Development of the Billet Cooling Devise Using Mist-jet and Its Performance*

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Synopsis

New mist cooling equipment for billets has been developed at Kamaishi Works, Nippon Steel Corporation. The equipment has a walking beam type cooling bed, and as-rolled hot billets are arranged on their corners and rotated on the bed in walking.

The billets are natural-cooled from the initial temperature to about 550 °C (core temperature) at the front part of bed and then mist-jet-cooled to about 100 °C at the later part.

This report concerns the new techniques developed, the basic design and main specifications of the equipment, the passages of constructions and operating performances, improved points and unsettled problems, and others.

Main techniques developed are the billet straightening mechanism using a billet pusher, the system of on-corner arrangement and rotation of billets on the cooling bed, and the mist-jet cooling device of billets having the crossflow type mist nozzles.

This installation has been smoothly operated since June 1975 with a sufficient cooling capacity using the mist-cooling method for all billets containing carbon lower than 0.75 wt%. This has given no cracking and less deformation, very small reject level of billets (about 0.05 %), and no nozzle clogging for about ten years.

I. Introduction

The Kamaishi Works of Nippon Steel Corporation has planned an increase in a billet weight to 2 t. This is to increase the weight of wire rod coils produced there. When this plan was formulated, a study was conducted to combine three existing billet cooling beds into one to simplify finishing operations at the billet mill. Restrictions of the mill building necessitated the forced cooling of all billets (121 mm ϕ in the cold condition) to handle them at a rate of 320 t/h at a cooling bed about 33 m long. For these reasons, a decision was made to introduce the mist-jet cooling technique reported in the previous paper,¹⁾ when designing the new cooling bed.

This report describes the development and operating performances of the cooling bed, that transfers billets by rotating them, and the mist-jet cooling equipment that is installed at the cooling bed. These facilities started their operation in June 1975 and have been smoothly performing since then.

II. Design of Cooling Bed and Mist-jet Cooling Equipment

1. Conditions Required of Cooling Bed and Forced Cooling Equipment

The conditions required of the cooling bed and

forced cooling equipment and the measures to meet these conditions are as follows:

- i) Prevention of billet bending after cooling → Straightening with pusher, prevention of deflection and prevention of bending on water cooling.
- ii) Prevention of billet cracks and other defects at cooling bed → Adoption of walking beam transfer system, uniform cooling and mild cooling.
- iii) Prevention of undesirable billet structure formed by forced cooling → Uniform cooling and mild cooling.
- iv) Positive cooling of billets on one cooling bed at maximum rate of 320 t/h → Adoption of forced water cooling (mist-jet cooling).
- v) Elimination of restrictions imposed by cooling bed and cooling equipment of preceding and succeeding operations → Prevention of equipment failures, prevention of billet bending and prevention of billet defects.
- vi) Reduction in equipment and operating costs → Simplification of equipment.
- vii) Assurance of good working environment → Installation of steam exhaust equipment and noise control equipment.

The cooling equipment that satisfies the above conditions was designed by referring to the results of the study presented in the previous report¹⁾ and the operating experiences of similar equipments.

2. Design of Cooling Bed

The walking beam system was adopted at the cooling bed to prevent scratches on the billets. In order to alleviate the deflection of billets in the high-temperature zone, the distance between the fixed beams was set at about 2 500 mm and was made shorter than 2 500 mm at the billet mill side to prevent bending of short billets at their end.

Two to four hot-rolled billets accumulated on the skew rollers are forced by the pusher against 17 stoppers removing large bends and then transferred in contact with each other onto the cooling bed. The billets are arranged on corner in the first transfer, turned through 90 deg in each of the subsequent transfers, and again arranged in contact with each other when moved onto the delivery zone (see Fig. 1 and Photo. 1).

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Fig. 1. Schematic illustration of billet rotation process on the walking beam type cooling bed.

Photo. 1. A view of billets arrangement on the cooling bed.

The diagonal of 121 mm ϕ billets is 163 mm, but the distance between the billets was set at 220 mm. This is because the end bending to a maximum of about 50 mm remains unremoved by pusher straightening. The natural cooling zone is about 22 m long and cools billets to a core temperature of about 550 °C in 44.5 min at an average production rate. The mist-jet cooling zone is 4.4 m long and cools five transfers of billets in an average time of 8.5 min. The delivery zone is about 6.6 m long (see Fig. 10 in the previous report¹⁾).

3. Design of Mist-jet Cooling Equipment

1. Water and Air Volumes

The billets remain in the mist-jet cooling zone for 8.5 min at an average production rate and for 7.5 min at a maximum production rate. According to the experimental results shown in Fig. 4 of the previous report,¹⁾ when 123 mm ϕ billets were mist-jet-cooled from about 550 °C at the top and the bottom water fluxes of 10 and 20 l/m²·min, respectively, the core temperature of all billets, except specimen B, dropped to 180 °C or lower after 7.5 min and that of all billets to 160 °C or lower after 8.5 min. According to the specifications of the mist-jet cooling equipment, the core temperature of the billet is 560 °C or lower at the entrance and 180 °C or lower at the exit of the mist-jet cooling zone. These specifications can be satisfied at an average production rate if the top and bottom water fluxes are set at 10 and 20 l/m²·min, respectively. The required volume of cooling water was designed to be twice the above two water fluxes (60 l/m²·min $\times$ 83 m² $\div$ 5 000 l/min), because this mist-jet

Fig. 2. Billets and mist nozzles arrangements on the mist-jet cooling equipment.

cooling equipment was the first one of its kind to be put into commercial operation and provision was made for future change in its operation.

If the air discharge speed is 40 m/s, the above volume of water can be atomized into a stream of coarse particle mist.²⁾ The required volume of air was thus put at 2 800 m³/min. At the maximum water volume, the ratio of air to water is 0.56 m³/l by volume and 0.68 kg/kg by weight.

2. Nozzle Arrangement

As shown in Fig. 2, the nozzles are arranged in almost symmetrical positions above and below the billets. The distance between the nozzles is about 300 mm in the longitudinal direction of the billets and is about 220 mm in the traveling direction of the billets (the same as the distance between billets). There are installed 1 280 top nozzles and 1 100 bottom nozzles at densities of 15.4 and 13.3 nozzles/m², respectively. The number of bottom nozzles is smaller than that of top nozzles, because their arrangement is restricted by the beams. As the effective spread angle of the mist-jet from crossflow type mist nozzles is about 15 deg,²⁾ the distance between the nozzles and billets was set at 700 mm by considering the further expansion of the mist jet at the billet level.

3. Header and Nozzle Construction

The nozzles and headers are constructed as illustrated in Fig. 3. Both the top and bottom headers have nozzle water pipe ⑤ located above water supply pipe ③. This is for the uniform ejection of the cool-

Fig. 3. Header and nozzle constructions of the mist-jet cooling equipment.

ing water into the longitudinal direction of the header (about 4 400 mm long) and for suspending solids in the cooling water to settle in the water supply pipe. The foreign matter settled and accumulated in the water supply pipe is periodically removed by water pressure.

Both the top and bottom nozzles have the inside diameter of water pipe ⑤, established at 6 mm, to prevent clogging. The nozzle water pipe ⑤ is also made straight and open at both ends for an easy cleaning. The air pipe ②' of the bottom header is larger than that of the top header, because the volume of air ejected through the bottom nozzles is larger than that ejected through the top nozzles.

4. Air Flow

As illustrated in Fig. 4, 2 800 m³/min of air (including steam and water droplets) is delivered by supply blower ⑥ to the mist-jet cooling zone and a maximum of 1 000 m³/min of air is discharged outside the system by exhaust blower ⑥'. The above 2 800 m³/min of air is ejected through 2 380 nozzles, with the ratio of air ejected through the top nozzles to that ejected through the bottom nozzles being about 1: 1.4.

Since the air discharged from the nozzles and steam generated from the billets affect the uniform cooling of billets at the mist-jet cooling equipment, it is important to control the flow of air and steam. The flow of air in the mist-jet cooling zone and the amount of air flowing outside the system are controlled by adjusting the damper of the exhaust duct ④. Although the installation of exhaust ducts at the bottom level was initially planned, they could not be equipped because of a lack of space. A general view of the mist-jet cooling equipment is given in Photo. 2.

5. Flow of Cooling Water

Figure 5 shows that the cooling water is supplied from head tank ① to top and bottom water supply pipes, ⑤ and ⑥, and is then distributed to top and bottom headers, ⑧ and ⑨. The flow rate of water to each header is preadjusted with flowmeter ⑦ and manual valve ⑪. The total volume of water supplied

Fig. 4. Cross sectional view of the mist-jet cooling equipment.

Fig. 5. Cooling water supply system of the mist-jet cooling equipment.

Photo. 2. A general view of the mist-jet cooling equipment.

ed to the top and bottom headers is controlled with motor-driven valve ③ while the mist-jet cooling equipment is in operation. When valves ⑫ are closed, and valves ⑬ are opened, water at a pressure of about 3 kgf/cm²-G is directly furnished to each header to clean the header pipes and nozzles. Each header pipe is openable at both ends for this cleaning purpose.

The level control of the 4 400 mm long headers is very important to uniformly eject the cooling water

from each nozzle.

4. Specifications of Cooling Bed and Mist-jet Cooling Equipment

The main specifications of the cooling bed and mist-jet cooling equipment are presented in Table 1.

The aimed value of billet bending after cooling is within 100 mm/18 m and the aimed value of billet press straightening rate (reject rate) is under 0.5 % (actual value in the past).

To decrease noise from the blowers and ducts, the blowers are equipped with silencers and the blowers and ducts are covered with rock wool of large sound absorbing capacity (see Fig. 6).

III. Operating Performance

1. History of Operation

Since June 1975, the billet cooling bed and mist-

Table 1. Main specification of the cooling bed and the mist-jet cooling equipment.

Item	Specification (Initial spec.)												
Billet	Size (at room temp.): 121 mm ϕ $\times$ 18 850 mm long (max.) Production capacity: 320 t/h (max.) Steel grade: Low to high carbon steels and low alloy steels												
Billet temp.	Entrance of NC zone: 1 000 °C (Core) Entrance of MJC zone: Below 560 °C (Core) Delivery end: Below 150 °C (Average)												
Cooling bed	Area: 20 250 mm wide $\times$ 33 020 mm long Length of NC zone: 22 027 mm long (104 billets) Length of MJC zone: 4 400 mm long (20 billets) Length of delivery zone: 6 593 mm long												
Number of beam	<table><tr><td></td><td>Fixed beam</td><td>Walking beam</td></tr><tr><td>NC zone</td><td>10</td><td>9</td></tr><tr><td>MJC zone</td><td>9</td><td>8</td></tr><tr><td>Delivery zone</td><td>10</td><td>0</td></tr></table>		Fixed beam	Walking beam	NC zone	10	9	MJC zone	9	8	Delivery zone	10	0
	Fixed beam	Walking beam											
NC zone	10	9											
MJC zone	9	8											
Delivery zone	10	0											
Header and nozzle	Header length: 4 400 mm Number of headers: Top 32, Bottom 27 Number of nozzles: Top 1 280 Bottom 1 100 Construction: See Fig. 3 Material of header and nozzle: 18Cr-8Ni steel												
Cooling water	Capacity of water: About 5 000 l/min (max.) Water flux: Top 20, Bottom 40 l/m ² ·min (max.) Water supply system: see Fig. 5												
Air and steam	Blower: 750 mm H ₂ O $\times$ 2 800 m ³ /min $\times$ 500 kW Exhaust blower: 210 mm H ₂ O $\times$ 1 000 m ³ /min $\times$ 75 kW Air flow system: see Fig. 4 Exit air speed at nozzle: about 40 m/s												

NC: Natural cooling, MJC: Mist-jet cooling

jet cooling equipment have been smoothly operating as of April 1985. At the begining, various troubles occurred as described later, but they were solved while the equipment was continuously operated.

The quantity of billets treated on the cooling bed (including air-jet cooled billets) is 500 000 to 600 000 t/y as shown in Fig. 7, or 250 000 to 300 000 billets per year. This means that the first target of this plan—replacing three conventional cooling beds by one new bed—was fully accomplished. Billets with a carbon content of 0.75 wt% or less are all mist-jet-cooled without any water-cooling-induced defects in the billets and the end product, wire rods.

2. Billet Temperature

The designed and actual values of billet temperature are as follows:

	Designed value (°C) (At billet center)	Actual value (°C) (At billet surface)
Entrance of cooling bed	1 000	1 052
Entrance of mist-jet cooling zone	560 or less	499
Exit of mist-jet cooling zone	180 or less	160 (mild cooling) 60 (intense cooling)

The aimed values of billet cooling temperature are

Fig. 6. Constructions of laggings for sound absorption of the mist-jet cooling equipment.

Fig. 7. The amount of billets cooled on the cooling bed and reject rate of billets suffered from deformation.

thus achieved by these facilities. The designed and actual values of water flux are as follows:

	Designed value ($l/m^2 \cdot min$)		Actual value ($l/m^2 \cdot min$)	
	Normal	Maximum	Mild cooling	Intense cooling
Top surface	10	20	3.2	18
Bottom surface	20	40	8.7	38

Among the probable causes for the differences between the designed and actual values of billet temperature are: residence time on the cooling bed (designed time is less than actual time), water flux, temperature measuring position (designed at the center, but measured at surface), billet size (designed to be 123 mm ϕ , but actually 121 mm ϕ), and billet surface property (designed for reheated billets, but actually hot-rolled billets). The difference in the temperature of billets at the entrance of the cooling bed is ascribable to the change in the operating conditions of the billet mill.

3. Billet Bending

Immediately after the start-up frequent billet bending occurred due to the problems with the cooling bed, mist-jet cooling equipment and their operating technology. These billet bendings are mainly attributable to the improper stroke of the walking beams, improper partitioning between the natural cooling zone and mist-jet cooling zone, incorrect levelness of the headers, improper water distribution to the respective headers, and misadjustment of the exhaust damper opening. As these causes were gradually removed, frequency of billet bendings decreased, and the aimed value of billet bendings (reject rate of 0.5 %) was attained six months after the start-up. After a successive decrease in the number of billet bendings, the present reject rate is about one-tenth of the aimed value (see Fig. 7).

4. Range of Mist-jet Cooled Billets

Under the initial plan, all billets to pass through the cooling bed were to be mist-jet cooled. Since the capacity of the actual cooling bed is smaller than the designed capacity and the production ratio of high-carbon billets is a mere few percent, billets with a carbon content of 0.75 wt% or more are now air-jet-cooled from the standpoint of safety assurance of end products, wire rods. Air-jet cooling refers to the cooling in which the water for mist-jet cooling is turned off. According to the operating performance of the cooling bed and mist-jet cooling equipment for the past ten years or so, products, chiefly wire rods, manufactured from mist-jet-cooled or air-jet-cooled billets have had no defects due to the forced cooling.

5. Nozzle Clogging

No nozzle clogging has occurred since the start-up, which was about ten years ago, of the cooling bed and mist-jet cooling equipment. The probable reasons

for this satisfactory situation are that the inside diameter of the nozzle water pipes is as large as 6 mm, that the nozzle water pipes are located above the header pipes and that the cooling water flows through the header pipes at such a slow speed as to allow suspended solids to settle and accumulate in the header pipes. These suspended solids are removed by water pressure at intervals of about three months.

6. Heat Extraction Efficiency of Cooling Water

As described in Section III. 3, the actual value of water flux for mild cooling is smaller than the designed value. Since the initial billet temperature of actual mist-jet cooling is smaller than the designed value, the actual water flux is lower than the designed value even if this difference is taken into account. In the experimental apparatus shown in Fig. 2 in the previous report¹⁾ the mist-jet cooling zone was only about 1 m wide, so that the mist jet flowed out smoothly along each side of the billets after impinging on the billets. In the present mist-jet cooling equipment, in contrast, the mist-jet cooling zone is about 4 m wide and the mist jet remains near the billets after impinging on the billets. This is considered to be responsible for the increased heat extraction efficiency of cooling water.

IV. Equipment Modifications and Problems

We discuss here the equipment troubles occurred after the start-up of the cooling bed and mist-jet cooling equipment, corrective measures that have been taken, and remaining problems to be solved.

1. Modifications of Cooling Bed

1. Cracks in Fixed Beams

Cracks occurred in the valleys of the fixed beams in the high-temperature region of the cooling bed, as shown in Fig. 8 (1 (a)). This problem was solved by dividing and welding the beam teeth as shown in Fig. 8 (1 (b)).

Fig. 8. Examples of troubles occurred in the cooling bed and the mist-jet cooling equipment.

2. Installation of Additional Fixed Beams

When short billets (minimum length: about 9 m), which were not included in the initial production plan, were manufactured and cooled on the cooling bed, they bent at the rolling mill side end. To prevent this situation, additional fixed beams were installed in the natural cooling zone of the cooling bed.

2. Modifications and Improvements of Mist-jet Cooling Equipment

1. Formation of Simple Air Curtain

When a billet is about to enter the mist-jet cooling zone and is intensely cooled on one side by a stream of mist, flowing from the mist-jet cooling zone to the natural cooling zone, it bends significantly (see Fig. 8 (2)). This problem was solved by turning off water to nozzles on the natural cooling zone side (2 to 3 nozzles / header) and discharging air alone through these nozzles; that is, by forming a simple air curtain.

2. Level Adjustment of Headers

Since the heat extraction efficiency of cooling water is high as mentioned in *Section III. 6*, the mist-jet cooling equipment was operated with about 40 % of the designed water volume for several years after the start-up (Refer to the mild cooling conditions in *Section III. 2*). The amount of water ejected from the top nozzles is about 0.21 l/(min. nozzle) on an average. The levelness of the headers was strictly adjusted and controlled for this small amount of water to be uniformly discharged through each nozzle.

3. Adjustment of Position and Area of Suction Openings in Exhaust Duct

The behavior of exhaust streams in the mist-jet cooling zone strongly affects the uniformity of billet cooling, in other words, the bending of billets. The suction volume distribution of the exhaust duct is very important in this respect. The position and area of the suction openings in the exhaust duct were adjusted on a trial-and-error basis after the start-up of the mist-jet cooling equipment.

3. Remaining Problems

1. Mist-jet Cooling of High-carbon and Low-alloy Steel Billets

Billets with a carbon content of 0.75 wt% or more are air-jet-cooled instead of mist-jet-cooled for the reasons stated in *Section III. 4*. Future plans for the billet mill envisage a gradual increase in the production ratio of high-carbon steel and low-alloy steel billets. These billets will have to be mist-jet-cooled.

2. Improvement in Method of Removing Foreign Matter Accumulated in Water Headers

At present, the foreign matter accumulated in the water header pipes is removed by water pressure at intervals of about three months. During this work, the header plugs are manually opened and closed. These manually opening and closing operations will have to be eliminated or simplified.

3. Prevention of Steam Escape from Mist-jet Cooling Equipment

Billets are handled with a crane on the exit side of

the mist-jet cooling zone, that is, in the delivery zone. Depending on weather conditions (temperature, humidity and wind direction), steam flows into the delivery zone and interferes with the operation of the crane. The steam exhaust method is important also for the uniform cooling of billets as mentioned in *Section IV. 2. 3*. It is thus necessary to solve this problem by increasing the capacity of the exhaust blower and improving the suction of steam by the exhaust duct.

4. Installation of Specialized Air Curtain

As discussed in *Section IV. 2. 1*, air alone is ejected from a few nozzles on the natural cooling zone side of the mist-jet cooling zone to separate the two zones. The area of the mist-jet cooling zone is narrowed by the air curtain formed as a result. An air curtain of small width and good efficiency will have to be provided to rectify this condition.

V. Conclusions

The billet cooling bed of the walking beam type and the billet cooling devise using mist-jet were developed. In the cooling bed, hot-rolled billets are arranged on corner, first naturally cooled to about 550 °C and then mist-jet cooled to 100 °C or lower while being rotationally transferred. These facilities have been smoothly operating at the Kamaishi Works of Nippon Steel Corporation since June, 1975. The features and performances of the facilities are described below.

1. Features

The main features of the facilities are as follows:

(i) The cooling bed is divided into three zones, *i.e.*, the natural cooling, mist-jet cooling and delivery zones to cool hot billets efficiently down to a desired temperature.

(ii) The walking beam system is adopted at the cooling bed to prevent surface defects on billets and to rotationally transfer the billets.

(iii) Pusher straightening, rotational transfer and mist-jet cooling are adopted to prevent billets from bending.

(iv) Billets are arranged on corner and narrow beams are installed for the uniform cooling of billets on all surfaces.

(v) Crossflow type mist nozzles are adopted to prevent nozzle clogging and to increase the water flux range.

2. Performances

The performances of the facilities are as follows:

(i) The facilities have been satisfactorily working for about ten years since the start-up in June 1975.

(ii) Billets are positively cooled from about 1 000 °C to 100 °C or less within the specified time.

(iii) With few billet bending after cooling, the actual reject rate of billets is about one-tenth of the aimed value of 0.5 %.

(iv) No nozzles have clogged since the start-up of the facilities.

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