This paper introduces the WISDRI Continuous Casting Direct Rolling System (WCCDR), which is suitable for the production of ordinary quality wire rod and bar products, and can completely cancel the reheating process. WCCDR is a green, environmentally friendly, low-cost, high-efficiency new technology for wire rod and bar by making full use of metallurgical thermal energy, which can also save the energy and reduce the emission and burning loss. By studying the production capacity matching, temperature matching, production rhythm matching and production management, the WCCDR technology is analyzed and the production capacity matching and rhythm matching equation expressions concluded in the paper. The temperature variation rule of continuous casting to rolling is studied, and the production system and typical process layout are provided. Through the application of a series of technical measures, the WCCDR system is feasible, and has good economic benefits and broad application prospects.

**Keywords:** wire rod and bar, continuous casting, direct rolling, energy saving and emission reduction
Green development is the only way for the transformation and upgrading of China's steel industry. Energy conservation, emission reduction and clean production are not only the internal requirements for the iron and steel industry to resolve excessive production capacity and achieve sustainable development, but also are the foundation and necessary conditions for iron and steel enterprises to seek long-term development. Bars and rods are the largest steel in China in terms of output and consumption. In 2015, the output of bars and rods was 420 million tons, accounting for 37.6% of the total steel output. In the production of bars and rods, the reheating furnace is a large energy consumer in the hot rolling process, and its energy consumption accounts for as high as 60% to 70%. It is also the major pollutant emission source (SO₂, NOₓ, dust, etc.). The hot rolling energy-saving and emission-reducing technologies is mainly related with the reheating furnaces, including hot charging & discharging, regenerative combustion, vaporization cooling, energy-saving coating applications, and low-temperature rolling. In recent years, many attempts and efforts have been made to cancel or replace the reheating furnace: Danieli has developed the technology of ABS “Luna” ECR. The continuous casting billet, which does not need to be cut-to-length, goes through the tunnel furnace and the induction heater. And then, it directly enters the rolling mill and achieves full continuous production. The bar production line of a certain iron and steel company in Taiwan uses an induction heater instead of a conventional reheating furnace. After the cut, hot billet is heated to 980°C, then directly enters the rolling mill. Tangshan Iron & Steel Bar Plant has added an induction heating channel through technical renovation, and the hot continuous casting billet enters the rolling mill without reheating furnace, only through the induction heater. Although these technologies eliminate the reheating furnace, they require induction heater as an alternative. Induction heaters have large installed capacity, low power conversion efficiency, and high maintenance requirements. They are not attractive to Chinese iron and steel enterprises and have not been widely promoted in China.

On the basis of a large number of continuous casting and hot rolling engineering practices, WISDRI Engineering& Research Incorporation Limited developed WCCDR System for the wire rod and bar production.

2 WCCDR System Introduction

2.1 WCCDR System Concept

The WCCDR system refers that the high-temperature and defect-free billet produced by the continuous casting machine (CCM) is directly fed into the rolling mill after cut-to-length without reheating or induction heating. This technology can completely eliminate the reheating process, make full use of metallurgical heat energy of continuous casting. It is a green, environmentally-friendly, low-cost, high-efficiency technology for wire rod and bar production.

2.2 Advantages of WCCDR System

The WCCDR system is suitable for the production of ordinary hot-rolled wire rod and bar products, especially the hot-rolled ribbed steel bars. Based on the development of traditional continuous casting machine and rolling line, WCCDR system has a low investment and is easy to promote. It is suitable for both new projects and upgrading projects of conventional production lines. The main technical advantages of WCCDR are as follows:
(1) Make full use of continuous casting metallurgical thermal energy, eliminate reheating process, save heating fuel and energy consumption, and greatly reduce the emission of pollutants such as SO$_2$, NO$_X$ and fume;

(2) Simplify the production process and adopt a flexible heat-insulating roller path, eliminating the investment and operating costs of equipment, fuel, refractories, maintenance, factory buildings in the furnace area;

(3) The production cycle is greatly shortened, and it only takes ten minutes from the pouring of molten steel to rolling out the finished product, which reduces the investment and operating costs of the plant and lifting and transportation equipment required for the stacking of billets;

(4) Reduce the scales burning loss caused by the reheating process, and the yield can be increased by about 1%. At the same time, less scales is beneficial to improve the surface quality of the product;

(5) The section temperature distribution of the billet is “outside low and inside high”. It makes the deformation deep into the center of the billet in the rough rolling stage, which is beneficial for the eliminating the internal defects of the billet and refining the microstructure.

2.3 Key Technology Analysis of WCCDR System

2.3.1 Production Capacity Matching of Continuous Casting and Rolling

The production capacity matching of continuous casting and rolling includes annual output matching and hourly output matching. The traditional continuous casting and rolling process are relatively independent and do not affect each other. The two process connection has sufficient buffering capacity. In the WCCDR system, the continuous casting and rolling process are directly connected by the flexible connecting roller table which breaks the traditional production mode. In the traditional production mode, those two processes are closely connected and influence each other, moreover, the production capacity must achieve both micro-matching and macro-matching, while micro matching determines macro matching.

For multi-machine and multi-strand billet continuous casting and wire rod and bar continuous rolling mills, as the continuous casting and rolling processes are all stable and continuous processes, the expressions for the complete matching of WCCDR continuous casting and rolling production capacity are as follows:

\[
\frac{60L}{v_0 m} = \frac{4\rho_0 B^2 L}{\pi D^2 \rho_1 v_1 n} + \Delta t
\]

where,

B——side length of the billet, m ;

L——length of the billet, m ;
v₀——casting speed, m/min ;
m——the number of caster flows; ;
ρ₀——billet density, 7700kg/m³ ;
D——diameter of the product, m ;
v₁——finished rolling speed, m/s ;
n——the number of rolling lines ;
ρ₁——density of finished products, generally take 7850kg/m³ ;
Δt——rolling gap time, 3~5s.

For a continuous casting machine in stable production condition, the B, L and m are fixed, and the casting speed v₀ is limited by the production rhythm of the steelmaking process with limited the adjusting range; while for the rolling mill, especially the wire rod production line, the hourly output of different sizes different widely. In actual production, if the rolling capacity is higher than that of continuous casting, complete matching can be achieved by reducing the rolling speed v₁ or increasing the interval time Δt. If the continuous casting capacity is higher than that of rolling, part of the billets will be cooled offline. Considering the offline cooling billet, WCCDR capacity production matching expressions are as follows:

\[
\frac{60L}{v_0m} = \left( \frac{4\rho_0B^2L}{\pi D^2 \rho_1 v_1 n} + \Delta t \right) \left( 1 - \frac{Lk}{60v_0m} \right) \tag{2}
\]

where, k——the number of offline billet per hour.

Combining equations (1) and (2), if the metal mass flows (πD²v₁n) of all the products are all equal and satisfy formula (1), the WCCDR production capacity can be completely matched (ie, k=0). Therefore, the hourly output of each specification product that uses slitting rolling to produce rebar can be basically equal, and has good compatibility with continuous casting production capacity. In this case, it is suitable adopting WCCDR process.

2.3.2 Temperature Matching Between Continuous Casting and Rolling Processes

Temperature matching is the key to the WCCDR system. Reducing the cooling time and increasing the temperature of the billet are the main measures to achieve temperature matching. The following analysis is performed on the continuous casting zone, the flexible connection zone and the rolling zone.
2.3.2.1 Continuous casting area

The temperature matching mainly depends on the continuous casting. The continuous casting process contains huge metallurgical thermal energy. By optimizing the design, heat loss after solidification of the billet can be reduced as much as possible, and high-temperature defect-free continuous casting can be realized. Its main technical measures are as follows.

(1) Reasonably increase the withdrawl speed. Increasing the withdrawl speed can shorten the cooling time of the billet in the continuous casting area, and its effect of increasing the billet temperature is obvious. With the other factors keeps the same, the average temperature of the billet section can be increased by about 20°C for every 0.1m/min increase in the casting speed. Of course, increasing the casting speed has a direct impact on the quality of billet and the stability of continuous casting. At the same time, it is also affected by the steelmaking process and should be considered comprehensively. The reasonable withdrawl speed of WCCDR is generally 2.5~3.5m/min.

(2) Optimize the cooling water distribution in secondary cooling zone. The cooling water control system with feedback is used to collect the real-time temperature data of the billet, establish a mathematical model, adjust the amount of the secondary cooling water flow, and reduce the cooling intensity to increase the billet temperature under the premise of ensuring the solidification quality of the billet.

(3) Optimize cut-to-length. Under the premise of guaranteeing the complete solidification of the billet, the WCCDR length cutting position can be advanced 4~5m than the conventional caster, and the cooling time of the billet can be reduced by 1~2min. At the same time, if hydraulic shears are used instead of flame cutting, the cooling time can also be reduced by about 30 seconds.

(4) Realize quick charging of the billet by substantially increasing the speed of the roller table after cutting and the conveying roller table and the roller table of each strand is controlled separately.

(5) Thermal insulation cover. The insulation cover is arranged for the roller table before and after cutting and the conveying roller table to reduce the heat dissipation of the billet.

By adopting the above technical measures, high temperature and defect-free continuous casting billet can be produced. For example, with the casting speed of 3.0m/min, the temperature distribution of 160mm×160mm×10000mm billet after cut-to-length is shown in Table 1.

<table>
<thead>
<tr>
<th>Location</th>
<th>Surface center temperature ℃</th>
<th>Core temperature ℃</th>
<th>Temperature difference ℃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Billet head</td>
<td>≥930</td>
<td>≥1050</td>
<td>120</td>
</tr>
<tr>
<td>Billet tail</td>
<td>≥1000</td>
<td>≥1160</td>
<td>160</td>
</tr>
</tbody>
</table>

2.3.2.2 Flexible Connection Area
After cut-to-length, the hot billet is rapidly sent out from the roller table of the continuous casting zone, and is feed to the rolling mill through a fast heat-insulating roller table. As shown in Fig. 1, the fast heat-insulating roller table is directly connected to the billet discharge roller table, and is arranged in a "flare type" to receive a single billet sent from different positions in a multi-strand continuous casting machine. The fast heat-insulating roller table is driven by variable frequency motors and is equipped with a thermal insulation cover. The billet is transported at 3~5m/s, and can automatically turn and climb on the roller tableas required. It is suitable for billet conveying under a variety of complex layout conditions.

The conveying speed of the fast heat-insulating roller table is fast because the traversing and lifting of the billet is avoided. The billet can be transported from the continuous casting exit to the entrance of the rolling mill within 90 seconds. At the same time, because of the billet transportation in a thermal insulation cover, the heat dissipation on the surface is slow. In addition, the heat spreads outward from inside, and the temperature distribution of the section tends to be uniform. Through the rapid conveying with heat-insulation in the flexible connection zone, the surface center temperature of the billet head at the rolling mill entry can reach above 910°C, while the billet tail can reach above 970°C at the rolling mill entry.

![Figure 1 Schematic diagram of the fast heat-insulating roller table](image)

2.3.2.3 Rolling mill area

Low temperature rolling technology is the guarantee of the temperature matching in WCCDR. The rolling speed of modern wire rod and bar rolling mills is high, and the rolling process generally shows a temperature-rising trend, which is the precondition of the low-temperature rolling. Relevant data show that, lower initial rolling temperature from 1000 ~ 1100 °C to 850 ~ 950 °C, grain refinement can be obtained, and product mechanical properties will be improved.

Compared with the conventional heating furnace plus rolling mode, the WCCDR has a lower initial rolling temperature, a nearby finish rolling temperature, and temperature distribution characteristic of “two low and two high” (lower temperature in outer and head, higher temperature in inner and tail of the billet). The deformation in the rough rolling stage can be deep into the center of the billet, and which can refine the internal structure, eliminate the internal defects such as looseness, cracks, etc. The temperature difference in the length
direction is caused by the fact that the cooling time of the billet head in the continuous casting process is much longer than that which in the tail. In the continuous casting area, the temperature difference between the head and the tail can reach more than 80°C. However, in the rolling zone, the tail enters the rolling mill 40–60s late than the head, so the temperature difference between the head and tail of the billet is gradually reduced and can be controlled within 50°C in the WCCDR. For the wire rod and bar product for construction, this temperature difference has little effect on performance, and the difference of yield strength between head and tail is about 30 MPa. The temperature change during the rolling process of a typical WCCDR product is shown in Figure 2.

![Figure 2: Typical temperature trend in the rolling process for bar](image)

2.3.3 Rhythm Matching of Continuous Casting and Rolling

The meaning of the WCCDR rhythm matching is that the multi-stream billets are cut in a step-like manner in sequence, and each flow billet is rapidly sent to the entrance of the mill immediately after cut-to-length.

\[
\text{discharge cycle } t_0 = \text{rolling cycle } t_1 + \text{rolling gap } \Delta t
\]  

(3)

As shown in Fig.3, the expression of the WCCDR rhythm matching is as follows when the casting speed of each strand is constant \(v_0\):

\[
\Delta L_1 = \Delta L_2 = \Delta L_3 = \ldots = \Delta L_m = \Delta L = \frac{L}{m}
\]

(4)

In the formula: \(\Delta L\)—distance between two adjacent billets, m.

Rhythm matching is also an inherent requirement for production capacity matching. The technical measures for "step-like" billet delivery are: setting up on-line position monitoring system for continuous casting, matching with automatic control system for crystallizer level, real-time fine-tuning the flow drawing speed of each flow, and realizing the high temperature billet delivered rapidly.
2.3.4 Integrated production management technology

The WCCDR technology reflects the highly continuous and integrated three processes of steelmaking, continuous casting and rolling. Production plan, maintenance time, and equipment replacement time must be under the coordinated management, to achieve full-process production temperature matching, rhythm matching, production matching. Table 2 shows the work schedule for typical WCCDR workshop.

Table 2 Work Schedule for Typical WCCDR Workshop

<table>
<thead>
<tr>
<th>Item</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calendar time</td>
<td>8760  h</td>
</tr>
<tr>
<td>Idle time</td>
<td>1608  h</td>
</tr>
<tr>
<td>Overhaul time</td>
<td>240   h</td>
</tr>
<tr>
<td>Minor repair time</td>
<td>720   h</td>
</tr>
<tr>
<td>Roller changing time</td>
<td>168   h</td>
</tr>
<tr>
<td>Accidental time for CCM</td>
<td>120   h</td>
</tr>
<tr>
<td>Accidental time for RM</td>
<td>120   h</td>
</tr>
<tr>
<td>External mechanical failure</td>
<td>120   h</td>
</tr>
<tr>
<td>Others</td>
<td>120   h</td>
</tr>
<tr>
<td>Rated annual working hours</td>
<td>7152  h</td>
</tr>
</tbody>
</table>

2.4 Typical process layout for WCCDR

(1) “1-1” typical process layout

1-CCM, 2-cut-to-length device, 3-billet collection table
4-fast heat-insulating roller table, 5-billet kick-off table, 6-RM
3 Application and Development Prospects of WCCDR system

WCCDR system is an innovative technology with obvious advantages and broad development prospects. It can not only save energy and reduce emissions, promote the green production of steel enterprises, but also greatly reduce project investment and production costs, and improve the competitiveness of enterprises. It is estimated that WCCDR system can reduce the cost per ton of steel by about 35 RMB/t (in China) compared with the 600°C hot charge-rolling process. At the same time, WCCDR is also promising technology, which can be applied for both newly-built and revamping projects.

The WCCDR technology is awarded many national patents and has received the attention of many steel companies in China. It has also been applied in Hanzhong Iron & Steel, Guangdong Guoxin Iron & Steel. In face of the mounting pressure of environmental protection, severe surplus of the production capacity and fierce competition, WCCDR technology will be widely applied and promoted in the field of wire rod and bar production.

References:


