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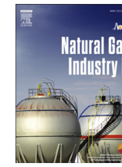

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Research article

Automatic welding technologies for long-distance pipelines by use of all-position self-shielded flux cored wires

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Abstract

In order to realize the automatic welding of pipes in a complex operation environment, an automatic welding system has been developed by use of all-position self-shielded flux cored wires due to their advantages, such as all-position weldability, good detachability, arc's stability, low incomplete fusion, no need for welding protective gas or protection against wind when the wind speed is < 8 m/s. This system consists of a welding carrier, a guide rail, an auto-control system, a welding source, a wire feeder, and so on. Welding experiments with this system were performed on the X-80 pipeline steel to determine proper welding parameters. The welding technique comprises root welding, filling welding and cover welding and their welding parameters were obtained from experimental analysis. On this basis, the mechanical properties tests were carried out on welded joints in this case. Results show that this system can help improve the continuity and stability of the whole welding process and the welded joints' inherent quality, appearance shape, and mechanical performance can all meet the welding criteria for X-80 pipeline steel; with no need for windbreak fences, the overall welding cost will be sharply reduced. Meanwhile, more positive proposals were presented herein for the further research and development of this self-shielded flux core wires.

Keywords: Natural gas; Pipeline; Self-shielded flux core wire; Automatic welding; Welding system; Welding technique; Welding efficiency; Mechanical property

In recent years, automatic welding, high in automatic degree, low in labor intensity, good in welded joint appearance shape, fast in welding speed, high in first-time welding pass rate, has been widely applied [1–6] in on-site welding of long-distance oil/gas pipelines intensity etc. Limited by the pipeline routes, welding techniques, equipment volumes, etc., the pipeline automatic welding technology is mostly applied in a flat operation environment rather than a complex operation environment. The self-shielded flux cored wire has been the hotspot [7–14] due to its advantages, such as excellent all-position operability, sound welding performance, high wind resistance, arc's flexibility and good directivity, sound fusion with base metal, low crack tendency, wide welding operation window, good detachability, no need for protective gas for welding nor windbreak fence against wind when the wind speed is below 8 m/s, low possibility of welding defects like incomplete fusion, etc.

In view of the significant advantages of the automatic pipe welding technology and self-shielded flux cored wires, PetroChina Natural Gas Pipeline Scientific Research Institute took the lead in research on the development of an automatic welding system by use of all-position self-shielded flux cored wires and welding techniques, carried out welding test for X-80 pipeline steel of West-East Natural Gas Transmission Line 3 on the basis of the existing finished self-shielded flux cored wires to explore proper automatic welding parameters, and put forward proper proposals for further research on the special self-shielded flux cored wires applicable to automatic welding, thus to guide actual project application and continual and in-depth research on automatic welding technology by use of self-shielded flux cored wires.

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1. All-position welding of pipes and automatic welding technology

1.1. Characteristics of all-position welding of pipes

A long-distance oil/gas pipeline is connected by joints of steel pipes with an average length of 12 m upon pipe joint welding. The whole joint welding procedure is composed of pipe end grooving, joint matching, root welding, hot welding, filling welding and cover welding with steel pipe fixed during welding, and manual arc welding. Semi-automatic welding or automatic welding can also be used to weld pipe jointS at all positions. Full-position welding of pipes generally takes downward welding at present. Compared with the single welding state of plane welding, the whole all-position welding process of pipes is a complex changing process from a plane welding state to a vertical welding state and then to an overhead welding state, and welding parameters also change in real-time with different welding positions.

1.2. Principles of automatic welding of pipes

Pipe automatic welding is a kind of technique realizing automatic welding of girth welded joints with pipes relatively fixed by automatic welding equipment. An automatic control system controls a welding carrier on a guide rail fixed near the pipe joint to be welded and further to control the welding speed, arc voltage, wire feeding speed, welding torch amplitude, frequency and change of other welding parameters, thus to realize the all-position automatic welding of pipe girth welded joints.

2. The automatic welding system of pipes by use of all-position self-shielded flux cored wires

An automatic welding system of pipes by use of all-position self-shielded flux cored wires (hereinafter referred to as an automatic welding system by use of self-shielded flux cored wires) mainly consists of a welding carrier, a guide rail, an auto-control system, a welding source, a wire feeder, and so on (Fig. 1).

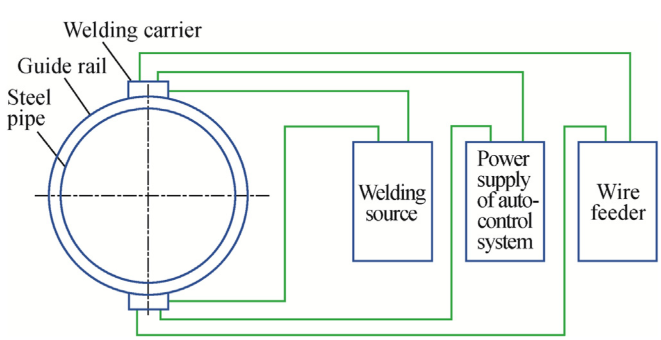

Fig. 1. Compositions of an automatic welding system by use of self-shielded flux cored wires.

2.1. Working principles

The welding torch of a self-shielded flux core wire is mounted on a welding carrier on the guide rail fixed near a pipe joint to be welded. Welding parameters are preset in the auto-control system to accurately control the spatial position of welding torch, welding speed, wire feeding speed, welding voltage, amplitude, swing trace, swing rate, etc., thus to realize an efficient and all-position automatic welding of pipe girth welded joints. Arc striking starts from a 12 o'clock position by a welding carrier at first during welding, and welding is toward a 6 o'clock position along one side of a girth welded joint, then another welding carrier is moved to the 12 o'clock position afterwards for arc striking, and welding is conducted at the 6 o'clock position along the other side of the girth welded joint (Fig. 2). The minimum time interval of arc striking is maintained on the premise of no interference between the space of the two welding carriers to ensure a basic symmetrical stress on both sides of the welded joint during welding, thus to realize hot welding, filling welding and cover welding of a girth welded joint in sequence. It should be noted that deslagging is required for the previous welding layer before the welding of the next layer.

2.2. Mechanical parts

The mechanical parts of an automatic welding system by use of self-shielded flux cored wires is mainly composed of a welding carrier and a driving mechanism.

2.2.1. The welding carrier

The welding carrier mainly consists of the angle swing mechanism and the cross adjustment mechanism of a welding torch (Fig. 3). The angle swing mechanism of the welding torch therein can realize optimal swing angles and the swing frequency of the welding torch to avoid incomplete fusion during welding; the cross adjustment mechanism of the welding torch can realize upward/downward adjustment and

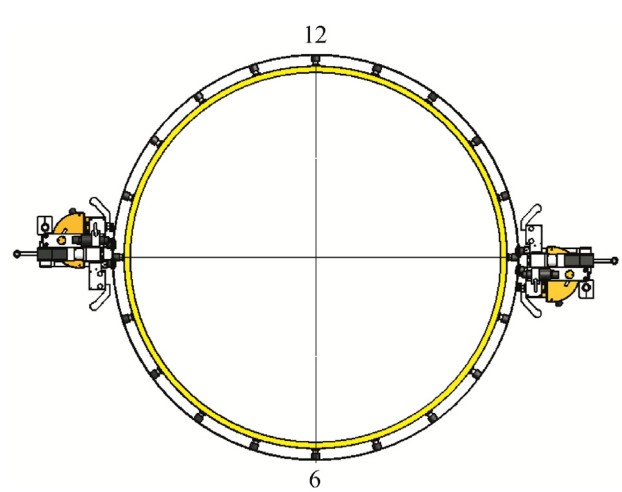

Fig. 2. Working principles of an automatic welding by use of self-shielded flux cored wires.

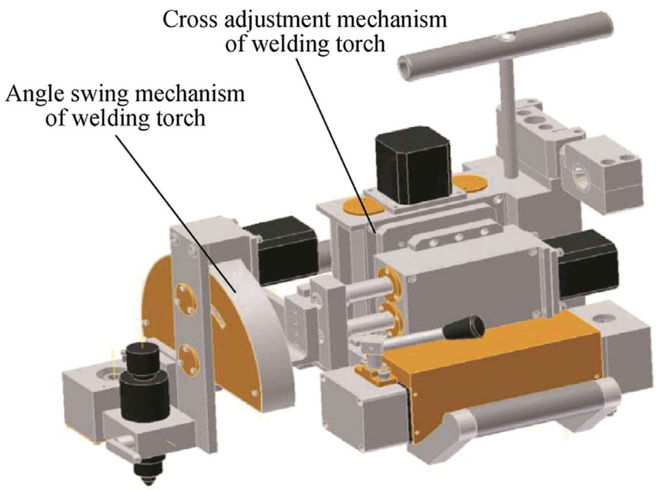

Fig. 3. 3D Design model of a pipe welding carrier.

left/right position adjustment related to the width of the welded joint for the welding torch, thus to meet the requirements of the distance and width between a pipe wall and wires at different positions at the pipe welded joints.

2.2.2. The driving mechanism

The driving mechanism is the core of an automatic welding system by use of self-shielded flux cored wires and is mainly made up of a welding carrier travelling mechanism and a guide rail. The combination of the travelling mechanism and the guide rail enables the circumferential motion of the welding carrier along the outer pipe wall.

The travelling mechanism is mainly composed of a travelling drive motor, a main belt wheel, an auxiliary belt wheel, a synchronous belt, a tightening axle, a main frame, a transmission gear axle, a gear, etc. (Fig. 4).

The working principle of the travelling mechanism: drive motor drives the main belt wheel and transmits power to the auxiliary belt wheel at an end of the transmission gear axle through tightening the wheel axle to put the transmission gear axle in rotation, thus to realize the circumferential motion of the welding carrier by gear of transmission gear axle meshing with the teeth of the guide rail.

The guide rail, in a split annular structure, is made up of two semicircle rails connected by connectors and a locking handle; a rack is set on the rail to realize power transmission with gears (Fig. 5).

2.3. The control part

The control part of an automatic welding system by use of self-shielded flux cored wires takes a programmable logic controller (PLC) as the master controller to perform data calculation and action control.

2.3.1. The welding mode

Automatic welding by use of self-shielded flux cored wires refers to a welding procedure of hot welding, filling welding, cover welding, etc. of outer welded joints of half round of pipes from both sides of a pipe respectively by two welding carriers with a welding torch; the outer girth welded joint of a pipe is divided into 24 sections on average, i.e. point 0 to point 0.5, point 0.5 to point 1 … point 11.5 to point 12, and each welding torch completes welding of 12 sections therein independently; welding parameters can be in real-time adjustment with the movement of the welding carrier to ensure the accuracy of welding parameters of each welding section.

2.3.2. Automatic control flow

Specific welding procedures and control buttons can be selected through a hand-held controller and control orders can be sent through I/O bus (Fig. 6). All the welding parameters are written into a programming unit and are transmitted by a conversion control unit. A signal is finally transmitted to a PLC master control unit for processing, and then transmitted to a motor driver upon shaping by a shaping unit after amplification, thus to realize control over the motion of a corresponding motor.

PLC performs data calculation, controls and coordinates action sequence, and responds to control instructions from the hand-held controller; two PLCs are in mutual coordination

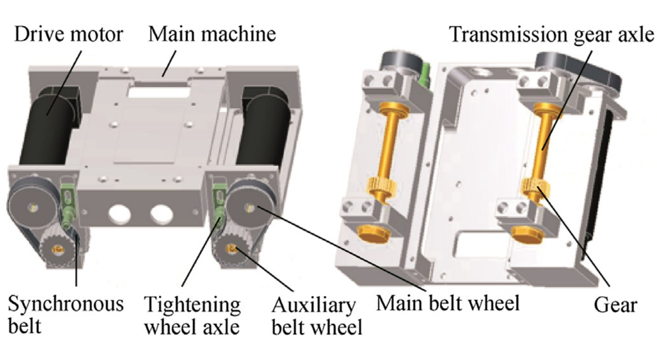

Fig. 4. Travelling mechanism model.

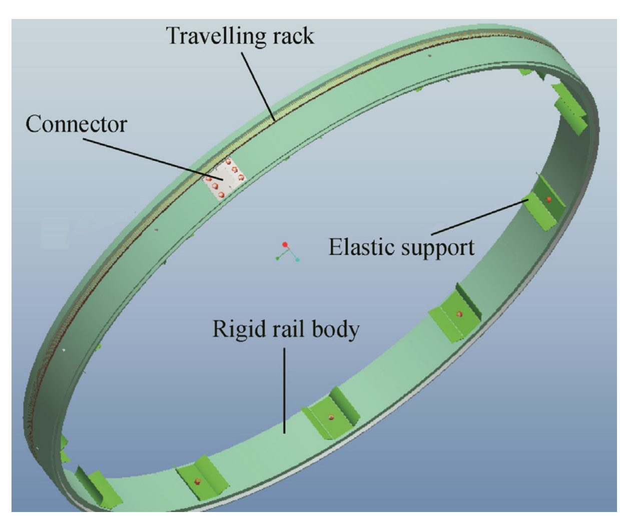

Fig. 5. Guide rail model.

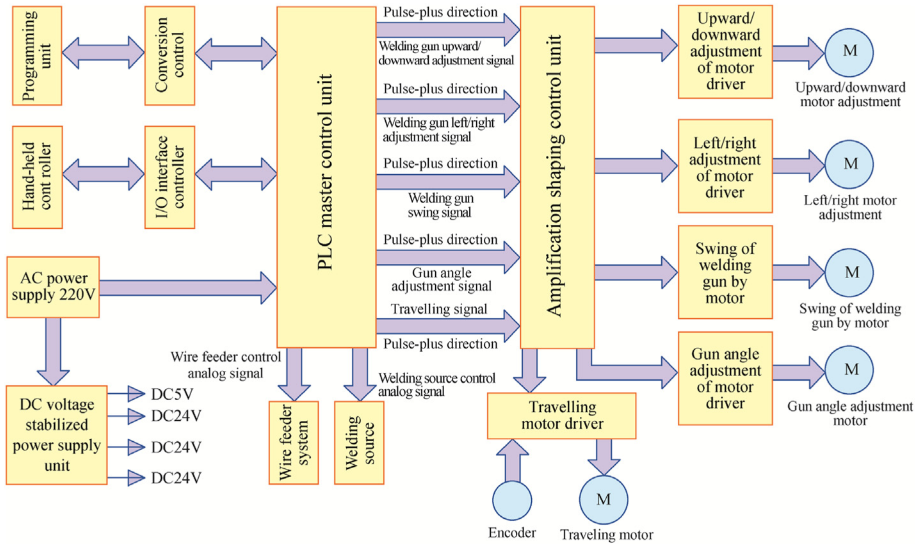

Fig. 6. Control system flow chart.

upon comprehensive consideration of PLC input and output ports to perform control jointly.

3. Automatic welding technology techniques of pipes by all-position self-shielded flux cored wires

Welding technologies comprise root welding, filling welding and cover welding, and are applicable to long-distance oil/gas pipelines made of X-80 steel; the welding torch is in plane swing with the amplitude set according to its groove width.

3.1. Groove determination

3.1.1. Groove types and parameters

The groove for the welding technique is in U-shape (Fig. 7).

U-shape groove parameters include: a groove is tangent with an arc at an angle (α) of 8°; the inner groove angle (β) is 37.5°; the height (h) is 1.2 5 mm ± 0.15 mm; the arc radius (R) is 3.2 mm; the root face (e) is 1.5 mm ± 0.15 mm; the staggered part of a joint is no more than 1.5 mm; the upper shed width (W) of a gapless pipe joint is 9.5 mm ± 0.2 mm.

3.1.2. Basis for groove parameter determination

Groove parameters of automatic welding by use of self-shielded flux cored wires are mainly determined on the basis of welding test data and effect.

1) The groove is narrow when $\alpha = 6°$ and $W = 8.5$ mm, hot welding and filling welding can take straight row welding which doesn't need to swing the welding torch, high in deposition efficiency. But it has the following problems: a. not good for molten iron detaching in bath, easy to cause slag inclusion and other defects; b. the wire is likely to contact the groove to ignite the arc during welding to cause unstable welding; and c. inconvenient deslagging increases deslagging time and labor intensity of welders.
2) Groove width is moderate when $\alpha = 8°$ and $W = 9.5$ mm, good for the formation of welded joints by hot welding, filling welding and cover welding, and can avoid slag inclusion, facilitating deslagging for welders and improving welding efficiency significantly.
3) Groove width is wide when $\alpha = 10°$ and $W = 10.5$ mm, good for molten iron detaching and slagging by welders, and the weld of hot welding looks nice. But this mode results in more filling welding layers, increasing welding material consumption and labor intensity of welders; in addition, wide groove structures require a large swing of a welding torch, likely to break the continuity and stability of bath to cause incomplete edge fusion, local dent of undercut and center of welded joint, serious drop of molten iron at an overhead position, resulting in poor formability.

3.2. Wire selection

The selection of wires is mainly based on welding test data and mechanical performance inspection results of welded joints. Hobart 81N1+ finished wires were selected as self-shielded flux cored wires for automatic welding through

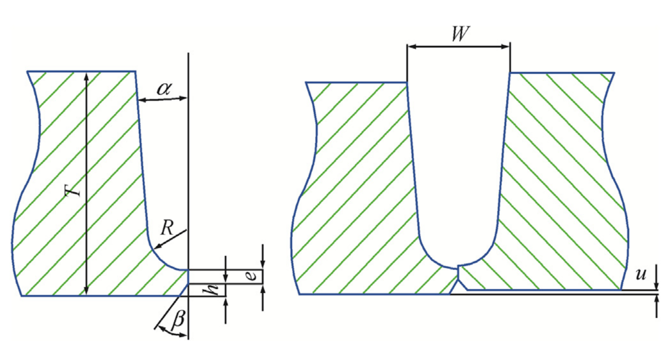

Fig. 7. Diagram of U-shape groove.

Table 1
The welding parameters of an automatic welding system by use of self-shielded flux cored wires.

Welding procedure	Welding equipment	Welding mode	Welding voltage/V	Welding current/A	Welding type	Wire feeding temperature/(mm·min^{-1})	Welding speed/(mm·min^{-1})	Shielding gas
Root welding	Internal welding machine	Multi-welding-torch sequence welding	18–20	200–220	BOHLER SG3-P Ø 0.9 mm solid wire with dry elongation between 15 and 20 mm	900–1000	700–800	Proportion of mixed gas: CO_2/Ar = 25%/75%; flow rate between 18 and 20 L/min
Hot welding	Automatic welding system by use of self-shielded flux cored wires	Single-welding-torch row welding	20–22	180–230	Hobart 81N1 + Ø 2.0 mm wire with dry elongation between 15 and 20 mm	1 700–1 800	400–500	Unnecessary
Filling welding	Automatic welding system by use of self-shielded flux cored wires	Single-welding-torch swing welding, swing speed between 21 and 24 mm/min; swing width between 5.0 and 6.5 mm; edge stay time between 450 and 550 ms	21–24	180–230	Hobart 81N1 + Ø 2.0 mm wire with dry elongation between 15 and 20 mm	1 500–2 390	125–250	Unnecessary
Cover welding	Automatic welding system by use of self-shielded flux cored wires	Single-welding-torch swing welding, swing speed between 23 and 26 mm/min; swing width between 8.0 and 10.0 mm; edge stay time between 450 and 550 ms	20–21	180–230	Hobart 81N1 + Ø 2.0 mm wire with dry elongation between 15 and 20 mm	1 250–2 000	115–210	Unnecessary

Table 2
Impact test results for welded joints and thermal effect area of automatic welding by self-shielded flux cored wires.

Specimen no.	Specimen type	Test temperature/°C	Energy absorbed/J	
			Single value	Average value
C1	Welded joint center Transverse	−10	223.5 155.0 121.5	166.5
C2	Fusion line Transverse	−10	219.5 202.0 153.0	191.55
C3	Welded joint center Transverse	−10	141.0 166.0 132.0	146.0
C4	Fusion line Transverse	−10	131.5 207.5 243.0	194.0

many indoor and outdoor welding tests since the wire features high arc stability, sound welded joint formability and detachability.

3.3. Welding parameters

3.3.1. Welding equipment

Welding equipment for an automatic welding technique by use of self-shielded flux cored wires include: one internal welding machine, a set of automatic welding system by use of self-shielded flux cored wires (including two welding carriers, two welding sources and two wire feeders).

3.3.2. Welding parameters

See Table 1 for welding parameters of the automatic welding system by use of self-shielded flux cored wires.

The following issues shall be paid attention to in hot welding, filling welding and cover welding: point 0 to point 2 welding section features plane welding, welding voltage and current should be slightly higher; point 2 to point 4 welding section features vertical welding, the bath is unstable and molten iron is prone to fall, thus it is better to lower the welding voltage, increase the welding current or welding speed properly; point 4 to point 6 welding section features overhead welding, the welding voltage and current should be low, and the welding speed should be relatively slow.

4. Test results

It has been proved by tests that automatic welding by use of self-shielded flux cored wires features stable process and sound formation of welded joints. Tensile strength, lateral bending performance, rigidity, impact power and other mechanical performance of welding joints comply with the X-80 pipe steel welding standard. See Table 2 for the impact test for welded joints and thermal effect area. In addition, automatic welding by use of self-shielded flux cored wires further lowers the labor intensity of welders, effectively avoids inconvenience of gas supply in welding, and lowers overall pipe welding cost.

5. Conclusions and suggestions

1) The automatic welding system of pipes by use of all-position self-shielded flux cored wires features an overall stable performance, a high wind resistance and a smooth welding process.
2) The automatic welding system of pipes by use of all-position self-shielded flux cored wires improves the continuity and stability of a welding process significantly, ensures the inherent quality and appearance formation of a welding joint, further lowers the labor intensity of welders and the overall pipe welding cost.
3) The automatic welding technique of pipes by use of all-position self-shielded flux cored wires is prepared properly. Performance indicators of welded joints meet the requirements of the pipe project construction-related standard. It is a welding technique featuring low cost and high efficiency in the pipe welding field.
4) Automatic welding of pipes by use of all-position self-shielded flux cored wires uses the current finished flux cored wires; though all the performance parameters meet the requirements of the relevant welding standards, it is suggested that further research be conducted on special self-shielded flux cored wires applicable to automatic welding to achieve better welding effect.

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