Pipe Welding Machine Modernization

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Abstract. There are the results of pipelines rolled joints welding machine modernization. The machine is designed using a welding rotator, linear electric drives, stepper motors, CNC system. The machine is controlled by a CNC system according to ISO 6983-1: 2009. The machine consists of: stepping rotary device, welding torch stepping device, controlled TIG welding power source, controlled welding wire feeder, welding current control system, workpiece rotation control system and welding torch. The welding torch movement trajectory controlling software has been created. It allows to weld by any type of welding torch recommended movements. The modernizing machine allows welding the pipelines rolled joints in automatic mode both in one pass and in multi-pass. The machine can be used for industrial pipeline elements welding, for welding modes testing, for studying the effect of welding modes on the quality of pipeline welds. The results can be adapted for sheet structures welding using the standard commands of the ISO 6983-1: 2009 standard. The results can be adapted to industrial welding robots control. The welding machine can be used for MIG / MAG welding and surfacing.

1. Introduction

Automation of main pipelines and other large diameter long pipelines welding is developing rapidly. As a result, it is possible to increase the quality and output rate while reducing their cost and labor intensity. Automation of rotary joints welding, flanges welding, tees welding is poorly developed. This is especially true for those industries, where there is a wide range of manufactured parts and a small number of similar products, as well as for multi-pass welding of thick-walled pipes (shipbuilding, aircraft, power engineering, etc.). This leads to scrap and poor production efficiency. In addition, modern pipeline welding automation solutions are stand-alone and are not integrated into the product development cycle - there are no tools for translating CAD developments into CAM programs for welding machines. One of the reasons for this is the development of a welding machine as an autonomous device with its own closed control system, configured to perform a narrow list of welding tasks.

Therefore, the development the automatic pipe welding machine with wide control possibilities and the possibility of its integration into the development and production cycle is an important task of automating not only production, but also research and technological activities.

2. Pipe welding automation state

Welding of a large number of pipeline elements has good automation approaches. This applies to roller joints, flanges, tees. But nowadays these operations are still mostly welded manually. It is
known that a large number of defects are formed in the places where welding starts and ends. Therefore, the welding "by sectors" leads to the defects formation, or requires the workpieces preparation before welding each joint. And this increases the labor intensity and reduces the output rate. Therefore, welding rotators are used, which only rotate the workpiece, and a person welds. Unfortunately, welding automation is not progressing further in many industries. There are automatic welding complexes. But their capabilities are severely limited, and they require welder adjusting the operating modes during welding process.

The automatic welding complexes operation is based on the welding tractors control principles. They have two independent DC drives. One rotates the pipe, the second moves the welding torch perpendicular to the weld axis. The second movement is most often carried out through a mechanical drive from the same DC motor. As a result, these welder machines can weld either straight seams (usually at a constant speed) or zigzag seams at a constant pitch and a constant speed. The welding power source control and the welding wire feed controls are not associated with the welding torch movement. The power source and wire feed controls consists in setting the required weld parameters, which usually do not change during the welding process. Welding machines are controlled from the operator panel and cannot be integrated into the CAD / CAM system. The price of the simplest devices exceeds 1 million rubles.

The industrial robotic manipulators allow welding with more complex welding trajectories. But the number of these trajectories is also very limited. Robots allow to adjust the welding current during the welding process, but they do it stepwise (the number of steps does not exceed 10) and with a low rate of current change. That is, they are not designed for welding by the current pulses. Wire feed is continuous with a fixed speed selection algorithm. Robot programming is integrated with CAD, but differs from the ISO 6983-1: 2009 standard. Different robots manufacturers use the different software and different command standards. The price of a robot is ten times higher than an automatic welding machine.

The welding torch movement trajectory during welding has a significant effect on the geometry, size and position of the weld pool, as well as on the weld pool lifetime and the crystallization conditions. Therefore, the correct choice of the torch movement trajectory greatly affects the quality of welding. For example, reciprocating movements along the weld axis increase the weld pool lifetime, increase pool size and deflect it from the horizontal position. As a result, thin-walled welding is performed better with a high current in the burn absence. The torch movement trajectories also make it possible to adjust the weld width and reinforcement, the degree of metal heating and penetration, weld pool metal mixing, and the metal crystallization conditions. The lateral movements keep the tilted weld pool and reduce the burn-through risk of thin sheet materials.

Changing the welding torch movement speed during the welding process also allows to adjust the degree of the metal heating and penetration in the joint desired areas (for example, at the edges of the seam). Alternatively to the speed changing, you can change the welding current in trajectory certain parts, which also allows to adjust the weld pool parameters. Current pulses welding allows to reduce thin parts burn-through while maintaining the required penetration depth.

Filler wire feed also affects the weld pool and weld. Recently, the popularity of pulsed wire feed with a long pitch and with a micro step has been increasing.

Thus, the conditions of the weld pool formation, existence and crystallization, and the conditions of the weld formation depend on all welding parameters, including: current, torch speed, torch trajectory, welding wire feed speed, welding wire feed algorithm. To improve the welding quality and productivity, as well as to study welding processes, the promising direction is to vary all specified parameters at each section of the welding torch trajectory. Existing automatic welding systems, including welding robots, do not allow this. Therefore, the manufacture of an automatic welding machine, that allows flexible programming of the specified parameters and is compatible with the CNC machines programming standards is an urgent task.

Research purposes – to design and manufacture a automatic welding machine for weld the pipelines rolled joints under the CNC control, that is compatible with the ISO 6983-1: 2009 standard,
which allows to separately adjust all the main welding parameters during the welding process (control the welding torch trajectory, speed at different trajectory parts, welding current at different sections of the trajectory, feeding the welding wire), develop a CAM program to control the welding machine.

3. Methods
The following equipment was used in the work: standard welding rotator М211080; KEMPPI MinarcTig Evo 200 MLP semiautomatic TIG welding machine; 28H30H0604A2, PL86H75-3,5-4, PR-SL57S254 stepper motors; wire feeder; NVUM3-SP control board; TB6600 stepper motor drivers.

Additionally, a welding current source control board was developed, which converts the milling machine spindle PWM control signals into signals, which simulate the welding machine control panel potentiometer. The control board also simulates pressing the welding torch control button. As a result, it became possible to remotely control the welding current source: welding current regulation during welding in the range of 15% - 100% (30 A - 200 A); welding current turning on and turning off; control of the welding source in Minilog mode.

The DC motor control board of the wire feeder was also designed and manufactured. This board allows to flexibly adjusting the welding wire feed mode: adjust the operating mode (continuous feed / pulse feed); adjust the feed reverse (wire feed in one direction / feed with reverse); adjust the wire feed speed during the pulse and during the pause; adjust the pulse duration and pause duration; adjust wire feed acceleration and other functions.

To ensure compatibility of the control system with standard CNC machines controls, a control system compatible with ISO 6983-1: 2009 standard was used. Control system uses the following codes: M0; M3 (switching on the welding current); M5 (switching off the welding current); M8 (turn on the welding wire feed); M9 (turn off the welding wire feed); M30; Sxx (welding current); G00; G01; G02; G03; G04 Pxx; Fxx. Also auxiliary commands were used: G90; G91; Oxx; M98 Pxx Lxx; M99. Minilog operation uses a subroutine, that gives a signal to turn on the welding current, pauses 0.5 s, and generates a signal to turn off the welding current. To turn off the welding current in Minilog mode, the pause between the on and off signals is set to 1.2 s.

4. Theoretical research
Upgrading the welding machine instead of making a new one can save time, labor and money. Therefore, the existing rotation mechanism was modernized in the work. At the welding rotator, the standard DC motor was replaced with a stepper motor. The standard DC motor control system was not used. To be able to move the welding torch across the weld axis and adjust the torch height, a mechanical positioning system for the welding torch was designed and manufactured (figure 1).

Figure 1. Automatic pipeline swivel welding machine.

Figure 2. Automatic welding machine control unit diagram.
Rotation of the workpiece is performed by a stepper motor (1) through a standard gearbox. Transverse movements of the welding torch are performed by a linear electric drive (2). The vertical movements of the welding torch are carried out by a linear electric drive (3). Welding torch (4) is fixed on the bracket (5). The same bracket holds the wire feed hose 6.

Welding machine control circuit is shown in figure 2. Control board (2) receives the control signals via USB interface from personal computer (1) or from a stand-alone control unit compatible with the Mach-3 system. Exceeding the welding torch permissible limits is detected by sensors (3). Alarm sensors (4) signal the need to stop. Welding torch position sensors (5) show the position of the welding torch relative to the weld. Control board (2) generates control signals to stepper motor drivers (6), (7), (8) in the form of “Step” and “Direction” commands. The stepper motor drivers control the drives stepper motors rotation (11), (12), (13). The control board (9) is used to control the welding current source (14). The board receives the commands "Turn on / off the current" and the PWM signal of the current value. The board converts the signals into a digital signal "Enable / Disable current", "Enable / Disable Minilog mode", and into an analog signal from a potentiometer. The control of the feeding of the welding wire is carried out by the control board (10) with its own mode controls. To synchronize the work, the board receives a Start / Stop signal. The board controls the DC motor of the wire feeder (15).

The wire feed control system feeds the wire according to different algorithms. The system allows to adjust: the forward stroke duration (t1), the reverse stroke duration (t2), the forward speed (V1), the reverse speed (V2). The speed V2 can be of any sign, that is, the system can feed the wire with reverse and without reverse. The pause time (tp) and acceleration / deceleration (a) are also adjustable.

Any control system compatible with Mach-3 (personal computer, laptop, stand-alone control unit, etc.) can be used to welding torch movement control, to welding power source and the wire feed system control. This gives great opportunities for adjusting all welding parameters and changing them during welding, including changing the welding current, the welding torch movement speed, torch trajectory.

To automate the welding control programs design, a special software was developed. The seam weld beginning coordinates, the seam weld end coordinates, path intermediate points, the curvature radii are transferred to this program. The welding torch movement trajectory type and the trajectory parameters (speed, current, width, main step, intermediate step, etc.) are also set. The software generates a control g-code for the welding machine control system. The software allows execute all the used welding torch trajectories, which are shown in figure 3 (green indicates the welding torch trajectories, and blue - the trajectory adjustable parameters).

In addition, the software allows to generate a large number of other trajectories, based on the "two-step" trajectory (figure 4). For this trajectory, the following parameters are set: seam width "b" with possible mirroring of the trajectory relative to the seam axis; intermediate step "L" (positive or negative); main step "h"; the first half step radius "R1" (the center of the circle can be on either side of the trajectory); the second half step radius "R2" (the center can be on either side of the trajectory); the upper side transition radius "r1" (the transition can be in the form of an arc or a loop); the lower side transition radius "r2" (the transition can be in the form of an arc or a loop); the first reinforcing loop diameter "d1" (the loop can be on either side of the path); the second reinforcing loop diameter "d2" (the loop can be on either side of the path). By adjusting these parameters, a large number of different welding torch trajectories can be obtained.

The software allows setting for each trajectory fragment the welding current and movement speed. Moreover, each trajectory segment can be divided into smaller sub-segments, and for each sub-segment, the welding current and movement speed can be set.

5. Practical results
The designed and manufactured welding machine and software were tested in automatic welding of a steel pipe with a diameter of 60 mm and a thickness of 4 mm.
The welding machine has the following characteristics: control command system - compliant with ISO 6983-1: 2009 (G-code, M-code); pipe rotation discreteness - 0.01°; discreteness of welding torch movement along the pipe - 0.003 mm; vertical welding torch movement discreteness - 0.05 mm; pipe rotation speed - 0 ... 1.6 rpm; movement speed along the Y axis - 0 ... 3000 mm / min; movement speed along the Z axis - 0 ... 3000 mm / min; welding current regulation range - 30 ... 200 A.

Features of the control program: welding with all types of recommended trajectories; design the new trajectories types, based on the developed "two-step" trajectory model; ability to change the welding speed and welding current during welding in different parts of the welding trajectory; compliant with ISO 6983-1: 2009 standard for integration into CAD programs.

6. Conclusion
The manufactured welding machine and welding software allow varying complexity welding rotary joints in automatic mode. The designed welding machine can be effectively used for practicing welding modes. Also, the welding machine can be used for scientific purposes to study the influence of various welding factors on the quality of the welded joint. This ensures a high degree of repeatability of welding conditions.

Due to the application of the ISO 6983-1: 2009 standardized control system, the welding machine can be controlled by a large number of CNC control systems. The results of welding modes working out can be transferred to other welding machines and robotic manipulators. The designed welding torch movement trajectory control software can be integrated into existing CAD systems.

7. References
[1] Krampit A G and Krampit N Y 2015 Methods for controlling the weld formation Technologies and Materials 3 pp 21-26.
[2] Lebedev B F, Pashin A N and Dudko S M 1984 Technology of mechanized CO2 welding of horizontal seams with solid wire Automatic Welding 4 pp 57–59.
[3] Chernishov G G 1970 Formation of a root weld when welding in carbon dioxide Automatic Welding 10 pp 6–9.
[4] Zinchenko A V 2004 Workshop on mechanized gas-shielded welding of multilayer vertical seams Professional Welder 3 p 22.
[5] Bakhmatov P V and Murav’ev V I 2017 Manufacture of high-quality ribbed titanium panels Steel in Translation 47 pp. 91-98 DOI: 10.3103/S0967091217020036.
[6] Bolmsjo G, Olsson M and Cederberg P 2002 Robotic arc welding - trends and developments for higher autonomy *Industrial Robot* **29** pp. 98–94.

[7] Chen S B and Lv N 2014 Research evolution on intelligentized technologies for arc welding process *J. of Manufacturing Processes* **16** pp. 109–22.

[8] Madsen O, Sorensen C B, Larsen R, Overgaard L and Jacobsen N J 2002 A system for complex robotic welding *Industrial Robot* **29** pp. 127–31.

[9] Langdon R 1994 Robotic system developments *Automotive Engineer* **19** pp. 32–33.

[10] Murav’ev V I, Bakhmatov P V, Pletnev N O and Debelyak A A 2016 Influence of the stress state on the structure and properties of welded steel and alloy structures *Steel in Translation* **46** (4) pp. 256–59 DOI: 10.3103/S0967091216040070.

[11] Fizulakov R A, Murav’ev V I and Pitsyk V S 2016 Estimation of the quality of gas laser sawing of sheets of aluminum alloys *Metal Science and Heat Treatment* **58** pp. 147–52 DOI: 10.1007/s11041-016-9979-6 WOS:000381983700005.

[12] Mamadaliyev R, Kuskov V, Bakhmatov P and Ilyashchenko D 2018 Influence of welding conditions and different current sources on formation of welded seam of steel austenitic stainless chromium-nickel steel *Metal Working and Material Science* vol **20** issue 4 pp. 35–45 DOI: 10.17212/1994-6309-2018-4-35-4.

[13] Murav’ev V I, Lonchakov S Z and Pitsyk V S 2015 Structural changes in local catastrophic-failure zones of petroleum-product pipeline systems *Steel in Translation* **44** (10) pp. 737–41 DOI: 10.3103/S0967091214100118.

[14] Murav’ev V I and Bakhmatov P V 2017 Research of the technological manufacturing operations limiting the reliability (Fatigue strength) of ribbed titanium panels *Izvestiya Ferrous Metallurgy* **60**(2) pp. 99–08 DOI: 10.17073/0368-0797-2017-2-99-108.

[15] Muravev V I and Pitsyk V S 2015 Prospects of obtaining of one-piece diffusion junctions from aluminum alloys *Tsvetnye Metally* **3** pp. 63–68 RSCI:23184025.

[16] Bakhmatov P V, Tishkova E and Bazhin V I 2016 On assessment stress weld conditions *Kontrol'. Diagnostika* **3** pp. 9–13 DOI 10.14489/td.2016.03.pp.009-013.

[17] Frolov A V 2020 Automation the Welding Trajectory Control *Int. Multi-Conf. on Industrial Engineering and Modern Technologies, FarEastCon 2020* (Vladivostok, Russia) DOI: 10.1109/FarEastCon50210.2020.9271607.

[18] Ovchinnikov V V 2016 Manual arc and plasma welding and metal cutting technology (Moscow: Academy).

[19] Efimov A Y, Gorkavyy M A, Egorova V P and Solovev D V 2019 Design of intelligent decision support system for robotized welding technological processes optimization *Int. Multi-Conf. on Industrial Engineering and Modern Technologies, FarEastCon 2019* (Vladivostok, Russia) DOI: 10.1109/FarEastCon.2019.8933908.

[20] Efimov A Y, Gorkavyy M A, Gorkavyy A I and Solovev D V 2019 Improving the efficiency of automated precision robotics-enabled positioning and welding *Int. Science and Technology Conf. EastConf 2019* (Vladivostok, Russia) DOI: 10.1109/EastConf.2019.8725362.

[21] Egorov P A, Belykh S V and Aung P Z 2018 Development of technology for automated assembly of aircraft using industrial robotics *Proc. of the International Conf.: Aviamechanical Engineering and Transport (AVENT 2018). AER-Advances in Engineering Research*, **158**, pp. 119-22 DOI: 10.2991/aevent-18.2018.23.

[22] Egorova V P, Gorkavyy M A, Efimov A Y and Solovev D V 2019 Synthesis of an adaptive system for diagnosing the quality of automated welding products *Int. Multi-Conf. on Industrial Engineering and Modern Technologies, FarEastCon 2019* (Vladivostok, Russia) DOI: 10.1109/FarEastCon.2019.8934286.

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