Study on automatic welding technology of single-side welding and double-side forming of large diameter steel

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Abstract: The installation of penstocks in the construction of water conservancy and hydropower projects should be a key link in the quality control of hydropower projects. It is of great significance to the stability and safety of hydropower projects. Based on the construction process requirements of the steel pipe in the tunnel of a water conservancy project in South China, this paper has developed an all-position automatic welding technology of single-sided welding and double-sided forming of the inner circumferential seam of a super large diameter steel pipe after many tests, and analyzed the factors affecting the welding quality. After repeated trials and adjustments of process parameters, a lower welding voltage (small molten pool) and a larger welding current (guaranteed penetration) are used to ensure a certain deposition efficiency, and finally stable welding quality is achieved. It has certain reference significance for the improvement and improvement of the automatic welding technology of single-side welding and double-side forming of large-diameter steel pipes.

1. Introduction
The important goal of water conservancy and hydropower project construction is to hope to gather a large amount of hydropower resources. Therefore, an important part is the transportation of water resources[1-4]. The application of steel pipes is indispensable in the construction of related pipelines. Therefore, the world's related penstocks, especially the large-diameter penstock manufacturing technology, has developed rapidly, and has generally received extensive attention from the industry[5-8]. The installation of penstocks should be a key link in the quality control of hydropower project construction. It has important significance for the smoothness and safety of hydropower project operation. In the welding of penstock installation sites in water conservancy projects, CO2 gas shielded welding is usually used for inner and outer circumferential seam welding[9-14]. Although this welding process is relatively mature, it has high labor intensity and low efficiency, and requires extremely high level of welder's skill level, and the weld quality is greatly affected by the welder's mental state. In this paper, relying on a water conservancy project in southern China, DN4800 penstocks are installed in the DN5400 tunnel, requiring a stiffening ring with a height of 120 mm on the outer wall of the steel pipe. Therefore, the welding of the installation seam can only be done by single-sided welding and double-sided forming all-position welding. For this reason, it is planned to use the Pipe Welding Robot automatic welding robot to carry out the experimental research on the all-position automatic welding technology of single-sided welding and double-sided forming of the inner circumferential seam of large diameter steel pipes, so as to obtain reasonable process parameters and provide technical support.
for engineering applications.

2. Test conditions

2.1. Equipment performance

The welding input power of the welder is 2-phase 220V±20%, 50/60 Hz alternating current, and the input capacity is 23 kV. The actual welding robot is shown in Figure 1, and the equipment performance is shown in Table 1.

![Figure 1. The welding robot](image)

| Equipment performance index | index                           |
|-----------------------------|--------------------------------|
| Wire reel specifications    | 5 kg                           |
| Wire feeding speed range    | 0-190 cm/min(0~750IPM)         |
| Swing speed                 | 0~254 cm/min(0~1001PM)         |
| Stay time on both sides     | 0~1s                           |
| Swing wide                  | 0~50 mm(2")                    |
| Horizontal adjustment range | 50 mm(2")                      |
| Up and down adjustment range| 50 mm(2”), The position of the welding gun can be changed to weld thick-walled pipes |
| Moving speed of machine head| 0~762 mm/min(300 1PM)          |
| Rated current of welding gun| 300A100% Duty cycle            |
| cable length                | 5 m(20’), Can be lengthened    |
| Pitch angle of welding gun  | ±30o                           |
| Deflection angle of welding gun | ±30o                          |
| Weight of machine head      | 14 kg                          |
| Volume (L×W×H)              | 524 mm×524 mm×250 mm           |

2.2. Base metal and groove process

The test base material is Q345 B, the base material thickness is 16mm, the test pipe diameter is DN2500, and the paired groove form is shown in Figure 2.
2.3. welding consumables
The selection of welding consumables is shown in Table 2.

| Welding level   | Welding wire material               | Model specification                  |
|-----------------|-------------------------------------|--------------------------------------|
| Root welding    | Metal powder cored welding wire ACL-X52 | AWS grade E70C-G, diameter Φ1.2 mm   |
| Wall surface    | Flux cored wire AFL-71M             | AWS grade E71T-1M, diameter Φ1.2 mm |

2.4. Shielding gas
The shielding gas is a mixed gas, with a composition of 80% Ar + 20% CO₂, in which the purity of Ar gas is greater than 99.99%, and the purity of CO₂ gas Greater than 99.96%.

3. Welding process parameter setting and forming quality
3.1. welding parameter setting and forming quality
According to the power supply characteristics of the welding machine and the forming characteristics of the welding wire, the root welding adopts downward welding (0° is set at the overhead welding position). Due to droplet's own weight The area of 0°~180° is divided into 6 areas, area 1 (0°~20°) is the upper welding zone, and area 2 (20°~40°) is the upper transition zone. Area 3 (40°~120°) is the vertical welding zone, area 4 (120°~160°) is the vertical flat transition zone, and area 5 (140°~160°) is the vertical flat transition zone. Domain 6 (160°~180°) is the flat welding area. Combining the quality of the groove group on site, the parameter settings of different areas are shown in Table 3. The front side and back side of root welding are shown in Figure 3 and Figure 4.

| Area | Wire feeding speed/ipm | walking speed/mmpm | Swing speed/mpm | Swing amplitude/mm | Bilateral delay/s | Compensation /V | Current/A | Voltage/V |
|------|------------------------|--------------------|-----------------|-------------------|-------------------|-----------------|-----------|-----------|
| 1    | 150                    | 230                | 1.80            | 2.5               | 0.20              | -0.5            | 130       | 14.5      |
| 2    | 160                    | 220                | 1.60            | 2.6               | 0.15              | -0.5            | 135       | 14.5      |
| 3    | 180                    | 250                | 1.61            | 2.5               | 0.10              | -1.3            | 140       | 14.5      |
| 4    | 170                    | 245                | 1.60            | 3.0               | 0.13              | -1.3            | 145       | 14.5      |
| 5    | 160                    | 225                | 1.70            | 3.2               | 0.20              | -1.9            | 150       | 14.5      |
| 6    | 155                    | 215                | 1.80            | 3.0               | 0.26              | -2.5            | 167       | 14.5      |
3.2. Filler welding technology and forming quality

According to the power supply characteristics of the welding machine and the forming characteristics of the welding wire, upward welding (0° set at the flat welding position) is used for fill welding. When filling welding, the 0°~180° area is divided into 3 areas, area 1 (0°~70°) is the flat welding area, area 2 (70°~140°) is the vertical welding area, and area 3 (140°~ 180°) is the upper welding zone. Combining the width of the weld bead on site, the parameter settings of different areas are shown in Table 4, and the filling quality is shown in Figure 5.

| Process   | Area | Wire feeding speed /ipm | Walking speed /mm/m | Swing speed /mpm | Swing amplitude /mm | Bilateral delay/s | Compensation /V | Current /A | Voltage /V |
|-----------|------|-------------------------|---------------------|------------------|--------------------|-------------------|-----------------|------------|------------|
| Hot welding | 1    | 180                     | 180                 | 1.30             | 5.5                | 0.45              | 0               | 210        | 21.5       |
|           | 2    | 165                     | 165                 | 1.30             | 6.5                | 0.50              | 0               | 210        | 21.5       |
|           | 3    | 173                     | 173                 | 1.30             | 6.1                | 0.45              | 0               | 210        | 21.5       |
| Fill 2    | 1    | 150                     | 150                 | 1.30             | 8.0                | 0.45              | 0               | 210        | 21.5       |
|           | 2    | 140                     | 140                 | 1.30             | 9.0                | 0.50              | 0               | 210        | 21.5       |
|           | 3    | 145                     | 145                 | 1.30             | 8.5                | 0.45              | 0               | 210        | 21.5       |
3.3. Filler welding technology and forming quality
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![Figure 6. Forming quality of cover welding](image)

| Process | Area | Wire feeding speed /ipm | Walking speed /mmpm | Swing speed /mpm | Swing amplitude /mm | Bilateral delay/s | Compensation/ V | Current/ A | Voltage/ V |
|---------|------|-------------------------|---------------------|------------------|--------------------|------------------|----------------|------------|------------|
| Cover welding | 1 | 290 | 110 | 1.30 | 14.0 | 0.40 | 0 | 210 | 21.5 |
| | 2 | 260 | 105 | 1.30 | 15.0 | 0.40 | 0 | 210 | 21.5 |
| | 3 | 270 | 113 | 1.30 | 14.5 | 0.40 | 0 | 210 | 21.5 |

4. Welding procedure qualification
Before the mechanical performance test, the weld bead is tested by UT and RT. Through the inspection statistics of multiple weld beads, the pass rate of the weld bead quality is accepted at one time. Exceed100%. After sampling the weld bead at each location and submitting it for inspection, the test results show that the welding procedure is qualified.

5. Analysis of factors affecting welding quality
(1) Before this technology was successfully developed, the bending test of the vertical welding zone and the vertical flat transition zone failed many times. After comparative experiments, it is found that the root is mainly The fusion of the weld bead is not good. There are many and complex factors that affect welding quality. After a summary, there are mainly the following 11 items.

(2) Groove quality and assembly quality The processing quality and the quality of the groove will directly affect the forming quality of the weld bead. In this item, the root welding of the inner ring seam single-sided welding and double-sided forming Quality requires higher bevel quality. The groove group requires a clearance of 3~4 mm, a blunt edge of 2 mm, and a groove angle of not less than one
side 250. If possible, the groove should be machined.

3) Welding walking speed The parameter setting of the welding speed during root welding depends on the size of the gap between the groove groups, the wire feeding speed and the welding phase. The larger the gap, the lower the speed. Fast wire feeding speed means faster walking speed, lower speed for overhead welding and flat welding, and higher speed for vertical welding. When filling the cover, the walking speed refers to the root weld.

4) Wire feeding speed Due to the use of downward welding during root welding, the parameter setting of the wire feeding speed depends on the size of the gap between the groove sets and the welding phase, and the larger the gap, the speed smaller, larger blunt side, higher speed, lower speed for overhead welding, lower speed for vertical welding. In filling and cap welding, the wire feeding speed is generally 100 ipm higher than that of root welding, and the speed of flat welding is the largest, followed by overhead welding, and the smallest vertical welding.

5) Swing The swing amplitude of root welding depends on the welding phase. The swing amplitude of overhead welding is large, while vertical welding is small. When filling and cover welding, each layer of weld bead is based on the size of the groove, The swing amplitude increases layer by layer, and vertical welding is the largest, followed by overhead welding, and flat welding is the smallest.

6) Swing speed The swing speed of root welding depends on the welding phase. The speed of overhead welding is higher than that of vertical welding. The swing speed remains almost unchanged during filling and cap welding, and the speed The degree is smaller than that of root welding.

7) Voltage The voltage during root welding is set to compensate pressure, overhead welding is small, vertical welding is the second, and flat welding is the largest. Because of the use of flux-cored welding wire when filling the cover surface, there is no need to set up compensation The voltage remains the same.

8) Bilateral delay The bilateral delay of the welding gun depends on the welding phase. In root welding, the bilateral delay of overhead welding is the longest, followed by flat welding, and vertical welding is the shortest. Fill cover At this time, the bilateral delay of overhead welding is the shortest, followed by flat welding, and vertical welding is the longest. The bilateral delay during filling is the longest overall, followed by root welding and the shortest cover.

9) Welding material factors In this experiment, a solid wire ER70S-6 was used for root welding. The root welding efficiency is lower than that of metal powder cored wire. Use drug core when filling The welding wire E71T-1C is welded, and the weld bead will not be formed in the end. When welding, the welding material should be the welding material suitable for all-position welding of the pipeline.

10) Gas composition and quality In order to create a sharp contrast, CO₂ gas was used as the shielding gas during the test, which caused more splashes during welding and was prone to pores. protection The gas flow is usually set to 20-30 L/min. When the gas flow is insufficient, a large number of pores will be produced. When Ar and CO₂ in the mixed gas When the body purity is less than 99.99% and 99.96%, a large number of stomata will also be produced.

11) Spot welding position In addition to the group of grooves that have a greater impact on the quality of the internal quality of the weld bead, it was found during the process test that the position of the spot welding Unfused defects often appear between them. By observing the internal conditions of the defects, we can use the method of lengthening the spot welding length and skipping the spot welding position during root welding. Method, proved that this process is feasible after many tests.

12) Welding joints Because the welding process will inevitably be stopped, such as changing the welding wire or changing the position, there will be many welding joints, The frequency of defects is also higher. After many tests, the welding joints were polished before welding to improve the fusion between the joints.

6. Conclusion

(1) The root welding process of the inner circumferential seam of penstocks with single-sided welding and double-sided forming all-position welding process is the focus of the entire process test.
(2) After many parameter experiments and researches, the all-position automatic welding technology of single-sided welding and double-sided forming of the inner circumferential seam of super large diameter steel pipes has been developed.

(3) After repeated trials and adjustments of process parameters, under the condition of ensuring a certain deposition efficiency, a lower welding voltage (small molten pool) and a larger welding current (guaranteed penetration) are used to finally achieve a stable welding quality.

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