Research on automatic welding equipment and technology of pipeline in mountain area

Feng Zhang¹, Xiaowen Liu¹, Xinxin Xu², Yi Zhang¹, Lianshan Niu¹

(1. Pipeline Research Institute of CNPC, Langfang 065001, China; 2. The Third Engineering Company of CNPC, Zhengzhou 451450, China)

Abstract: It is a difficult issue during large diameter long distance pipeline laying process to implement Pipeline welding construction under the condition of steep slope. Traditional welding method is of low construction efficiency; meanwhile defects like porosity, slag inclusion & incomplete fusion are prone to be found. Automatic pipeline welding under the condition of 30° longitudinal grade is achieved through improvements in equipment and process parameters. This article analyzes technical difficult points of automatic welding in mountain area and introduces an equipment and techniques designed for automatic pipeline welding in mountain area. Welding test was taken through which it is showed that the welding equipment and welding method is able to adapt to welding under the condition of 30° longitudinal grade. Welding quality is guaranteed while welding efficiency is raised by a big margin.

Key words: long-distance pipeline; welding on steep slope; automatic welding

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Preface

As the demand of energy increases in recent years, the step of pipeline construction is pacing fast¹. And new requirements are required in pipeline steel, pipe diameter and pipeline construction in the booming pipeline industry and facts shows that the welding efficiency and welding qualification rate of manual welding and semi-automatic welding are much lower than that of automatic welding. Thus it is imperative to promote the application of automatic welding². And in mountain and hilly areas, it is really a challenge in pipeline construction due to harsh terrain conditions, large longitudinal slope and narrow construction space. It is a new challenge to automatic welding equipment and welding process. The traditional slope pipeline construction used to adopt group welding method in the trenches inside the tube, the welding method used to be manual welding and semi-automatic welding STT³. Due to the longitudinal slope of the pipeline, the welding operation faces higher challenge, the molten bath is easily shift to the side groove in the process that affected by the gravity, defects like undercut at the upper seam, lower slag produced and incomplete fusion will happen if the electrodes were improperly transported, the weld quality is not easy to control and it is influenced by the performance of the welder⁴. By now, large slope area automatic welding technology research has been reported, in order to improve the operation efficiency, reduce labor costs and labor intensity, carry out automatic welding equipment and welding process is in the imperative.

1 Analysis of technical difficulties in automatic welding of pipeline in mountain area

1.1 Requirements of automatic welding equipment for pipeline construction in mountainous area

In all kinds of pipeline welding construction method, automatic welding has the advantages of simple, efficient and stable, amongst these methods machine guns to fill the primer and the external cover construction method is of high efficiency and widely used⁵. Restricted by the special working environment, the traditional automatic welding equipment is difficult to carry out construction work in the mountainous area.
Internal welding machine carries out the task in the pipe nozzle pair and root welding in the pipeline automatic welding work, the welding process and principle as shown in figure 1. After the positioning and tightening mechanism complete the pairing of nozzles, the rotating disc which controls eight welding units (CW1-CW4, CCW1-CCW4) will rotate and complete the CW and CCW welding in two directions respectively. In the mountainous area, due to the influence of the longitudinal slope, the internal welding machine is easy to slip in the process of working, even have the risk of internal welding machine slipping which will lead to the failure of nozzle pairing; in the larger slope area, when the internal welding machine stop, it will glide, and that will affect the centering of welding gun in welding unit and lead to defects like welding seam bias, heat welding burning through. Therefore, in the construction of automatic pipeline welding in mountainous area, the internal welding machine must have enough driving force to ensure that it can walk up the slope, at the same time, it is necessary to have a good parking ability to ensure that the welding gun can be accurately positioned.

External welding machine is responsible for accomplishing external hot welding, padding and welding of cover layer. It is consisted of welding tractor, walking track, welding control system, welding gun and power system, and no special requirements are needed for external welding machine as long as the track is stable which can ensure the tractor running stably.

1.2 Requirements of automatic welding technology for pipeline construction in mountainous area

In addition to welding equipment, welding process is the main factor that affects the quality and efficiency of welding. How to overcome the influence of gravity flow of molten bath is the key to solve the problem of automatic welding in mountain area.

In the construction of automatic pipeline welding in mountainous area, the molten pool is in a special state of stress, assuming that the longitudinal slope is 30° degrees, the vertical position is taken as an example, the stress state of the molten pool is shown in figure 2. It can be seen that the molten pool is mainly affected by gravity $G$, arc force $F$. 

![Fig.1 Schematic diagram of welding process of internal welding machine](image)

![a CW Directional welding](image)

![a CCW Directional welding](image)

![Fig.2 Force analysis of molten bath in vertical welding position](image)

(a) Force analysis of longitudinal section of molten bath

(b) Force analysis of transverse section of molten bath

Fig.1 Schematic diagram of welding process of internal welding machine

Fig.2 Force analysis of molten bath in vertical welding position
and surface tension $\sigma$. The component force of gravity drive the molten bath flow below the arc hindered the arc heat input on the bottom of the groove, will lead to interlayer fusion defect; force gravity along the direction perpendicular to the direction of welding molten pool flow accumulation to drive the lower side of the groove, hindered the side arc groove heat transfer the side wall, will lead to defects of lack of fusion. At the same time, the molten bath affected by the the surface tension of the groove on both sides of the bottom and the surface tension of the concreting weld seam behind the molten bath, molten pool on the weld center symmetry should be maintained in the welding process thus the force is simplified as a force to the opposite direction. The arc force direction is affected by the angle of welding gun, as shown in a figure (a), while adjusting the welding gun toward the weld pool, the arc force can hinder the molten bath from shedding; in diagram (b), when the welding gun pointing to the higher side of the groove, the arc force can hinder the molten bath flowing to the lower side and pile up.

In order to ensure the quality of weld forming and weld quality, it is needed to reduce or avoid the impact of falling on the molten bath, and the falling of molten bath is mainly affected by the joint forces (by previous force analysis, gravity is the driving force of molten bath, by adjusting the angle of welding gun, arc force can be used as resistance force of falling the molten bath) and affected by the melting time in the molten bath (i.e. cooling time, the equivalent of the exercise time), thus reduce the gravity of the molten bath, increase arc force and speed up the cooling rate of molten bath are conducive to inhibit the molten bath from falling down. In the welding parameters, improve the welding speed, reduce the wire feed speed has advantageous to reduce the gravity of molten bath and shorten the cooling time, but at the same time the arc force is reduced accordingly. Hence, in the slope welding operation, meeting requirements of the welding speed and wire feeding speed is more strict and it is necessary to develop suitable welding parameters to meet the the weld seam quality requirements.

2 Automatic welding equipment and process optimization in mountainous area

In order to meet the construction requirements of pipeline automatic welding in mountainous area, CPP900 series automatic welding equipment and supporting process is optimized, CPP900 automatic welding equipment is the fruit of independent R&D production by China Petroleum Pipeline Bureau, it includes beveling machine, internal welding machine and external welding machine, and it has been widely used in Moda, Shan si, Zhong Jing and China and Russia East line etc, and it is well received by these customers, the automatic welding equipment used in this study is CPP900-IW48 internal welding machine and CPP900-W2 external welding machine. Using φ1219mm, 18.4mm thick X80 steel for pipe welding experiment, root welding method for GMAW-S (gas metal arc welding), BOEHLER SGB8-P (ER80S-G) φ1.0mm solid welding wire. 80%Ar+20%CO$_2$ is used as welding protective gas in internal and external welding. Using hydraulic lifting platform to simulate the large slope welding conditions, as shown in figure 3. The groove used in the test is shown in figure 4.

(a) Schematic diagram of test platform

(b) Welding test site

Fig.3 Test platform for simulating slope welding

Fig.4 Schematic diagram of the groove used in the experiment

2.1 Optimization of automatic pipeline welding equipment in mountain area

In order to ensure that the internal welding machine can climb smoothly and parking steadily in large slope, it is necessary to optimize the design of the internal welding machine running and braking mechanism. While the internal welding machine walks in the pipeline
steady (assuming with constant speed), the driving force provided by pneumatic motor (which is the driving wheel / rolling friction between pipe wall and static friction) is equal to sum of the axial component force by the gravity on the pipeline and the rolling friction force between the driven pulley of internal welding machine and the pipe wall. When the longitudinal slope increases, the component force of gravity in the axial increases, a greater driving force is needed for walking: when the driving force equals to the sliding friction between the pipe walls and the driving wheel, the driving wheel will start to slip, the welding machine will stagnate, therefore, at the same time of enhancing of the driving force, the sliding friction between the driven wheel and the tube wall should improve (i.e. the maximum driving force for internal welding machine).

The driving force for internal welding machine is provided by the pneumatic motor, thus improving the driving force required a greater torque of the pneumatic motor, and COOPER A8R336M is a replacement of A8R338M, the detailed parameters are shown in Table 1, the motor stall torque and the starting torque is increased by 65%. The sliding friction between the driving wheel of the internal welding machine and the tube wall is determined by the support pressure of walking supporting cylinder and friction coefficient between driving wheel and tube wall, the upper limit of supporting pressure is systemic pressure. The sliding friction coefficient is related to the material of contact subject and the surface smoothness, thus changing the surface material of driving wheel and its lines can increase the sliding friction, reduce the risk of slipping of driven wheel. Carry out the same modification to the brake disc, the stopping ability of the internal welding machine has also been significantly improved, so that the internal welding machine can meet the requirements of the welding pairing and welding requirements of slope with 30 degrees.

Table 1 Comparison of different types of pneumatic motor parameters

<table>
<thead>
<tr>
<th>Model</th>
<th>Maximum power speed/rpm</th>
<th>Free speed/rpm</th>
<th>Stall torque /N·m</th>
<th>Starting torque /N·m</th>
</tr>
</thead>
<tbody>
<tr>
<td>A8R338M</td>
<td>64</td>
<td>125</td>
<td>522</td>
<td>386</td>
</tr>
<tr>
<td>A8R336M</td>
<td>38</td>
<td>75</td>
<td>865</td>
<td>639</td>
</tr>
</tbody>
</table>

2.2 Optimization of automatic welding technology for pipeline in mountainous area

Previous experiments show that when the welding is in the condition of high slope, the defects often occur in the padding layer, in this study the technology optimization mainly focuses on welding in the padding layer. In the condition of 30 degree longitudinal gradient, perform experiments respectively by changing the wire feeding speed and welding speed. According to the numerical values in Table 2, the welding parameters are set up and 9 sets of welding experiments are carried out, each group has three repeated tests and qualified experiments and defects are shown in Table 2. After the experiment, the optimal welding parameters are obtained as the parameters of the fifth groups in table 2.

Figure 5 shows three typical weld seam comparison, three seams are the results of using different filling welding parameters, amongst them Fig(a) and (c) show unqualified seam and the defects are all incomplete fusion in vertical welding part, the sample is taken from the defect part. Fig(b) shows qualified welding seam taken from vertical welding. Comparing fig(a) and fig(b) , while the feeding speed and filling amount is decreased, welding layers increase accordingly. Although the area of molten bath is decreased, it can not hold the molten bath from falling down, thus incomplete fusion happened in the bottom and groove part of molten bath: compared fig(b) and fig(c), incomplete fusion was detected in the groove side wall of the padding layer even with the same filling amount and increased welding requirements.

Technical results show that:

The speed of wire feeding and welding is either too large or too small will affect the quality of the weld, resulting in the unqualified welding.

The main defect of the welding seam under the slope condition is that the side wall is incomplete fusion at the lower part of groove, and the defects are more seen in the padding layer in vertical welding part.

In this condition, the requirement of the groove size and the precision of the welding is higher, the groove should be strictly processed in accordance with the requirement of the size, and the clearance of the corresponding shall be less than 0.5 mm, and the maximum error shall be less than 1 mm.

In addition, setting different welding gun inclination test shows that if the welding gun angle is too large, it is not conducive to the formation of weld groove and fusion, in 30 degrees vertical slope conditions, suitable angle is 5° along the longitudinal angle and 7° along the horizontal angle, as shown in figure 6.

3 Conclusion

(1) Automatic welding construction has the characteristics of high efficiency and high quality. However, due to the limitation of equipment
(c) feeding speed 9.5~11 m/min Welding speed 450~550 mm/min

Fig.5  Macroscopic metallographic photographs of joints obtained by different welding parameters

and technology, manual or semi-automatic welding used to be adopted in mountainous area. In this study, through the optimization of equipment and technology, the automatic welding construction in the condition of 30 degree slope is realized. The welding efficiency is high, and the welding quality can meet the requirements of field testing.

(2) Automatic pipeline welding machine requires favorable climbing function and stable parking ability, by adopting CPP900-W48 internal welding machine and replace pneumatic motor for a larger torque, change material and lines of driving wheel thus increased the driving force as well as the friction coefficient so as to realize pipeline pairing and root welding in the condition of slope with 30 degrees.

(3) Solving the problem of molten bath falling is the key to realize automatic welding, adopting CPP900-W2 as external welding machine and adjusting technical parameters, Welding gun inclination can overcome such challenge and acquire qualified welding seam.

Reference: