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Research on the Comprehensive Control Strategy of Over-welding Based on Decoupling- Design for Tandem Cold Mills

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Abstract

The strategies of the welding seam dynamic passing control and feasible loose edge rolling technology are put forward. In the process of cold mill welding, by dynamic regulation roll-gap, bending force and stand speed. The control strategy of reducing tensions between stands and strip edge is achieved. At the same time, the decoupling control strategy of plate shape and thickness can reduce the influence of roll-gap on plate shape and of bending force and stand speed on the steel thickness. Simulation analysis and practical application show that the technology effectively reduces the occurrence of steel strip fracture of tandem cold mill units.

Keywords: *tandem cold mills; decoupling- design; over-welding; loose edge rolling*

1. Introduction

On the production line of high-precision tandem cold milled strip steel, the production is always organized in the form of pickling-rolling combination line, with the head and tail of the strip steel welded together. The production is continuously transferred to the rolling of next volume of strip steel after the completion of the last volume of steel [1, 2]. If the specifications of the two volumes of steel are difference, it is required to change the specifications dynamically, but in the actual production, this case just accounts for less than 20% of the total. The case that the two volumes have the same specification is called “over-welding”.

Currently, the deceleration-over-welding is used in the over-welding of the tandem cold mill units, which cannot solve the problem fundamentally, but just minimize the loss of the weld-off, avoiding the serious production loss of roll explosion due to high-speed steel strip fracture of the weld. In order to reduce the occurrence of cold-rolled strip steel fracture, we need to actively adjust the control parameter of the tandem cold mill unit, thereby reducing the tension of the strip steel edge and the overall tension between the stands where the weld is.

This paper presents the techniques of viable tandem cold mill unit roll gap dynamic adjustment and loose edge rolling, and reduces the negative impact due to bending force and roll gap by decoupling control algorithm. Simulation studies and practice application show that this technology effectively reduces the occurrence of cold rolling weld strip fracture, while the product quality has been effectively controlled.

2. Loose Edge Rolling Control Strategy

During over-welding, if the flatness of strip steel between the stands is controlled to be bilateral waves, the purpose of the wide edge can also be achieved, which can avoid the tensile stress along the width direction of the steel being concentrated at the strip edges [3, 4].

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Adjusting the stand bending force can flexibly control the change of the flatness of the strip steel at the outlet of each stand, with the individual bending force dynamic adjustment. According to the formulas of strip steel flatness and strip crown increment at the outlet, we can get the formula to set the ith stand bending force adjustment amount, as shown in formula (1) [5,6].

(1)

Wherein δF_i is the bending force adjustment amount of the ith stand; K_F is the bending force horizontal stiffness of the ith stand; δC_{Hi} is the inlet strip crown changing amount of the ith stand; C_{hi} is the outlet strip crown changing amount of the ith stand; C_{Hi} is the inlet strip crown of the ith stand; C_{hi} is the outlet strip crown of the ith stand; H_i is the thickness of the strip steel at the inlet; hi ~~is the~~ thickness of the strip steel at the outlet; δH_i is the changing amount of the strip steel thickness at the inlet; δh_i is the changing amount of the strip steel thickness at the outlet; $\delta \varepsilon_{hi}$ is the changing amount of the strip steel flatness at the outlet; $\delta \varepsilon_{Hi}$ is the changing amount of the strip steel flatness at the inlet; η_i is the flatness genetic factor of the ith stand.

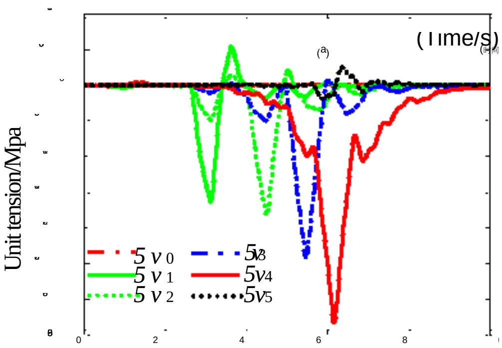
1.

In order to prevent the dramatic changes between the stands in the bending force adjustment, we must ensure that the change starting point and ending point of each stand corresponds to the same positions of the strip steel, as much as possible to ensure a minimum proportion strip crown fluctuation between different stands. The distance between the starting point of rolling force dynamic adjustment on each stand and the ith stand is shown in formula (2); The distance between the ending point of rolling force dynamic adjustment on each stand and the ith stand is shown in formula (3).

(2)

Wherein L_B is the total length of the set flatness change region of the stand at the end; hn is the outlet thickness of the stand at the end; ΔL_i is the distance between the bending force adjustment starting point of the ith stand to the ith stand; $\Delta L'_i$ is the distance between the bending force adjustment ending point of the ith stand to the ith stand.

The analysis is conducted for the over-welding of each bending force with MATLAB and the analysis result is shown in Figure 1, where, let's take L_B =2m; and the stand bending force adjustment amount δF_i=-10kN.


Unit tension/Mpa
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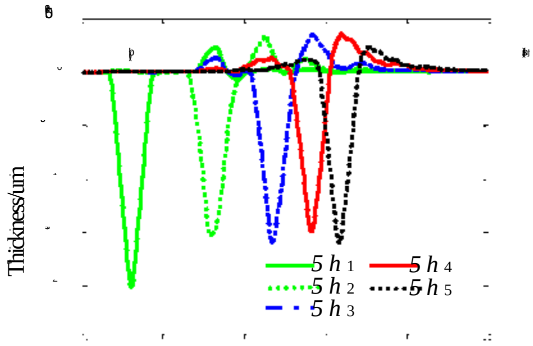
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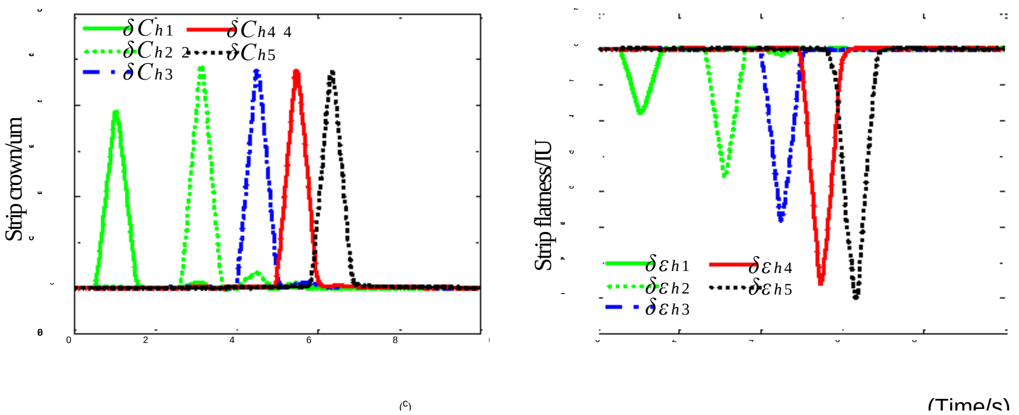

Figure 1. Dynamic Bending Reduction Over-welding Technology; a: Tension Change at the Outlet of Each Stand; b: Thickness Cange at the Outlet of Each Stand; c: Strip Crown Change at the Outlet of Each Stand; d: Flatness Change at the Outlet of Each Stand

As can be seen from the simulation analysis of Figure 1, the bending force of the stand where the dynamic adjustment weld is and the flatness of the strip steel at the outlet of each stand are developing into the trend of edge wave. The bending force can be set for each stand during over-welding according to formula (1), by which, the flatness change amount can be flexibly controlled between the stands and the concentration of stress on the edge of the strip steel can be reduced, thereby reducing the occurrence of strip fracture due to edge tear-off [7-9].

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3. Dynamic Adjustment of S1 Roll Gap Over-welding Control Strategy

When the roll gap is increased at S1,the outlet thickness of S1 increases, and when the thickness increasing points gradually pass the stands behind, the unit tension between each stand will be caused to decrease. This feature of tandem mill can be used to achieve the purpose of decreasing the regional unit tension where the weld is when reaching the over-welding [10, 11].

When the weld reach the distance of S before S1, gradually increase the roll gap of S1, when the weld is passing S1, the roll gap gradually restores to the original settings, making the strip steel forming a “diamond” with the center of weld, as shown in Figure 2.

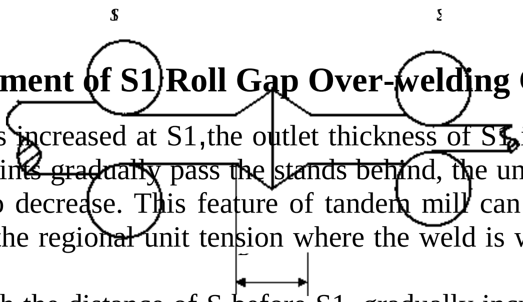

Figure 2. Schematic Diagram of S1 Roll Gap Adjustment, Strip Steel Forming a “Diamond Area”

For the stands behind S1, due to the inlet thickness increase, the tension at the outlet and inlet of the stand will be reduced and the strip crown will be increased, with the steel plate between the stands developing into the edge wave. These two trends will undoubtedly benefit to the smooth over-welding [12].

In order to ensure that when the head of the "diamond" area of S1 is coming out of the stand at the end, the tail is out of S4,according to the equation of L_D mass flow, the calculation of the length L_D of the "diamond" area of S1 is shown in formula (4).

$$\qquad (4)$$

Where: L_D— is the total length set for the diamond area; h_n is the outlet thickness of the stand at the end; L is the distance between the stands.

The simulation analysis is conducted to the adjustment of S1 roll gap over-welding control strategy with Matlab, in which, S1 bending force uses the flatness plate thickness decoupling control strategy to achieve the purpose of feed-forward control to the bending force of S1. The result of simulation analysis is shown in Figure 3, in which, wherein the roll gap increase amount of S1 is $\delta S_1 = 0.1H_1$.

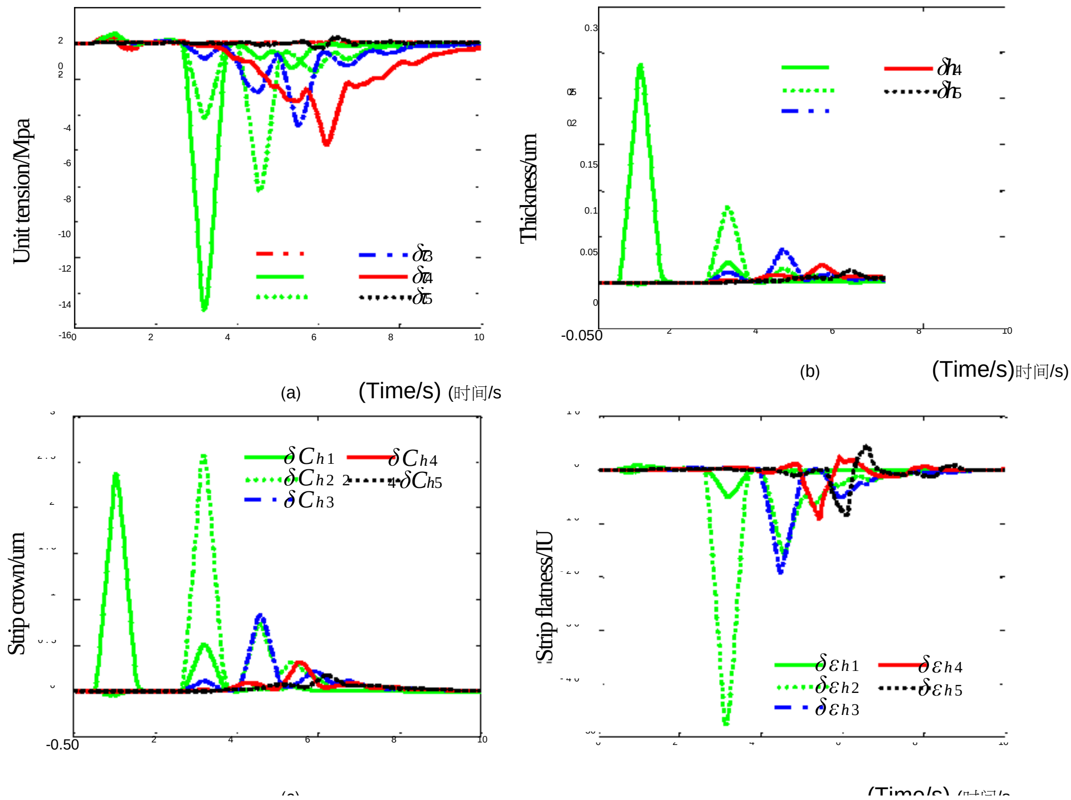

Figure 3. Dynamic Roll Gap Lifting Over-Welding Technology, [$\delta S_1 = 0.1H_1$]; a: Unit Tension Change at the Outlet of Each Stand; b: Thickness Change at the Outlet of Each Stand; c: Strip Crown Change at the Outlet of Each stand; d: Flatness Change at the Outlet of Each Stand

The roll gap of S1 is increase by dynamical adjustment to make the strip steel rolling direction form into a diamond, which can achieve the purpose of reducing the outlet tension of each stand. Except S1, the flatness of the strip steel at the outlets of other stands is developed into the trend of edge wave, conducive to the loose side rolling of the units in the downstream. If the bending force of S1 is also adjusted in the adjustment of S1 roll gap, then the flatness of the strip steel at the outlet of each stand will be in the trend of edge wave.

Notably, the method of reducing the unit tension and side tension stress between stands by adjusting roll gap can only be used for S1. This is because although adjusting the stands behind can reduce the tension of the outlet strip steel, but this will increase the inlet unit tension, which is not conducive to weld smooth passing[12].

4. Integrated Dynamic Control Over-welding Control

The two methods described above of improving weld passing rate of tandem cold milling by controlling angle: the method of dynamically adjusting the bending force and the method of dynamically adjusting S1 roll gap and relative velocity between the stands. The weld passing rate is improved by the two ideas of loose edge rolling and tension reduction between the two stands.

Singly using of a certain kind of dynamic over-welding method has some limitations:

1) Method of dynamically adjusting the bending force: as shown in Figure 1, the purpose of loose edge rolling can only be achieved by this method, which has little effect on the overall tension between the stands. This cannot effectively alleviate the main factors causing the weld strip fracture.

2) The method of dynamically adjusting the roll gap of S1: firstly the S1 roll gap adjustment amount cannot be too large. It can be seen from the simulation analysis of Figure 3, when the roll gap is adjusted to δS_1/=-0.1H_1(0.223mm), S1 outlet unit tension decreases by 15MPa. The outlet unit tension of S4 decreases by 6MPa. If the S1 roll gap is continuously to be increased, it will inevitably lead that the rolling pressure change of the units in the downstream is too large, not conducive to the stable rolling.

4.1. Over-welding Integrated Control Strategy

The integrated use of the over-welding control strategies of loose edge rolling and dynamically reducing the overall tension between the stands can achieve the high speed over-welding of tandem cold mills, improving the yielding of the units and the quality of the products.

(1) Systematic function structure of dynamic over-welding strategy

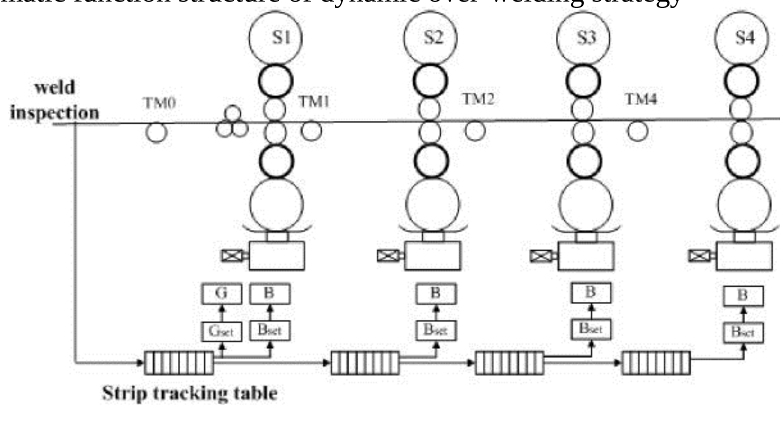

Figure 4. Systematic Function Structure of Dynamic Over-welding Strategy

Figure 4 presents the systematic function structure of dynamic over-welding process, where, G is the implementation inner seam of roll gap; B is the implementation inner seam of bending force; $_{GSET}$ is the over-welding roll gap giver; $_{BSET}$ is over-welding bending force giver; TMi is the ith stand outlet tension detector[13,14].

h h

L_D ' 1 3 L 1 3

h h

The dynamic over-welding method only adjusts the bending force of the four stands and the roll gap of S1. During dynamic adjustment, the output sequence of the S1 roll gap giver and the bending force giver is shown in Figure 5.

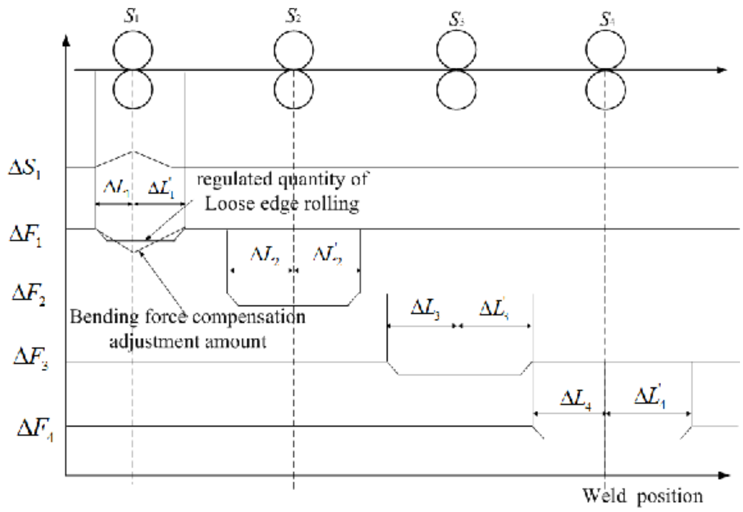

Figure 5. Giving Sequence of Dynamic Adjustment Amount

h

1) The length of S1 "diamond" area and roll gap variation

In order to ensure that when the head of the "diamond" area of S1 is coming out of the stand at the end, the tail is out of S4,according to the equation of L_D mass flow, the calculation of the length L_D of the "diamond" area of S1 is shown in formula (5).

h

' 3

h

The weld strip fracture is mainly concentrated at the first and S4 outlet. The improvement of weld passing rate is mainly to ensure the loose edge rolling of the first stand and S4. In order to ensure the minimal change of flatness at each the outlet of each unit, after determining the flatness adjustment amount of each stand, the bending force adjustment amount shall be calculated according to formula (1).

In the adjustment of S1 roll gap, S1 rolling force decreases and its outlet strip steel is in the trend of middle wave. Also, the adjustment of S1 bending force will affect the formation of the "diamond" area of S1 roll gap adjustment, which can be resolved by decoupling design with the decoupling control strategy on the flatness and plate thickness.

1

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The variation of the roll gap is represented with the highest thickness point in the center of the “diamond” area.

2) The variation of bending force dynamic adjustment area of each stand and bending force

In order to maintain the synchronized adjustment with the roll gap, the distance between the bending force dynamic adjustment starting point of each stand and the ith stand is shown as formula (6); the distance between the bending force dynamic adjustment ending point and the ith stand is shown as formula (7):

□L.□ (6)

1

(5)

4.2. Dynamic Over-welding Control Function Structure based on Decoupling Control

During dynamic over-welding process, except S1, only the bending force is adjusted. Roll gap and bending force adjustment process function structure in S1 over-welding are shown in Figure 6.

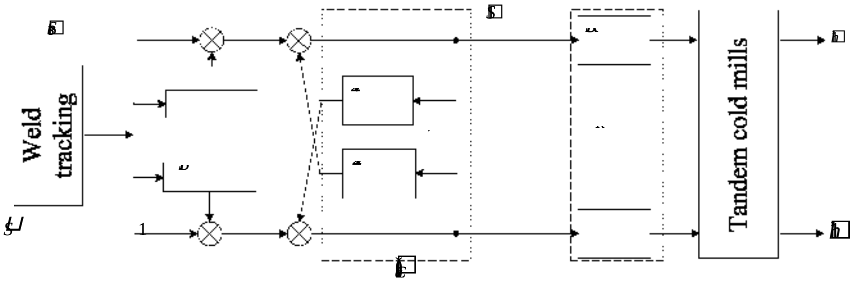

Figure 6. Adjustment Function Diagram of Roll Gap and Bending Force during S1 Over-welding Process

Wherein, S_S is the roll gap "diamond " generator; F_S is the bending force generator; V is the flatness and plate thickness decoupler; R is the hydraulic valve transfer function; δS_{set} is adjustment amount of the roll gap of each control loop, mm; δF_{set} is the bending force adjustment amount of each control loop, kN.

Decoupler V is responsible for the compensation of coupling affecting relationship between the flatness and thickness of S1 during over-welding process, making the strip steel from regular "diamond" lengthwise[15].; at the same time, avoiding the edge tensile stress concentration due to strip steel middle wave lead by the increase of S1 roll gap. The adjustment amount of roll gap and working bending force of each plate shape and thickness controlling aspects add to each other , and then we can get δS_{1D} and δF_{1D}, and then the calculation can be conducted in the decoulper, and the actual implementation inner seam correction amount of δS_1 and δF_1 can be obtained, as shown in formula (8).

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Wherein:

(8)

a_{h1}, a_{tf1}, a_{tb1}, a_{H1}, and a_{K1} are the partial difference coefficient of rolling pressure equations; C_{P1} is the longitudinal stiffness coefficient of S1 rolling force; C_{F1} is the longitudinal stiffness coefficient of bending force; K_{P1} is the lateral stiffness coefficient of S1 rolling force; K_{F1} is the lateral stiffness coefficient of S1 bending force[16].

Except S1, the bending force is just adjusted and there is no need to precisely control the thickness during over-welding, so only the bending force generator shall be designed. The bending force generator is the same as what shown in Figure 5.

4.3. Effect Analysis on Application of Dynamic Over-welding Control Strategy

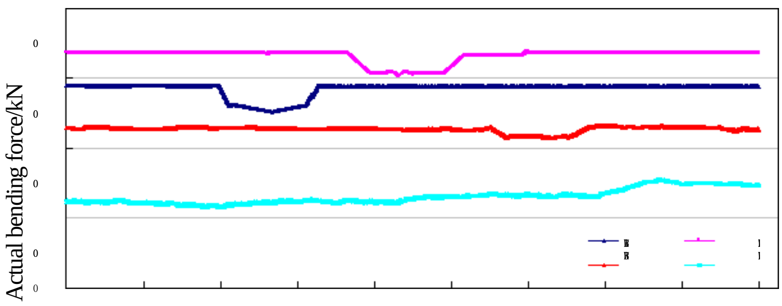
During dynamic over-welding process, except S1, only the bending force is adjusted. Roll gap and bending force adjustment process function structure in S1 over-welding are shown in Figure 6.

The test of the comprehensive over-welding control strategy of decoupling-based designed tandem cold mills developed in this paper has been conducted in a 1720mm large pickling tandem cold mill units, with the test steel of MGW1300, 1235mm width, material thickness of 2.00mm and finished product thickness of 0.5mm, and under the typical rolling schedule, the rolling process parameters measurement curves of a certain volume of strip steel stands are shown as figure 7.

The adjustment change amount of flatness and bending force for each stand is calculated according to formula (1), as shown in table 1. As the unit outlet tension is generally small and there is no occurrence for strip fracture. In order not to interfere with the normal operation of the flatness closed loop of the stand in the end, the adjustment is not conducted for the bending force and outlet flatness of the stand in the end.

Table 1. Adjustment Amount of Flatness and Bending Force for Each Stand

Stand	S1	S2	S3	S4
$\delta\varepsilon h_i$/IU	30	35	8	0
δF_i/kN	5.3	3.8	2.2	0



Sampling point

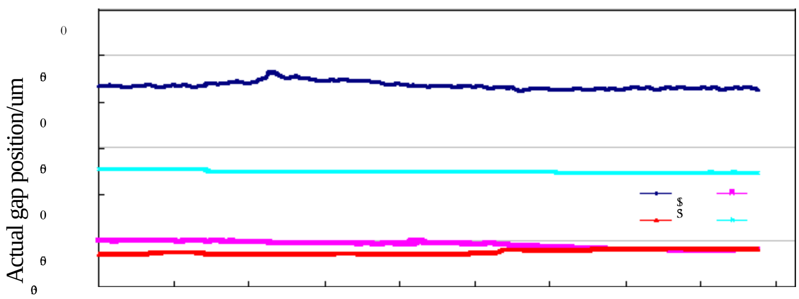
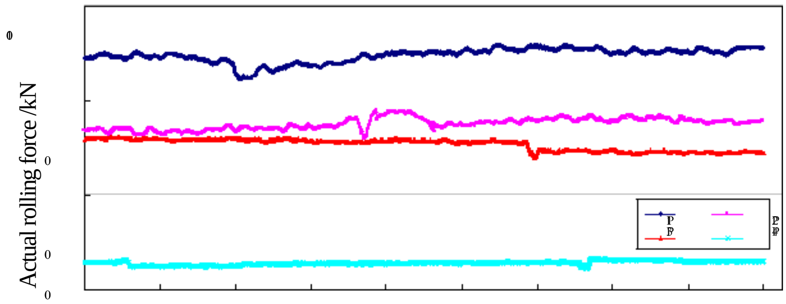


Figure 7. Measured Value Curve of Bending Force of Each Stand During Over-welding

Sampling point

Figure 8. Measured Value Curve of Opening Degree of Each Stand During Over-welding



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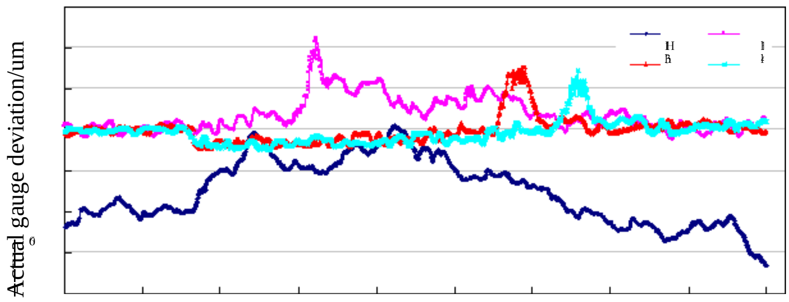

Figure 9. Measured Value Curve of Rolling Pressure of Each Stand During Over-welding

Sampling point

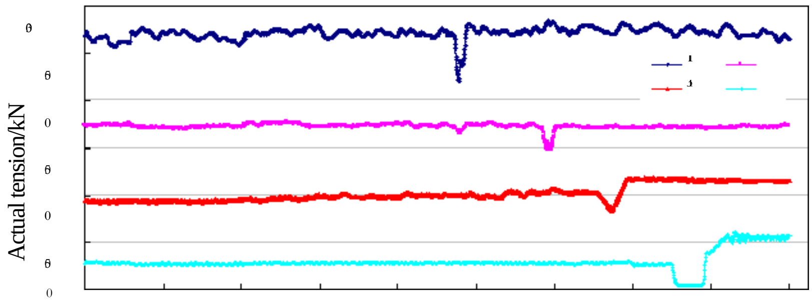

Figure 10. Measured Value Curve of Outlet Thickness of Each Stand During Over-welding

Sampling point

Figure 11. Measured Value Curve of Overall Outlet Tension of Each Stand during Over-welding

(1)Changing process of bending force

According to the set values in table 1, the bending force of each stand shall be dynamically adjusted in the weld area, with the measured value shown in figure 7. We can see that the adjustment amount of S1 bending force consists of two parts: adjustment amount of loose side rolling and adjustment amount of flatness and thickness decoupling bending force during S1 roll gap adjustment. The bending force of S2 and S4 shall be adjusted one by with the weld tracking, with the sampling point is circled by the time, so the bending force adjustment duration of each stand is the same. Since the dynamic adjustment is not conducted to the stand in the end, the variation of the bending force for the stand in the end is the adjusting amount of the flatness closed loop.

(2)Roll gap adjustment process

During over-welding, the opening degree for each stand is shown as Figure 8 and the overall adjustment amount of S1 roll gap is 120μm, with the opening degree of the remaining stands unchanged. The rolling pressure variation is shown as figure 9. The increase of S1 roll gap causes the decrease of S1 rolling pressure by about 500kN. S4 rolling pressure increases and S4 rolling pressure is essentially the same. The stand in the end uses the rolling pressure closed loop, of which, the measure pressure is stable. Figure 10 presents the thickness deviation amount at outlet and inlet of each stand. As can be seen from the figure, in the dynamic adjustment of S1 roll gap, the outlet strip steel forms "diamond" along the rolling direction, with the thickness increasing, and when the "diamond" passes through the stands in the downstream, the outlet thickness of each stand increases, with the increasing amplitude reducing.

As can be seen from figure 11, measured value curve of overall outlet tension of each stand, When the roll gap is increased at S1,the outlet thickness of S1 increases, and when the thickness increasing points gradually pass the stands behind

As can be seen from the measure data during dynamic over-welding, the technical solutions of dynamic adjustment of S1 roll gap introduced in this paper achieves the purpose of reducing the tension of the stand where the weld is.

The analysis is conducted to the unit weld strip fracture after the application of the technology of dynamic over-welding. The weld strip fracture rate of the rolled silicon steel is reduced to below 5%. When the material is bad, the strip fracture is reduced to below 18%. It is found by the analysis on the feature of weld fracture points; the non-welding point strip fracture significantly decreases. The fracture within 3m of the weld is 15.3%, and within 8m to 3m, 15.2%. From the practical point of view, the dynamic adjustment of bending effectively reduces the tensile stress concentration of on the edge of the strip steel, reducing the incidence of the strip fracture.

5. Conclusion

(1) The dynamic adjustment of bending force control strategy can effectively reduce the tensile stress concentration of on the edge of the strip steel, reducing the incidence of the strip fracture.

(2) The dynamic adjustment of S1 stand roll gap can make S1 outlet form a diamond, which can effectively reduce the total tension of the strip steel in the rolling of the subsequent stands, making a very positive effect on the reduction of weld strip fracture. But the adjustment of S1 roll gap will make S1 outlet strip steel too tight, likely to cause S1 outlet strip steel fracture.

(3) The dynamic over-welding strategy of dynamic adjustment of S1 roll gap and bending force, combined with S1 flatness and thickness decoupling control strategy, substantially increases the over-welding rate during silicon steel rolling, in which the strip steel "fracture" achieves loose side rolling during cold rolling process, since the concentration on the edge significantly decreases.

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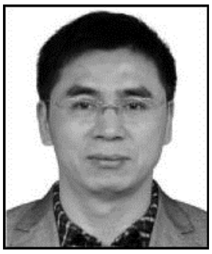

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