,5	149	+0.26	3.8	$2.7^{+0,3}$	$2.7^{+0,3}$	$3.7^{+0,3}$	$4.2^{+0,3}$
219 × 12,0	199	+0.30	8.8	$3.0^{-0,3}$	$3.0^{-0,3}$	$4.0^{-0,3}$	$4.5^{-0,3}$

tively, to micro and macro destruction of its edges engaged in cutting. In the case of vibrations, adhesion of chips with the tool front surface has a particularly adverse impact on the tool wear.

The system ability to resist the force that causes deformation characterizes the system rigidity. Increased rigidity of technological system reduces the vibrations of its parts, which can increase the cutting intensity without affecting the precision. However, it should be noted that since the equipment for pre-welding treatment of fixed butts of pipelines must be mobile (i.e., portable), have a limited weight and belong to the hand tools, it is almost impossible to ensure for the hand tools the rigidity of technological system typical for the stationary equipment (e.g. machine tools).

The scope of optimal treatment (cutting) regimes has been studied with recommendations of [18] taken into consideration, on the samples of 08X18H10T steel pipe elements having nominal diameters of 18 and 38 mm and nominal wall thicknesses of 2.5 and 3.5 mm, respectively; nominal diameters of 57 and 108 mm and nominal wall thicknesses of 4.0 and 5.00 mm, respectively; nominal diameters of 159 and 219 mm and nominal wall thicknesses of 6.5 and 12.0 mm, respectively. The results shows that the optimal regimes of treatment (cutting) of 08X18H10T steel pipe elements should comply with parameters set in Table 5.

During the study, in addition to the generally accepted standard laboratory methods (metallographic survey, mechanical tests, nondestructive techniques, etc.) the researchers applied graphic programming technique using Lab VIEW software packages and CAD/CAE computer systems.

While designing the key solutions for the pre-welding treatment of fixed butts of NPP pipelines having a diameter of 14—159 mm the following factors were taken into account:

- Requirements for the mechanical treatment of pipeline elements to be welded, the equipment for this treatment, as well as for the methods and means of controlling the intermediate and final results of the treatment;
- Specific operational conditions at NPP, in particular, simultaneous effects of high temperature and humidity and radioactive contamination (in many cases);
- Specific requirements and conditions for the repair and assembly of NPP units in Ukraine;
- Available experience in design, manufacture, and operation of prototypes of similar destination [12—15];
- Results of experimental and technological research, analysis and study of specific features of foreign-made equipment and machinery for pre-welding treatment of fixed butts of pipelines;
- Industrial know-how and technological capacity of leading machine-building corporations.

Table 5

Parameters of Treatment (Cutting) of 08X18H10T Steel Pipe Elements Established Upon Results of Research on Their Optimal Sphere

Operation	Nominal size of pipe ($D_{НОМ} \times S_{НОМ}$), mm	Parameters of cutting regime	
		Cutting speed, m/min	Rate of feed for finish turning, mm/rev.
Undercutting and cutting; Bore of inner diameter	18 × 2.5	10.0	0.05
	38 × 3.5	12.0	0.06
	57 × 4.0	15.0	0.07
Shaping of bevel; Formation of root face; Bore of inner diameter	108 × 5.0	10.0	0.08
	159 × 6.5	15.0	0.10
	219 × 12.0	20.0	

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The survey and analysis of available information on the existing models of equipment for pre-welding treatment of fixed butts of pipelines have showed that each model of equipment for treatment of pipe ends and edge profiles before welding must contain such key components as driving gear; gear box to bring into correspondence the speed of rotating output shaft and circular table with working tools fixed on it; circular table with support(s) with each of them equipped with two knife holders (for end facers) or, at least, with one holder (for pipe cutters).

Among the most important and necessary nodes of equipment for pre-welding treatment of fixed butts of pipelines there are driving mechanisms that in the view of their purpose and specific operating conditions at NPP should be made as pneumatic power drive. As compared with other types of drives, the pneumatic power drive has many advantages, including:

- The pneumatic motors have much smaller specific volume, dimensions, and weight as compared with the electric motors having the same basic parameters (power, etc.);
- The pneumatic motors can work reliably under simultaneous action of high temperature and air humidity, vibrations and shocks, as well as external environment factors;
- The pneumatic motors are more reliable than the electric engines;
- Unlike the electric engines, the pneumatic motors ensure the compliance with safety requirements under dangerous and extremely hazardous operating conditions [16—18];
- As compared with the electric engines, the maintenance of pneumatic motors is simpler and cheaper.

The most widely used are single-side blade-type pneumatic motors notable for the fact that for their operation compressed air should be supplied to inlet only with no necessity to control the outflow of compressed air. For each pneumatic motor, one can build a diagram that shows dependence of torsion torque M, power P, and compressed air consumption rate Q on rotation speed

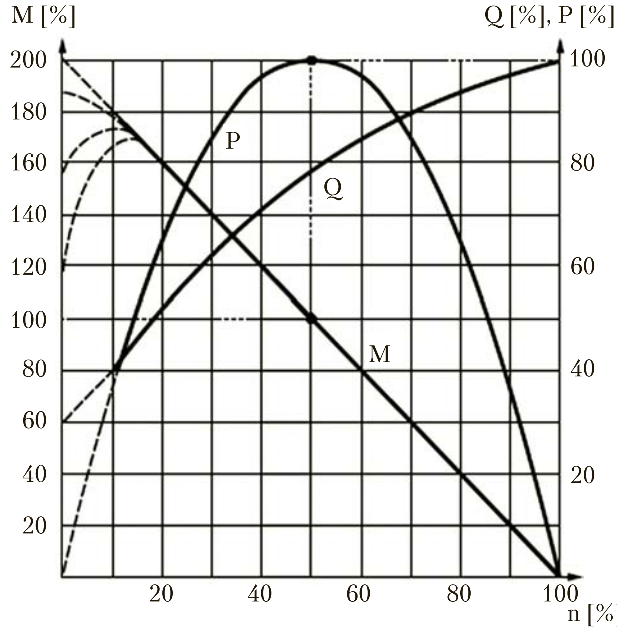

Fig. 4. Dependence of Torsion Torque *M*, Power *P*, and Compressed Air Consumption Rate *Q* on Rotation Speed *n*

n. Fig. 4 shows that the highest value of pneumatic motor power at nominally loaded output shaft is reached provided rotation speed of the shaft is about 45—55 % of its maximum rotation speed. It is possible to control the speed and torque of pneumatic engine by varying pressure of air supplied to it. To this end, a pressure controller (a pressure reducing valve) is installed at the inlet pipe. As a result, the pneumatic motor regularly gets almost unlimited volume of compressed air at a lower pressure, with a smaller torque appearing at its output shaft as load is applied thereto. The typical features of production of blade-type pneumatic motors are as follows:

- Mandatory compliance with requirements for the strength and rigidity of cylindrical body and precise treatment of inner surfaces, which implies, on the one hand, the production of body by forging or by using other very complicated shaping techniques, and, on the other hand, mandatory application of not only high-precision metal processing machines, but also special equipment and tools for control of linear and angular dimensions;

- Mandatory compliance with requirements for materials and optimal profile of blades, precision of their shape, and gaps between the blade edges and the inner surfaces of the body, as well as for the standard dimensions of outlet.

The mentioned specific features of manufacture of pneumatic engines are associated with significant costs of equipment and facilities as well as for process preparation, which can be justified only in the case of large-scale or mass production. In addition, it should be noted that for the time being, no pneumatic motors have been manufactured in Ukraine. Therefore, while designing the equipment for pre-welding treatment of fixed butts it is advisable and feasible to use commercial pneumatic motors imported from CIS countries or from South Eastern Asia.

For implementing the real regimes of mechanical treatment the circular table of equipment for pre-welding treatment of fixed butts of pipelines with cutting tool fixed thereon should rotate a much lower speed as compared with the rotation speed of output shaft of pneumatic motor, which can be reached by reduction only. This implies the mandatory use of special gear box as component of the equipment for pre-welding treatment of fixed butts of pipelines. There are different types of reduction gears, including the planetary-type, the helicoid, and the worm-like ones. Unlike the other reduction gears, the planetary ones are notable for a high performance factor and a low inertia torque, are capable of ensuring high gearing ratio and have the least dimensions with respect to torsion torque generated by the reduction gear [20, 21]. Among the main advantages of planetary gears there are also possibility of simple flanged connection, location of gear shaft in the center, and free choice of attitude position. The calculations of planetary reduction gear include the determination of optimal number of teeth with neighboring conditions and coaxiality taken into consideration. For the last low-speed pass of gearing where the circular table with cutting tool is fixed it is advis-able to use cylindrical involute tooth gear.

The effectiveness of pre-welding treatment of pipeline elements, especially during the repair of NPP units under conditions of possible radioactive contamination depends not only on the basic time of cutting, but also on the setting-up time. Therefore, the principal factor that puts limitation on the treatment of pipeline elements in aggressive environment and on permissible time of stay of the personnel under these conditions, is the time interval required for both the cutting itself and the adjustment of the tool for cutting. One of the ways to ensure effectiveness of equipment for fixed butt-joint preparation, including the end facers, is to design the circular table in such a way as to enable simultaneous treatment of several surfaces due to the table having several cutter holders. This reduces the number of transitions and switch-overs of end facer, raises its efficiency, cuts time of pipe treatment, and improves the precision of geometric relationship of surfaces to be treated due to avoiding necessary repositioning of end facer (its rearrangement on the pipe). While elaborating the technical solutions related to the equipment for pre-welding treatment of fixed butts of pipelines a special design of the circular table of end facer has been proposed to make it possible to prepare pipe ends simultaneously using four cutting tools (blades). In this case, per one pass one can do pipe facing, formation of the outer and inner bevels, and internal boring of the pipe. Fig. 5 features the proposed diagram for special circular table of end facers and location of slides with cutting tools *3* fixed in the brackets *2*. As compared with the holders where the cutting tools are fixed directly in the body, the brackets are less rigid, but more cross functional. Dual fixing of cutting tools on the circular table ensures better conditions for cutting during the butt-joint preparation by end facers that are not sufficiently rigid. Consequently, this enables reducing the vibrations. Among the advantages of proposed special circular table *1* there is the fact that the cutting tools *7*, *8*, *9* and the bracket *2* are fixed using various screws *5*, *6*, which makes it possible to set required size of blade with the help of slide's elevating screw *4* fixed by bolt *5*.

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As the analysis of technological capabilities of existing models of end facers and the experience have showed, one of major disadvantages of the existing equipment for pre-welding treatment of fixed butts of pipes is complicated control with measuring operations that are necessary for pre-welding mechanical treatment of fixed butts. Due to a single-block structure of the head with circular table rotating around the pipe, the majority of measurements can be done only if the equipment for mechanical treatment is removed from the pipe, the attitude position of the blades is adjusted and the tool is repeatedly installed on the pipe. However, the repeated installation practically excludes a precise rearrangement of working bodies with respect to the pipe axes, which adversely affects the precision of mechanical treatment and increases time for performing quite complicated preparatory operations and adjustments. To avoid this, within the framework of R&D works, an innovative solution has been offered. According to it, the head of end facer has a mechanism for positioning on the outer surface of pipe and a stationary body inside which the circular table with blade holders is placed. The mechanism of head positioning is made by quick joint with the stationary body of the head due to incorporating into the head, at least, two quick spring-loaded locks. In addition, the head has a self-aligning mechanism connected to the mechanism of head positioning coaxially with the longitudinal axis of pipe to be treated and the longitudinal axis of positioning mechanism [22].

As compared with circular tables of end facers, the special circular table of pipe cutter has a more sophisticated design, because of its functional purpose and specific character of operations to be done in the course of fixed butt-joint preparation. One of the main specific features of the circular table of pipe cutter is its structure that enables optimal simplification and reliable fixing of pipe cutter on the indefinitely long pipelines. It is designed as a turret with two longitudinal carriages and one boring carriage (support). The proposed design of the circular table foresees the cutting

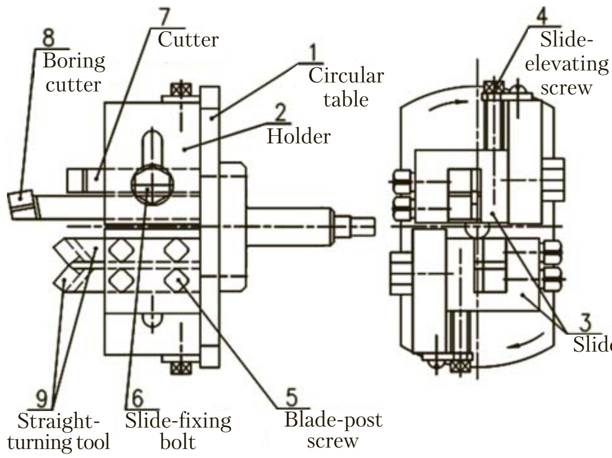

Fig. 5. Scheme of special circular table of 4-blade end facers

tools to be fixed on the table itself and on cross-feed carriages using accessory tools, i.e. various holders. The circular table is triggered by pneumatic drive to which it is connected using a cylindrical toothed gear. The pneumatic drive consists of a pneumatic motor and a planetary gear reduction with a small cylindrical gearwheel at its output. Inside the cutter body, the circular table is rotating on adjustable roller-type supports. This enables adjusting the center-to-center distance from the output gear of pneumatic drive to the wheel of circular table in the elements of toothed gearing to minimize striking of the table on the drive rotation spindle. The rotation axes of the table and the spindle are parallel to each other. According to the proposed design, the slides bearing two longitudinal or two cross-feed carriages are placed opposite to each other on the circular table. These slides enable shifting the supports in radial direction and fixing them at a required distance depending on the diameter of pipeline to be treated. A major advantage of the proposed design of cutter's circular table is possibility of transversal feed of cutting tools by rotating the table due to which it is not necessary to use a special kinematic link of the mechanism with independent motion for moving the cross-feed carriage. The cutting tools are fixed in the sliding holders mounted on the front or on the back side in cross-feed carriages of the element to be treat-

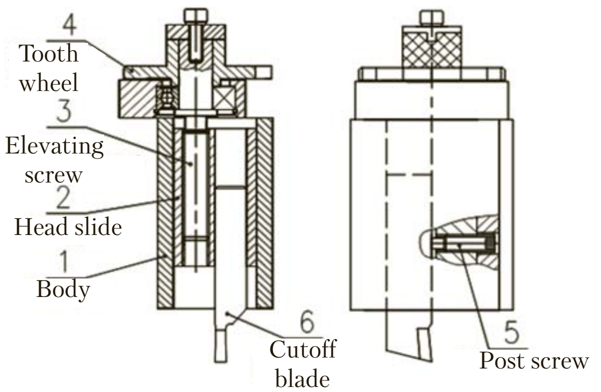

Fig. 6. Scheme of cross support of cutter's circular table

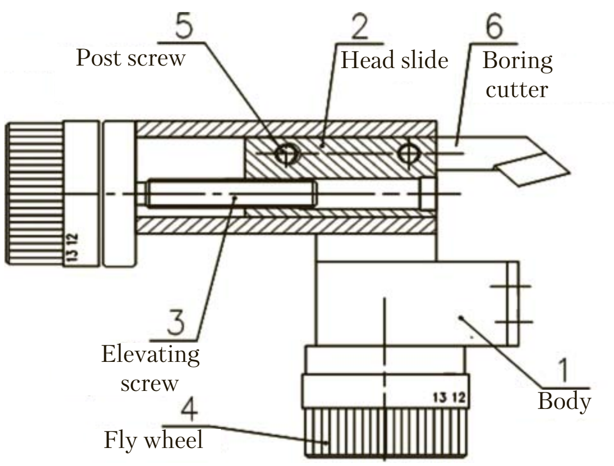

Fig. 7. Scheme of boring support of cutter's circular table

ed. In this case, the cutters in cross-feed carriages move in radial direction automatically, at fixed feed rate per complete revolution of the circular table. If necessary, the feed can be switched off. An important feature of proposed design of the circular table is the fact that the cutting tools move in the radial direction due to cross-feed carriages, which makes it possible to combine the operation of some cutters of different configuration and purpose. For example, in each of two cross-feed carriages one cutting tool can be fixed, otherwise, the cutoff blade is fixed in one cross-feed carriage, with the straight-turning tool mounted in the other one. The latter can be adjustable for shaping the outer beveled edge (in this case, it is extremely important to turn off the automatic feed in due time).

Fig. 6 shows the proposed diagram of cross-feed carriage of the circular table of pipe cutter for the case of fixing of cutoff blade therein. When the tooth wheel *4* starts to rotate from its initial position fixed by the bracket located on the circular table, it triggers the elevating screw *3*, with the head slide *2* with the cutoff blade *6* placed on it moving with respect to the body *1*. If the cutoff blade is fixed in one cross-feed carriage, while the straight-turning tool is put in the other one, the pipe cutting and the external edge bevel shaping operations are performed simultaneously during one pass.

Fig. 7 shows a diagram of boring support of proposed circular table of the pipe cutter for butt-joint preparation of pipelines having a diameter of 108—159 mm. The support is fixed on the circular table instead of the transversal one, and its body *1* is mounted at a required distance depending on the pipeline diameter to be treated. When rotating the fly wheel *4* triggers the elevating screw *3* and consequently, the head slide *2* bearing the boring cutter *6* moves with respect to the body *1*. If the cross-feed carriages are fully replaced by the boring ones, their two-side location is reproduced on the circular table, which ensures more favorable conditions for cutting due to reduced vibrations.

The experimental and in-process researches, determination of requirements for pre-welding treatment of fixed butts of NPP pipelines having a diameter of 14—159 mm, the development of design proposals for this equipment, the computer simulation of nodes and mechanisms of end facers and pipe cutter, the full-scale modelling of their elements, and the mathematical computations of their power circuits and kinematic links have enabled developing and elaborating the design and technical documents, including working drawings for prototype equipment for pre-welding treatment of fixed butts of NPP pipelines having a diameter of 14—159 mm, including end facers TRC 38 U3.1, TRC 76 U3.1 and pipe cutter

Fig. 8. General view of prototype end facers TRC38 U3.1 (*right*) and TRC76 U3.1 (*left*)

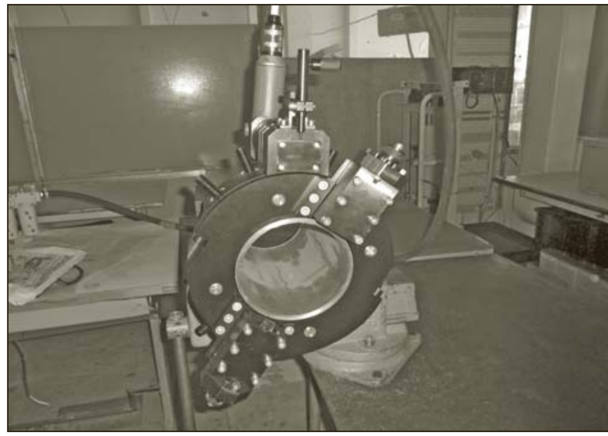

Fig. 9. General view of prototype cutter TTC660 U3.1

TTC 660 У3.1. technical specifications have been developed for the bench equipment for nonstandard controlling and measuring hardware for testing of prototypes. In 2014, JSC *Chezara* with REC WCNE elaborated the design and technical specifications for prototypes of end facers TRC 38, TRC76 and pipe cutter TTC 660, manufactured the prototype equipment, and carried out the required tests. Further tests of prototype equipment for pre-welding treatment of fixed butts of NPP

Table 6

Basic Parameters of Prototype Equipment for Fixed Butt-Joint Preparation of Pipelines

No.	Parameter or characteristic feature	Value			
		Model			
			TRC 76 U3.1	TRC 660 U3.1	Mongoose-2MT (Russia)
1	Minimum outer diameter of pipe to be treated, mm	14	38	108	45
2	Maximum outer diameter of pipe to be treated, mm	38	76	159	120
3	Maximum wall thickness of pipe to be treated, mm	5.0	7.0	15.0	5.0
4	Length of boring of inner diameter of pipe, mm, at least	10	15	20	No bore option
5	Location	On the outer surface of pipe			Inner
6	Method of cutter feed	Manually	Manually	Automatically	Manually
7	Cutter feed, mm/rev., at most	0.20	0.15	0.10	0.20
8	Frequency of rotation of cutter holder, nominal, rpm	110	100	60	70
9	Compressed air consumption per hour of idle time, m^3/min	1.5	1.5	1.5	1.7
10	Dimensions, mm, at most	350 × 140 × 170	370 × 160 × 175	520 × 500 × 435	470 × 400 × 120
11	Weight with drive gear, kg, at most	9.5	12.6	19.3	9.5

pipelines having a diameter of 14—159 mm were made at EWI, REC WCNE, and *Atomremontservice* subsidiary of NNEC *Energoatom*.

Table 6 contain basic parameters of designed prototype equipment for fixed butt-joint preparation. In Figs. 8 and 9, one can see a general view of these prototypes.

Comprehensive tests have showed that the proposed technical solutions are efficient, with the prototypes complying with requirements for advanced equipment for fixed butt-joint preparation and having advantages over the existing foreign counterparts.

CONCLUSIONS

1. Design, manufacture and testing of prototype end facers TRC 38 U3.1 (for the pipes having a diameter from 14 to 38 mm) and TRC 76 U3.1 (for the pipes having a diameter of 38—76 mm) and pipe cutter TTC 660 U3.1 (for the pipes having a diameter 108—159 mm) and their further commercialization enable providing the assembly and repair contractors and the power engineering corporations with advanced Ukrainian-made equipment for fixed butt-joint preparation for welding. This will allow them to avoid one of the main factors hampering large-scale implementation of well-proven and cutting edge Ukrainian technologies for automated fixed-butt welding of pipelines having a diameter of 14—76 mm and a wall thickness of up to 7.0 mm and a diameter of 76—159 mm and a wall thickness of up to 12.0 mm (material: austenitic and perlitic steels and high alloys to significantly improve quality and to raise efficiency and effectiveness of welding works when assembling and repairing the power engineering facilities and other potentially dangerous industrial objects.

2. The results of preliminary and in-process tests have showed that as compared with the best foreign equipment for treatment of fixed butts of pipes and pipelines for manual and automated welding, the prototype end facers TRC 38 U3.1 and TRC 76 U3.1 and the pipe cutter TTC 660 U3.1 enable:

- Expanding the engineering capabilities of equipment for pre-GTAW treatment of fixed butts of steel pipelines;
- Raising the productivity of mechanical treatment of fixed butts of steel pipelines due to simplified control of internal geometric dimensions of pipes to be treated;
- Simplifying and cheapening the maintenance of equipment for pre- GTAW treatment of fixed butts of NPP pipelines due to maximum utilization of Ukrainian-made component parts and materials and significant improvement of its repairability;
- Reducing the product self-cost, at least, 1.5—2 times;
- Improving quality and precision of treatment of fixed butts of steel pipelines for GTAW.

The above mentioned advantages concern mainly the end facers and are achieved due to locating them externally on the pipes to be treated and by ensuring a possibility of simultaneous crosscutting, shaping of outer and inner bevel edges, boring of internal diameter of these pipes, and quick coupling/decoupling of fixed mechanism for locating the operating head and its fixed housing.

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Orbital Welding with the Use of Non-Fusing Electrodes and Design of Prototypes of Import Substituting Equipment for Implementation of These Processes".

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ОБЛАДНАННЯ ДЛЯ ПІДГОТУВАННЯ НЕПОВОРОТНИХ СТИКІВ ТРУБОПРОВОДІВ ДО ЗВАРЮВАННЯ

Наведено результати доробку Інституту електрозварювання ім. Є.О. Патона та його спеціалізованих підрозділів по створенню вітчизняних зразків обладнання для підготування до зварювання торців та крайок стиків неповоротних сти-ків трубопроводів діаметром від 14 до 159 мм при монтажі, ремонті та модернізації об'єктів енергетики, включаючи енергоблоки атомних і теплових електростанцій, в хімічному та енергетичному машинобудуванні, на підприємствах нафтогазового комплексу та в інших галузях промисловості.

Ключові слова: неповоротні стики трубопроводів, автоматичне орбітальне зварювання, механічна обробка, пневмоприводи, торцювачі, труборізи, супорти, різці.

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ОБОРУДОВАНИЕ ДЛЯ ПОДГОТОВКИ НЕПОВОРОТНЫХ СТЫКОВ ТРУБОПРОВОДОВ К СВАРКЕ

Приведены результаты наработок Института электросварки им. Е.О. Патона и его специализированных подразделений по созданию отечественных образцов оборудования для подготовки к сварке торцов и кромок неповоротных стыков трубопроводов диаметром от 14 до 159 мм при монтаже, ремонте и модернизации объектов энергетики, включая энергоблоки атомных и тепловых электростанций, в химическом и энергетическом машиностроении, на предприятиях нефтегазового комплекса и в других отраслях промышленности.

Ключевые слова: неповоротные стыки трубопроводов, автоматическая орбитальная сварка, механическая обработка, пневмоприводы, торцеватели, труборезы, супорты, резцы.

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