CLOSED-LOOP CONTROL OF COLD TEMPERATURE AND PROCESS IMPROVEMENT ON THE HIGH SPEED-WIRES EQUIPMENT

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Abstract: In the process of wire rod production, the rolled wire products must be cooled from the red-hot state to the normal temperature state. How to cool the wire rod after rolling is one of the key links of product quality control in the whole wire rod production process. In this paper, combined with the closed-loop transformation project of controlled cooling temperature of Xuanhuan iron and steel group co., LTD., the closed-loop related controlled cooling equipment (including water cooler, valve table, etc.), nozzle layout and process layout of water tank, and closed-loop software control system of controlled cooling temperature of high-line are analyzed and designed. Closed-loop system design USES temperature of cooling water cooling and water cooling two temperature closed loop regulating circuit, through temperature feedback and feedforward to achieve the uniformity of temperature adjustment, in order to prevent occur due to temperature closed loop control function with the phenomenon of a steel before and after the temperature difference is bigger, system Settings have "absolute temperature regulation" and "relative temperature regulation" selection mode. The system has a self-learning mode, which can modify the temperature feed forward formula. In addition, this paper takes the hard wire 82B rod as the test object, and studies the process parameters and the comprehensive mechanical properties of the rod before and after the water cooling system reform. The research results show that the temperature closed loop system, can ensure the rolled piece temperature control precision of plus or minus 10℃, enhances the stability of wire rod cleaner performance. It can reduce water consumption by about 186m3/h and improve the utilization rate of cooling water.

Keywords: High speed-wires;Cold temperature;Closed-loop;Improvement

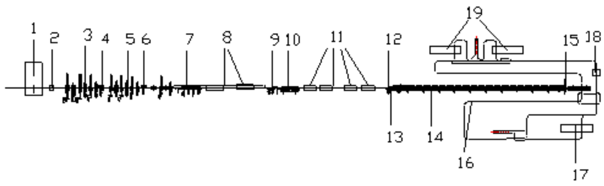
1 INTRODUCTION

In the process of wire rod production, the rolled wire products must be cooled from the hot red state to the normal state after rolling. The temperature and cooling rate after rolling determine the intrinsic structure, mechanical properties and the amount of iron oxide scale on the surface of the wire rod, which has a very important impact on the quality of the product. Therefore, how to cool the wire rod after rolling is one of the key links of product quality control in the whole wire rod production process. [1]

Because of the low control precision, the water cooling and controlled cooling system of Xuanhua Iron and Steel High-speed Line can not effectively guarantee the spinning temperature of rolling process, and can not meet the process requirements of controlled rolling, controlled cooling and efficient cooling of variety steel and screw. Therefore, the upgrade of water cooling control system and the realization of temperature closed-loop control are of positive significance to the future development and production of Xuanhua Steel.

2 BRIEF INTRODUCTION OF PRODUCTION TECHNOLOGY

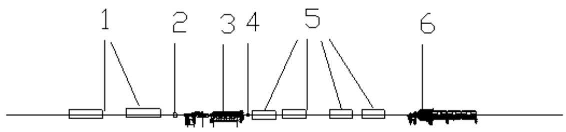
As shown in Figure 1, the process flow is as follows:Heating Furnace → Roughing mill→Medium rolling mill→ Pre-finishing rolling→1#.2# water tank → Finish rolling → 3#.4#.5#.6# water tank→Pinch roller→Silking machine→ Stelmore Air Cooling Line → Collect tidily.Bundle up.Packing.Warehousing



1-reheating furnace;2-descaling device;3-rough rolling mill; 4-1#flying shear;5-medium rolling mill; 6-2# flying shear;7-pre-finishing mill; 8-pre-finishing water tank; 9-3# flying shear; 10-finishing mill; 11-finishing water tank; 12-pinch roll; 13-spinning mill; 14-bulk coil transport line; 15-coil collector; 16-P/F line; 17-baler; 18-weighing station; 19-coil unloading station

Figure 1. The layout of Xuanhua Steel high-speed wire rod production line map

The production line after high-speed wire rolling can be divided into five zones: water cooling zone, circle forming zone, uncoiling control zone, uncoiling collection zone, PF line and finishing zone. Water cooling zone includes water cooling devices before and after finishing mill. As shown in Figure 2.



1 - Water cooler before finishing rolling; 2 - pyrometer; 3 - finishing mill; 4 - pyrometer;5 - Water cooling section after finishing rolling; 6 - pyrometer

Figure 2. Water cooling control equipment

3 EQUIPMENT DESIGN OF CONTROLLED COOLING SYSTEM

3.1 Design of Controlled Cooling Equipment

3.1.1 Water-cooled line equipment

After pre-finishing rolling, the water-cooled section equipment includes two Morgan six-generation water tanks. The equipment set of water cooling section after finishing mill includes four Morgan sixth generation water tanks, and two-hole guide grooves are used between the water tanks. Water tank nozzles and double-hole guide grooves are made of 17-4PH materials. Heat treatment reached HB340-360.

3.1.2 Control Selection of Water Tank Valve Station

All three-way valves of water tank valve station adopt FISHER three-way valve, a high-speed three-way reversing valve specially designed for Morgan high-speed water tank. The quick switching action of FISHER three-way valve ensures that the cooling control speed of water tank is accurate, reduces the length of abnormal cooling and improves the product yield. The three-way valve is controlled by two four-way solenoid reversing valves to control the position of the actuating cylinder to regulate the spool. The cylinder is controlled by a single solenoid and two basic cooling valves. When the rolled piece is separated from the water tank, the three-way valve immediately directs the cooling water to the slag flushing ditch.

The improved pressure regulating valve improves the internal components of the valve body on the basis of the ordinary valve, effectively reduces the resistance during the movement of the valve core, so that the pressure control is more reliable and accurate, and ensures that the cooling water quantity is always effectively controlled. The opening of each pressure regulating valve in the water tank valve station is regulated by the I/P controller located on the valve body.

The regulating valve is located between the electromagnetic flowmeter and the three-way valve, which is used to regulate the cooling water flow into the water tank. The cooling water flow into the slag flume is controlled by a gate valve located between the reversing valve and the flume. The position of the control valve is signaled by the I/P regulator on the valve. The I/P unit can receive 4-20mA signals from the main control, so that the valve can be opened from minimum to maximum. Ensure that the amount of cooling water is always effectively controlled.

The flow and pressure transducer signals of the water tank valve station are introduced into the field distributor.

3.1.3 Pyrometer

The pyrometer measures the temperature of the rolled piece and displays it to the operator together with the PI temperature control loop. The 1 # pyrometer in front of the entrance of the finishing mill shows the temperature of the rolled piece entering the finishing mill. When the temperature of the rolled piece entering the finishing mill is too low, the cryogenic alarm signal warns the operator. The 2 # pyrometer shows the temperature of the workpiece after the finishing mill. The outlet pyrometer of the spinning machine shows the temperature of the finished product.

3.1.4 Water Quality

Because of the wide range of cooling water flow, the cooling water quality, temperature and pressure may have a great impact on the cooling process. Better quality water can reduce the corrosion of valve and tank equipment, and reduce the deposition on the nozzle, so as to avoid blocking the nozzle's spray hole. The water quality requirements of the cooling system are as follows: the cooling medium of the water tank is neutral (pH 7-9) to purify industrial water. The suspended particles in water are not more than 25-30 mg/L, the particle size of impurities is not more than 250 m, the allowable deviation of water temperature is (+5 C), the maximum of water temperature is not more than 35 C, and the water pressure is stable.

3.2 Design of Closed Loop System for Controlled Cooling Temperature

3.2.1 Principle of L1 Closed-loop Temperature Control

When the temperature closed-loop automatic control is put into operation, the L1 system measures the temperature of the rolled piece according to the pyrometer installed at the outlet side of the water cooling section, compares it with the target temperature, makes PI adjustment, and outputs the auxiliary circuit for controlling the flow regulation. In the pre-water cooling section and the water cooling section, a closed-loop temperature regulating circuit is set up to control the temperature of the rolled piece at the entrance of finishing mill and spinning mill respectively. In order to prevent the phenomenon of large temperature difference between front and back of the same steel due to closed-loop temperature control, the system is equipped with "absolute temperature regulation" and "relative temperature regulation" selection switches. In the "absolute temperature regulation" mode, the closed-loop temperature control system is always in the working mode, and the opening of the control valve (flow rate) is automatically adjusted by feedback according to the exit temperature of the rolled piece. In the relative temperature regulation mode, the temperature closed-loop control system only adjusts within a certain length of the head of the rolled piece, and then the regulator is in a "frozen" state, and the output component of the closed-loop regulation remains unchanged. According to the tracking signal of rolling piece generated by PLC of rolling line, non-cold section control of head and tail is executed.

In order to prevent the regulator from producing wrong output due to the incorrect signal of temperature detection, a software filter circuit is set up in the temperature detection link. Firstly, the temperature detection is filtered by moving average filter. Considering that the temperature of the same rolling piece will not change abruptly, the detection value is eliminated when the detection value exceeds a certain range of the last moving average value.

3.2.2 Temperature Feedforward Control

Due to the inevitable lag of temperature feedback control, the system is mainly based on temperature feed-forward regulation under normal conditions. Because the opening of the control valve and the temperature drop of the rolled piece through the water cooling system are typical non-linear/multi-variable/large inertia links, the temperature feed-forward control mode is adopted as the main control mode. For different inlet temperatures, L1 calculates feed-forward flow rate by using temperature feed-forward formula provided by L2. According to different rolling products and specifications, L2 sends out corresponding feed forward flow calculation formulas for L1 to use.

When there is a "watermarking" in the raw material or a temperature difference between the head and the tail caused by other reasons, the temperature will not change immediately due to the effect of moving average filtering, and the amplitude of the change will also decrease. At this time, the function of temperature feedforward controller is to minimize the effect of temperature inhomogeneity caused by watermarking, but it can not be eliminated. For the pre-water cooling section, its significance is to ensure as much as possible the temperature stability of the same part of the finishing mill.

The L2 self-learning function automatically maintains feedforward formulas for different rolling products, specifications and speeds. When rolling a steel grade and specification for the first time after the system is put into operation, the system can be in a closed-loop control state of temperature open-loop flow. Operators can set the flow or control the opening of manual control valve according to historical experience for production. If the slab temperature of reheating furnace is stable, the next steel can be put into closed-loop temperature control. If the slab temperature of reheating furnace fluctuates greatly, after several steels are produced, the temperature closed loop is put into operation.

In the cooling process, the temperature feedforward formula is self-corrected by the control system according to the actual temperature drop of the rolled piece and the actual flow rate of cooling water. After the modification, the flow setting component based on temperature feed-forward control will basically meet the cooling requirements when the subsequent steel arrives.

3.2.3 Closed Loop Flow Control

The control system can choose to disconnect the temperature control loop and control the flow closed-loop separately. At this time, the flow can be set directly on HMI. The system can automatically control the opening of the control valve according to the actual flow.

In the initial setting of the system, a flow setting value can be set according to production experience, and then the temperature feedforward coefficient can be learned automatically according to population temperature, exit temperature, rolling speed, actual flow rate and other parameters in the cooling process. The temperature feed-forward coefficient can be manually modified after analyzing the actual cooling curve.

3.2.4 Manual Control of Regulating Valve

The control system can choose to directly control the opening of the control valve. At this time, the opening of the control valve is manually set on HMI or manually adjusted on site.

Manual control mode is only used for manual intervention in emergencies to meet production requirements. The principle block diagram of the through-water cooling control system is shown in Fig. 3 (taking the pre-water cooling section as an example).

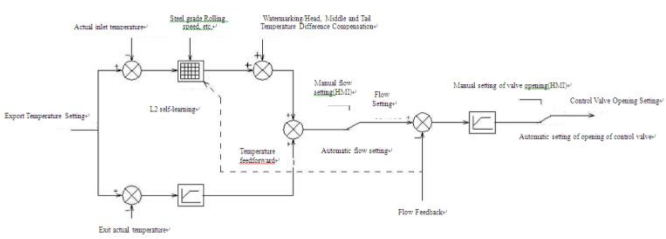


Figure 3. Block diagram of control system of water cooling control system

4 TEST RESULTS AND ANALYSIS

4.1 Rolling process plan of hard wire rod

With the chemical composition of billet in Table 1 as raw material, the cold billet is used in the trial rolling, and the surface defects such as stripping, torsion, bending, dimension error, inclusion, skin turning, scratch and scarring are strictly eliminated.

Table 1. Chemical composition of steel billet

Brand name	**chemical composition（%）**					
	C	Si	Mn	P	S	Cr
82B	0.78-0.86	0.15-0.35	0.60-0.90	≤0.025	≤0.025	0.15-0.35

The billet is heated uniformly and burned thoroughly to ensure the heating quality, and the temperature difference of the pass bar is less than 30 C. When stopping rolling due to faults, cooling and insulation measures should be taken in the furnace. The atmosphere in the furnace remains reductive. High-pressure water descaling equipment ensures normal use and iron oxide scale removal.

Before rolling, the wear condition of pass, guide, roller table, transition guide groove and other process equipment should be checked in detail to ensure the installation accuracy of guide and no sharp angle with the contact part of red steel, so as to prevent the scratches and folds caused by the above equipment on the products. Execution standard of product appearance dimension: GB/T 14981-2009, control precision is allowable deviation (+0.25mm), non-roundness (<0.40mm).

The water nozzles in the water cooling section are balanced throughout the whole process, and adjusted appropriately according to the rolling speed and heating temperature changes to ensure that the inlet temperature and the spinning temperature of the finishing mill meet the requirements.

4.2 Analysis of Water Cooling Control before and after Reconstruction

4.2.1 Analysis of Water Cooling System before Reconstruction

After the closed-loop transformation of high-speed wire controlled cooling temperature, the length of each water tank and recovery section has different changes, which has a certain impact on product performance control. 2# water-cooled tank temperature drop 58 ℃/water tank, 3# water-cooled tank temperature drop 165 ℃/water tank, 4 # water-cooled tank temperature drop 117 ℃/water tank, 5 # water-cooled tank temperature drop - 10 ℃/water tank, 6 # water-cooled tank temperature drop 23 ℃/water tank.

Before the transformation, the water cooling distribution of each water tank was extremely uneven, and the 1 # water tank in the pre-water cooling section could not record data because of no flowmeter. According to the field water quantity and the actual situation of 1 # water tank equipment, the average water consumption of 1 # water tank is 148.99 m^3/h according to the average 60 m^3/h statistics, and the average water consumption of pre-water cooling is 231.34 m^3/h after finishing rolling.

4.2.2 Analysis of Water Cooling System after Reconstruction

The average water consumption of pre-cooling is 124.43 m^3/h, and that of finishing rolling is 69.22 m^3/h. The average water consumption of pre-cooling decreases by 24.56 m^3/h and 162.12 m^3/h after finishing. Under the same technological conditions, the water saving is about 186 m^3/h after modification, especially after finishing rolling.

From Figure 4, we can see the temperature change process of wire rod in each section of water-cooled tank before and after transformation. After modification, compared with before modification, the inlet temperature of 3# water cooler after finishing rolling (the same as the outlet temperature of finishing mill) decreases by about 100 C. When the inlet temperature of finishing mill is basically the same, the temperature rise of finishing mill decreases. It can be seen that after modification, the temperature gradient of surface and core of pre-finishing red steel is smaller. At the same time, the appropriate grain size can be obtained by reducing the outlet temperature of finishing mill, which is conducive to the later group. Weaving transformation. The temperature of each water-cooled tank and recovery section changes greatly after the transformation, which indicates that the water-cooled section and recovery section can play their respective roles better, and the temperature control is better, which provides good grain and temperature conditions for later air-cooling control.

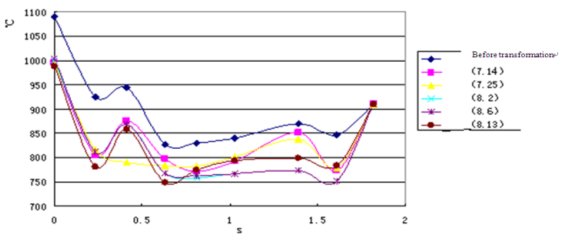


Figure 4. Before and after the transformation of cooling process after rolling wire surface temperature curve

4.3 Performance analysis of hard wire rod before and after modification

4.3.1 Performance analysis of wire rod before modification

Table 2 shows the mechanical properties of wire rod before modification. Through data analysis, the extreme difference of tensile strength increases by about 15 MPa, and the performance of lap joint is worse than that of non-lap joint. After removing the minimum value of 9.27%, the average value is 28.23%, and the range is 9.09%, which is basically consistent with the lap point.

Table 2. Before the transformation of intensive sampling performance record of wire rod

	Non-contact points	Contact points	Compare	Non-contact points	Contact points	Compare	Non-contact points	Contact points	Compare
	Tensile strength/MPa			Area shrinkage/%			Elongation/%		
MAX	1196.42	1192.26	25.63	32.02	32.62	6.31	11.00	11.00	3.00
MIN	1143.66	1124.57	-36.87	9.27	24.27	-17.26	6.00	7.00	-4.00
AVE	1168.63	1168.38	0.36	27.77	28.40	-0.60	8.76	8.80	-0.03
RANGE	52.76	67.69	62.50	22.74	8.35	23.57	5.00	4.00	7.00

4.3.2 Performance Analysis of Revamped Wire Rod

The mechanical properties of the reconstructed wire rod after natural aging for 7 days are shown in Table 3.

Table 2. After the transformation of mechanical properties of wire rods record (7 days of natural aging)

Project	Tensile strength 1/M	Tensile strength 2/M	Area shrinkage 1/%	Area shrinkage 2/%	Elongation 1/%	Elongation 2/%

	Pa	Pa				
MAX	1246.76	1238.61	40.53	40.77	13.00	13.00
MIN	1124.53	1140.82	26.18	22.00	8.00	8.00
AVE	1189.81	1193.21	33.69	33.18	10.37	10.31
RANGE	122.23	97.78	14.35	18.78	5.00	5.00

According to 168 groups of data analysis, the percentage of tensile strength distribution between 1160 MPa and 1220 MPa after 7 days of natural aging is 84.52%, and that between 1155 MPa and 1225 MPa is 92.26%. The percentage of section shrinkage (>30%) after 7 days of natural aging is 82.74%. The section shrinkage rate after 7 days of natural aging needs to be further improved. From the analysis of Fig. 5, the percentage of elongation (> 9%) and (> 10%) after 7 days of natural aging is 97.62% and 76.19%, respectively.

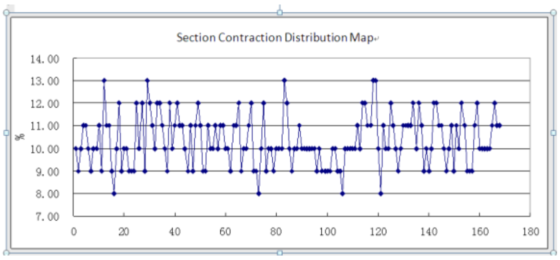


Figure 5. Section Contraction Distribution Map

5 CONCLUSION

Combining with the closed-loop cooling temperature reform project of Xuanhua Iron and Steel Co., this paper analyses the closed-loop related cooling equipment (including water cooler, valve table, etc.), nozzle layout and process layout of water tank, closed-loop software control system of high-speed wire cooling temperature, and analyses and designs the closed-loop temperature control system of high-speed wire. Taking hard wire 82B as the test object, the paper studies the pre-and post-transformation of water cooling system. The technological parameters and the comprehensive mechanical properties of the wire rod are also discussed. The results show that the temperature closed-loop system can ensure that the temperature control accuracy of the rolled piece reaches (+10 C) and improve the stability of the wire rod. It can reduce the water consumption of about 186 m^3/h and improve the utilization rate of cooling water.

(1) The temperature closed-loop system can ensure that the temperature control accuracy of the rolled piece reaches (+10 C) and improve the stability of the wire rod.

(2) By using advanced closed-loop equipment and software of high-speed wire controlled cooling temperature, the water consumption can be reduced by 186 m^3/h and the utilization rate of cooling water can be improved.

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