



Design of Curvature Radius of Finishing Roll for Crimp JCO Formed Welded Pipe

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Abstract

JCO means that the cross-section of steel pipe forms geometric shapes such as J, C and O in turn. The steel pipe blank directly formed by crimp JCO process has flat area along the edge of the pipe blank seam, which affects the quality of final pipe product. It is necessary to eliminate the flat area along the pipe seam by finishing process. In order to meet requirements of finishing process, it is necessary to optimize the roll surface curvature radius of finishing roll. Aiming at the design requirement of finishing roll for straight seam welded pipe forming, the optimum calculation method and result of roll surface curvature radius of finishing roll were obtained by using the theoretical analysis of metal sheet plastic forming. The result was successfully used in actual production.

Subject Areas

Mechanical Engineering

Keywords

LSAW Pipe, Edge Finishing Roller, Curvature Radius, Optimal Design, JCO Forming

1. Introduction

In the past two decades, due to the large-scale construction of oil and gas pipelines in China, the LSAW (Longitudinal submerged arc welded) pipe industry has developed rapidly. JCOE technology has been widely applied and developed. There are many technical studies on JCOE technology. For example, some researchers have studied the optimal design of punch parameters for JCO forming of X80 pipeline steel by finite element method. It is revealed that the springback varies with the radius of the punch and the shape of the blank [1]. Pre-bending,

JCO forming and mechanical expanding were taken as research objects [2], and the optimal scheme of JCOE forming process parameters and die parameters was obtained. E means expansion of pipe diameter by mechanical or hydraulic method. In addition, through theoretical analysis of progressive bending process, the mathematical models of asymmetric bending and symmetrical bending in free bending were established respectively [3], and a series of analytical expressions between bending force, bending radius and bending angle in sheet metal bending are established. The pre-bending process of JCO is studied based on the theory of small deformation bending and theoretical analysis [4], and the analytical formulas of pre-bending angle before springback, pre-bending angle after springback, pre-bending die stroke and pre-bending forming force are derived. The forming process of these research objects is progressive die-pressing JCO process, which is different from the coiled JCO process described below.

The crimp JCO forming technology is to form steel pipe blank by crimping steel plate with mandrel. This technology originates from abroad and is suitable for the production of super large diameter straight seam welded pipe. After the introduction of this technology, the steel pipe production of a series of major projects in China and abroad has been completed through further development [5]. In order to ensure the production of tens of thousands of tons of large diameter steel pipes in a short time and ensure the quality, a series of problems need to be solved in the production process. In addition to design the forming mandrel of pipe, the finishing roll for pipe finishing process also needs to be designed. Because finishing is the way of rolling with upper and lower rollers, the surface curvature of finishing rollers is the core of design because the surface of the rollers is used to force bending the edge of the plate.

2. Introduction to Finishing Process of Crimp JCOE Steel Pipe

For the crimp JCOE process, there is no pre-bending process in the whole process, and there is a flat area along the longitudinal edge of pipe opening after forming. The length of the flat area along pipe seam varies with the diameter of the pipe. The existence of flat area at edges leads to an increase in the rate of non-conformity. In order to eliminate the flat area, a finishing process was added after the pipe blank was formed, and a pair of finishing rolls were used to finish the longitudinal pipe edge to form the ideal cylindrical shape of the whole tube blank. The so-called finishing proposed here is relative to the pre-bending of the edge of tube blank in UOE process.

The finishing principle was shown in **Figure 1**, the edge of the pipe blank was clamped between the upper and lower rollers.

In **Figure 1**, the busbar of the upper roll working surface is a convex arc, while the busbar of the lower roll working surface is a concave arc. Choose suitable upper and lower rollers according to pipe blank diameter, adjust the roll gap slightly larger than the wall thickness of the pipe blank when finishing, so that the longitudinal seam of the pipe blank passes through the finishing roll, and the

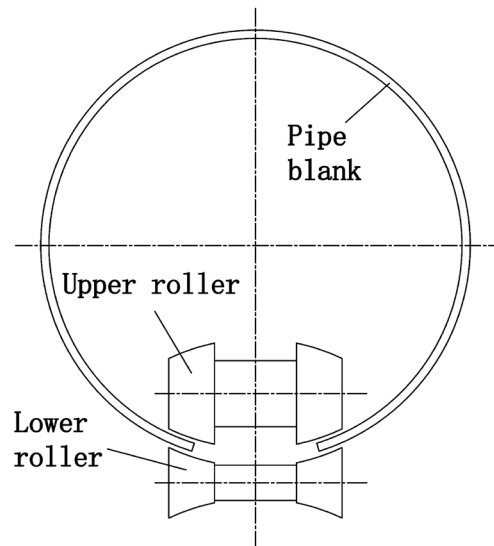


Figure 1. Diagram of crimp JCOE steel pipe finishing.

roll rotates to drive the pipe blank forward and finish the finishing.

3. Design of Roll Surface Curvature Radius of Finishing Roller

3.1. Determination of Pipe Blank Diameter

The diameter of pipe blank is directly related to the selection of finishing roll, and the ideal diameter of pipe blank is mainly determined by the expanding ratio. The diameter of pipe blank formed according to the expanding ratio shall satisfy the following relationship:

$$D = \frac{D_{out}}{1+k} \quad (1)$$

where D is the ideal diameter of pipe blank after pipe forming, D_{out} is nominal outside diameter of pipe, k is expanding ratio.

The above calculation can get the ideal diameter of steel pipe forming. In fact, the actual diameter of steel pipe forming after forming depends on the diameter of forming mandrel. In actual production, because the strength and thickness of steel plate fluctuate, there is a deviation between the actual diameter of pipe blank formed by forming mandrel and the ideal result calculated by the above formula. In order to reduce the residual stress and improve the forming quality, the size of pipe blank opening must be considered when choosing the specific diameter of forming mandrel [6]. In order to simplify the problem, the parameters of finishing roll are calculated according to the ideal diameter of steel pipe.

3.2. Parameter Design and Calculation of Finishing Roller

When choosing finishing roll, the influence of pipe wall thickness shall be considered. As can be seen from **Figure 1**, the upper and lower rollers contact with the inner and outer surfaces of the pipe blank respectively, and the corresponding curvature radius is different. The effect of wall thickness is more obvious

when producing smaller diameter or submarine pipelines with thicker thickness. When the springback is not considered, the relationship between the pipe blank after finishing and the curvature radius of the finishing roll surface is satisfied, as shown in **Figure 2**. The upper and lower rollers are explained separately below.

For upper rollers, the curvature radius of roll surface is related to wall thickness of steel pipe as follows:

$$r_u = \frac{D - 2t}{2} \quad (2)$$

where r_u is the curvature radius of upper roll surface, D is the diameter of pipe blank and the t is nominal wall thickness of steel pipe.

For the lower roll, the curvature radius of roll surface is related to wall thickness of steel tube as follows:

$$r_d = \frac{D}{2} \quad (3)$$

where r_d is the curvature radius of lower roll surface, D is the diameter of pipe blank.

The springback of steel sheet is unavoidable for the bending process of materials, and has a great influence on the shape of parts [7] [8] [9]. The bending process of steel plate can be solved by analytic method because of its simple shape.

For finishing process, because the width of flat edge of pipe blank is generally 30 mm to 50 mm, the springback of steel plate is relatively small when the yield strength is low, if the requirement is not high, the springback can be ignored. If the yield strength of material is very high, the springback effect will increase correspondingly, which will lead to the increase of weld defect rate of steel pipe. Therefore, when the high quality of edge finishing is required, it can be treated as following method.

Set r_0 as the bending radius of the neutral layer before rebound of the steel plate as shown in **Figure 2**. If the bending radius of the springback neutral layer is r_1 , without considering the effect of work hardening, the relationship is as

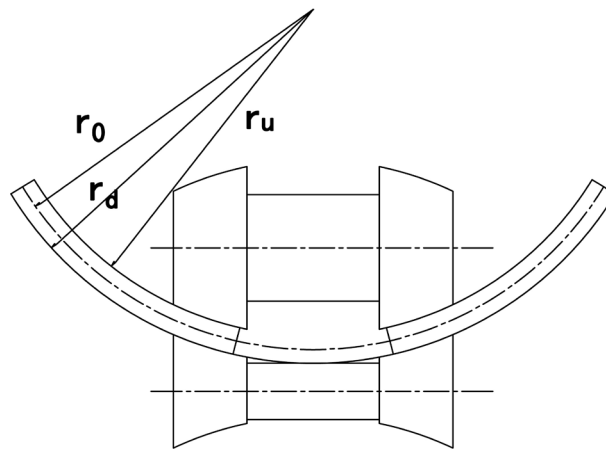


Figure 2. Dimension relation of pipe blank finishing process.

follows [10]:

$$\frac{1}{r_0} - \frac{1}{r_1} = \frac{3\sigma_s}{Et} \quad (4)$$

where σ_s is yielding strength of material, E is the modulus of elasticity and t is the thickness of steel plate or wall thickness of pipe blank. After transformation, it can be obtained:

$$r_0 = \frac{r_1 Et}{Et + 3\sigma_s r_1} \quad (5)$$

Ideally, the curvature radius at outer surface opening of pipe blank after finishing should be equal to the radius of the pipe blank, that is, $D/2$, then $r_1 = (D-t)/2$. Bring r_1 expression into equation (5), we can get:

$$r_0 = \frac{Et(D-t)}{2Et + 3\sigma_s(D-t)} \quad (6)$$

As shown in **Figure 2**, because $r_u = r_0 - t/2$, the curvature radius of upper roll is obtained by introducing equation (6):

$$r_u = \frac{Et(D-t)}{2Et + 3\sigma_s(D-t)} - \frac{t}{2} \quad (7)$$

Because $r_d = r + t/2$, the lower roll curvature radius is obtained by introducing Equation (7):

$$r_d = \frac{Et(D-t)}{2Et + 3\sigma_s(D-t)} + \frac{t}{2} \quad (8)$$

Equation (9) Subtracts Equation (8) to get:

$$r_d - r_u = t \quad (9)$$

The ideal curvature radius of finishing roll can be calculated according to Equations (7) and (8). When calculating, MPa is used for yield strength unit, mm is used for diameter and wall thickness unit of steel tube, and mm is used for curvature radius unit. In this way, the curvature radius of the pipe blank after finishing process is the same as the curvature radius of the whole pipe blank, which fully meets the follow-up process requirements. The practical application also proves that the above analysis and calculation methods are correct and effective.

4. Design and Calculation Example of Curvature Radius of Finishing Roll

Panyu Pearl River Steel Pipe Group once produced 48 inches of submarine pipeline with longitudinal seam welded pipe, wall thickness is 20.6 mm, and minimum yield strength is 360 MPa. When the expansion rate k is 0.8%, the diameter of billet is calculated as follows according to Equation (1):

$$D = \frac{D_{out}}{1+k} = \frac{1219}{1+0.8\%} \approx 1209.3 \text{ mm}$$

The curvature radius of upper and lower roll busbar of finishing roll without considering springback is calculated according to Equations (2) and (3) as follows:

$$r_u = \frac{D - 2t}{2} = \frac{1209.3 - 2 \times 20.6}{2} \approx 584.1 \text{ mm}$$

$$r_d = \frac{D}{2} = \frac{1209.3}{2} \approx 604.7 \text{ mm}$$

The busbar curvature radii of finishing roll surface considering springback were calculated according to Equation (7) and Equation (8). The modulus of elasticity is 2.0×10^5 , the yield strength is 360 MPa, and the nominal thickness is 20.6 mm. The design calculation is as follows:

$$r_u \approx 503.9 \text{ mm}$$

$$r_d \approx 524.5 \text{ mm}$$

Through comparison, it can be seen that the curvature radius of finishing roll considering springback of steel plate is obviously smaller than that of finishing roll without springback. The reason is that in order to counteract the impact of springback, the bending degree of steel plate must be increased, so the curvature radius of finishing roll surface must be reduced.

5. Conclusions

The curvature radius of the flat edge of pipe seam after finishing should be the same as that of the pipe blank. Therefore, in order to verify the correctness of the above calculation results, it is necessary to compare with the forming mandrel used in the crimp JCO forming process. For a 48-inch submarine pipeline steel pipe with yield strength of 360 MPa and wall thickness of 20.6 mm, the radius of the mandrel used in actual production is 508 mm. The radius of the mandrel is slightly different from the curvature radius of the upper roll of the finishing roll. It is acceptable in the forming of this kind of super-large diameter pipe. Because the design of mandrel takes into account the production of steel pipes with different wall thickness specifications. Although there are some errors, it can reduce the number of dies, reduce costs, and make it easier to play the flexible features of crimp JCO forming.

According to the theory of sheet metal bending forming, using analytic method to meet the need of optimum design of finishing roll for LSAW pipe, the optimum design calculation method and results of calculating the curvature radius of finishing roll surface were obtained. The finishing roll designed on this basis has been put into operation, which proves that the results of design calculation are correct and reliable.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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