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Making to High Performance and Productivity Improvement of Steel Bar and Wire Rod Rolling Process

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Abstract

It is a feature in the steel bar and the wire rod products that various heat treatments and processes are applied to become the mechanical parts such as those used in automobiles in the end. The need for omission and for further simplification in these processes continues to grow each year. Moreover, recently, the demand trend of the steel bar and the wire rod products was in the increasing tendency, the steel bar and the wire rod rolling line was remodeled in the Nippon Steel Corporation Bar and Wire Rod Division to better support these user needs and to further improve productivity. This paper outlines the introduction and the remodeling case with a new rolling machine in each bar and wire rod mill.

1. Introduction

Steel bars and wire rods are used for a wide variety of industrial machinery typically such as automobile parts; they are transformed into usable final products through heat treatment and working such as annealing, drawing, forging and machining by secondary and ternary manufacturers. Users of these steel products request omissions and simplification of post-processing steps to reduce costs, enhance productivity and to preserve our natural environmental. The calls for process omissions and simplification are grown in strength year by year. The Bar & Wire Rod Division of Nippon Steel Corporation has introduced various modifications to bar and wire rod plants at different steel works such as replacing obsolete equipment with the most advanced to better respond to these requests and to improve productivity. As examples of the efforts made, this paper presents: (1) introduction of new types of rolling mills to the bar rolling plant of Muroran Works; (2) installation of a new finishing mill at the wire rod mill plant of Muroran Works; (3) introduction of a new finishing mill to the wire rod mill plant of Kamaishi Works: and (4) productivity enhancement at the wire rod mill plant of Kimitsu Works.

2. Introduction of New Rolling Mills to Muroran Bar Rolling Plant

The bar rolling plant of Muroran Works produces straight bars 19 to 120 mm in diameter and bars-in-coil 19 to 45 mm in diameter of special steels. These products are processed through heat treatment and working, such as annealing, drawing, forging, quenching and tempering, at secondary manufacturers' plants and turn into safety-related parts of automobiles. To enhance the dimensional accuracy of the products, to apply controlled rolling and cooling to produce bars that would allow skipping the whole or part of heat treatment, and to improve productivity, a new-type, three-roll finishing mill called the Reducing & Sizing Block (RSB) was introduced to the Muroran bar mill plant in February 1999, and a compact and high-rigidity roughing mill called the Compact Rolling Mill (CRM) in December 2001.

2.1 Outlines and features of new rolling mills

2.1.1 CRM

With regard to a roughing stand of a bar rolling line, the highest mill rigidity conventionally attainable was approximately 200 t/mm.

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For the purpose of improving the dimensional accuracy at the exit from the roughing mill train and lowering rolling temperature, the high-rigidity CRM of Danieli, Italy, having a mill rigidity of 440 t/mm, were installed at the top end of the bar rolling line (see **Photo 1**). **Table 1** shows the specifications of the CRM.

2.1.2 RSB

(1) High mill rigidity

Three-roll mills have been used in Japan and abroad since some time ago, but because of their low mill rigidity, they were unsuitable to realize good dimensional accuracy at low rolling temperatures. The RSB installed in the finishing section of the rolling line has far higher mill rigidity owing to new structural design, and is capable of realizing high dimensional accuracy even at low rolling temperatures (see **Photo 2**). **Table 2** shows the specifications of the RSB, and **Fig. 1** its roll arrangement.

(2) Free-size rolling

One of the novel features of the RSB is that the positions of the rolls and guides are adjustable during rolling, and it is possible to produce products of intermediate sizes easily without having to change the rolls.

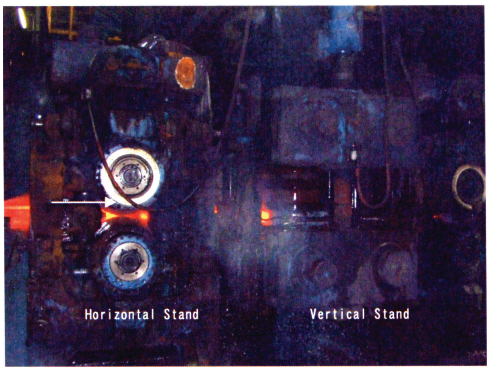

Photo 1 Compact rolling mill

Table 1 Specifications of Compact Rolling Mill

Type	Hauzing-less
Motor capacity	AC 5400 kW
Rolling passes	4
Mill rigidity	440 t/mm
Roll diameter	720 mm ϕ × 700 mm long
Roll gap adjustment	Remote control (onload screw down)
Manufacturer	Danieli (Italy)

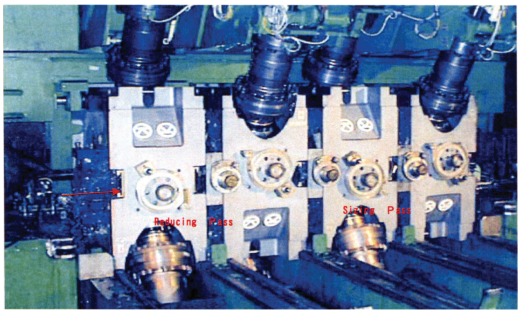

Photo 2 Reducing and sizing block

Table 2 Specifications of Reducing and Sizing Block

Type	Three input drive shafts
Motor capacity	DC 3000 kW
Rolling passes	4 (2 reducing and 2 sizing passes)
Product size	19 - 70 mm ϕ
Rolling speed	Max: 18 m/s
Rolling temperature	Min: 750 ℃
Roll diameter	380 mm ϕ
Roll gap adjustment	Remote control
Manufacturer	Kocks GMBH & Co. (Germany)

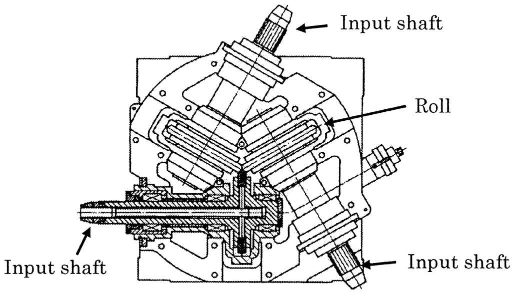

Fig. 1 3 roll stand

2.2 Controlled and high-precision rolling

Low-temperature rolling is essential for producing soft bars that allow a secondary manufacturer to skip the entire or part of the heat treatment. The CRM installed at the exit from the reheating furnace were designed exactly for this purpose. Additionally, three intermediate water-cooling boxes were installed along the course from the CRM to the finishing section so that the steel temperature during the finishing rolling would be low enough (see the layout in **Fig. 2**). As explained earlier, the RSB installed in the finishing section also has a high mill rigidity to allow an entry steel temperature of as low as 750℃. Thanks to the high loading capacities of the newly introduced mills, the capability of the Muroran bar mill line for controlled rolling became one of the best of this kind.

As a result of the controlled rolling made possible by the new rolling mills and the controlled cooling on the cooling bed with a slow cooling cover, it became possible to lower the tensile strength of the products by approximately 20% (see **Fig. 3**), allowing a secondary manufacturer to skip or simplify a heat treatment process.

Besides the above, the rolling line was provided with four profile meters along its path, which, in combination with the high dimensional accuracy of the RSB, enabled the free-size rolling mentioned earlier as well as precision rolling to a size tolerance of ± 0.1 mm or less.

2.3 Product quality

2.3.1 Dimensional accuracy

Fig. 4 shows the dimensional measurement results of bar products rolled to a nominal diameter of 40 mm by low-temperature rolling; the graph shows that all the products fell within a dimensional tolerance of ± 0.10 mm. As explained earlier, it is also possible to produce bars of intermediate sizes simply by adjusting the screw-down setting of the RSB rolls without having to change them.

2.3.2 Material softening by controlled rolling

As Fig. 3 shows using a 50 mm JIS SCM 440 bar as an example, the controlled rolling and cooling by the new rolling mills proved to

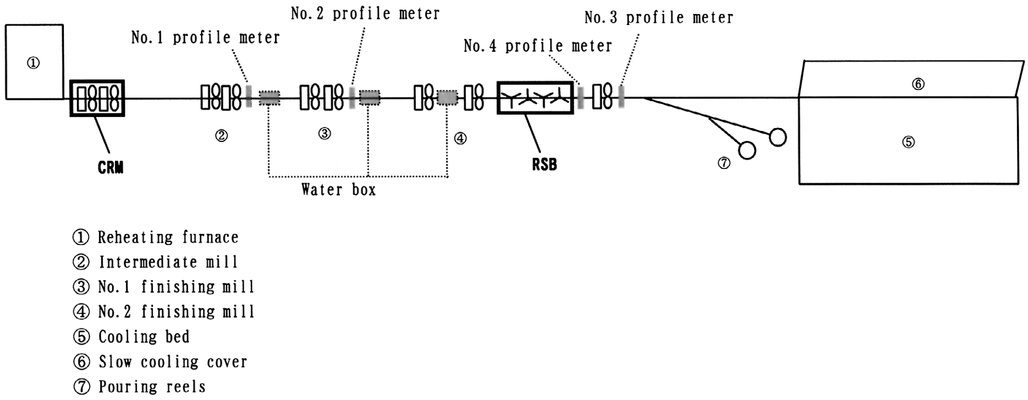

Fig. 2 Layout of Muroran Bar Mill

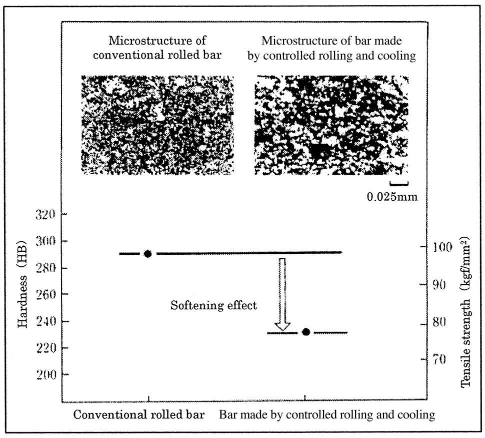

Fig. 3 Application of in-line softening technique to SCM 440 (50 mm ϕ)

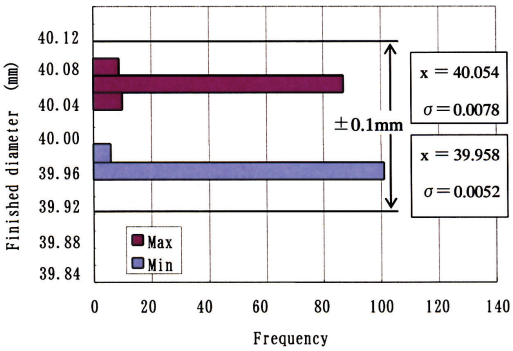

Fig. 4 Resulting tolerance

be effective in lowering the tensile strength of the products. Refinement of crystal grains is effective in lowering tensile strength and hardness, making it possible to omit a conventionally indispensable annealing process from secondary working. In addition, the softer material may allow simplification of drawing work when combined with higher dimensional accuracy.

2.4 Productivity enhancement

The RSB introduced to the finishing rolling section comprises four three-roll stands, or passes; the former two passes form the steel material for the latter two passes, which shape the steel nearly to prescribed product sizes. Since the former two passes are capable of forming the steel for different final sizes simply by changing the roll screw-down setting, it became possible to decrease the number of the sizes of bars coming from the preceding two-roll stands, dramatically simplifying the roll pass schedule and reducing the necessary number of rolls for the preceding stands. The time for roll change due to roll wear or size change has been significantly reduced thanks to the quick changing method with standby roll stands waiting in front of respective positions. Because of the simplification of the roll pass schedule and the quick changing stands, non-operating time of the bar rolling line decreased significantly.

In addition to the above, the introduction of the high-rigidity CRM to the roughing section made it possible to increase the rolling speed in some size ranges where it had been lower because of an insufficient load capacity. All in all, the production capacity of the rolling line increased by roughly 20%.

2.5 Closing

The introduction of the RSB and CRM, which were commissioned in February, 1999 and December, 2001, respectively, increased the controlled rolling capacity of the bar rolling line, enhanced dimensional accuracy of the products and increased the overall production capacity of the plant.

3. Installation of New Finishing Rolling Mill at Muroran Wire Rod Mill Plant

The wire rod mill plant of Muroran Works produces wire rods of special steels. These products undergo heat treatment and secondary working such as annealing, drawing, forging, quenching and tempering by secondary and ternary manufacturers and finally turn into safety-related parts for automobiles and other machines. Customers' requirements for high-quality and high-functionality wire rods that allow skipping or simplification of part of the post-processing have increased year by year.

The Muroran wire rod mill plant had responded to these requirements by improving a wide variety of material property items through controlled rolling and cooling, and to further improve the capacity for controlled rolling and cooling, enable a secondary manufacturer to skip annealing and increase the productivity of the plant, introduced the Reducing Sizing Mill (RSM) to the finishing rolling section in July 2001.

3.1 Outlines of new finishing mill

The new finishing mill, which is called the RSM, is a four-stand tandem mill. The former two stands are responsible for the reduction for controlled rolling and the latter two are responsible for light reduction for sizing (see **Photo 3**). **Table 3** gives the main specifications of the new mill. The principal features of the RSM and its effects are described below.

3.2 Controlled rolling and high-precision rolling

To produce soft wire rods that allow users to omit or simplify heat treatment processes, low-temperature rolling is indispensable. For this purpose, the new finishing mill was installed behind the existing finishing mill and between two water-cooling boxes to sufficiently lower the steel temperature during finishing rolling (see the schematic layout in **Fig. 5**). The former two stands of the RSM were designed for high rolling loads of low-temperature rolling (the lowest steel temperature at the mill entry of 750℃); the roll diameter for these stands are 246 mm, larger than that of conventional mills by nearly 20%. All these contributed to achieving the world highest level of controlled rolling capacity.

As a result of the controlled rolling by the new finishing mill and the controlled cooling in the processes after coil laying, the wire rods have tensile strengths lower than those of conventional products by approximately 10% (see **Fig. 6**), making it possible to omit or simplify the heat treatment at secondary manufacturers' plants.

The latter two stands of the RSM are light-reduction and high-precision rolling stands capable of achieving a dimensional tolerance of ± 0.1 mm or less (see **Fig. 7**). The roll gaps of these stands are adjustable during rolling through remote control, and thanks to this remote, on-load screw-down function, operators can easily and

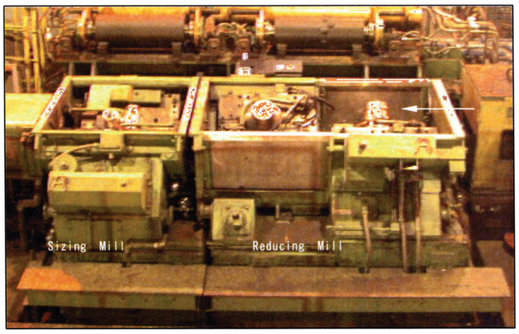

Photo 3 Reducing sizing mill

Table 3 Specifications of Reducing Sizing Mill

Type	4-stand ultra-heavy-duty mill (2 reducing and 2 sizing stands)
Motor capacity	AC 4100 kW
Product size	5.5 - 22 mm ϕ
Rolling speed	Max: 120 m/s
Rolling temperature	Min: 750 ℃
Roll diameter	247 mm ϕ / reducing mill 156 mm ϕ / sizing mill
Roll gap adjustment	Remote control (onload screw down)
Manufacturer	Morgan

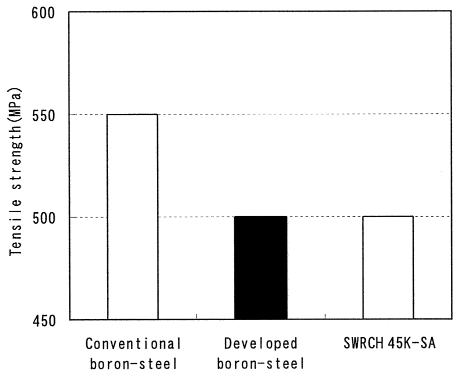

Fig. 6 Tensile strength of boron-steel and JIS SWRCH 45K

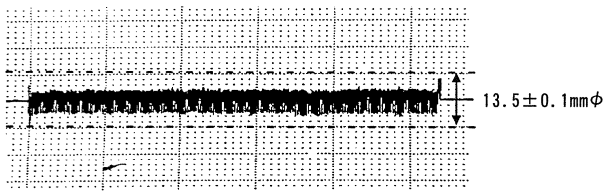

Fig. 7 Size chart (13.5 mm ϕ)

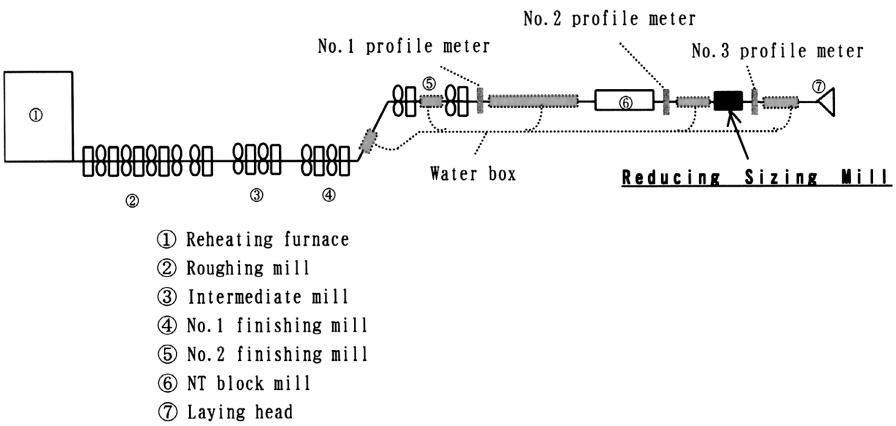

Fig. 5 Layout of Muroran wire rod mill

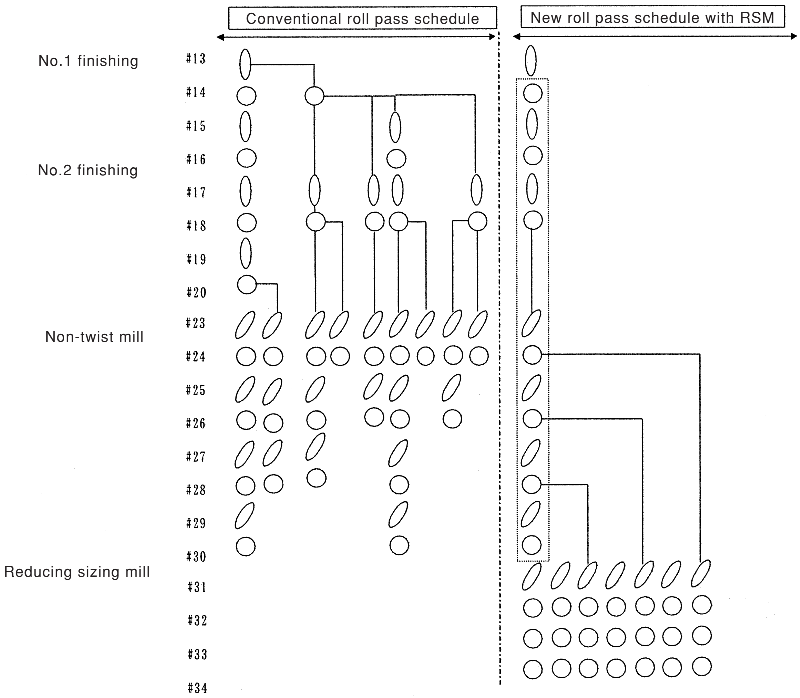

Fig. 8 Roll pass schedule

quickly adjust the roll gaps based on the readings of the profile meters provided before and after the RSM.

3.3 Productivity enhancement

Whereas the inter-stand speedup ratio of the old finishing mill was constant, the gear multiplying unit of the new mill is equipped with a variable transmission so that the inter-stand speedup ratio can be changed, which means that the reduction of area from one pass to another can be changed as appropriate. With this, it became possible to decrease the number of sizes of the incoming material and simplify the roll pass schedule as shown in **Fig. 8**. The time for roll change due to roll wear or size change was significantly reduced thanks to the quick changing method with standby roll stands provided at the line side. Because of the simplification of the roll pass schedule and the quick changing stands, the average size change time was reduced by roughly 30%.

The maximum rolling speed of the new finishing mill is 120 m/s (more than 430 km/h), about 20% higher than that before the introduction of the new finishing mill, and as a result, the production capacity of the wire rod mill line was increased by about 5%.

3.4 Closing

The new finishing mill, the RSM, commissioned in July, 2001, has increased the controlled rolling capacity of the Muroran Wire Rod Mill, improved the dimensional accuracy of its products and increased the production capacity of the plant.

4. Introduction of New Finishing Rolling Mills to Kamaishi Wire Rod Mill Plant

The wire rod mill plant of Kamaishi Works is one of the oldest of this kind in Japan; it was commissioned in October, 1961, and achieved a cumulative production of 20 million tons in September, 2005. Ever since the initial start-up, the mill has undergone various equipment modifications to improve productivity and product quality to keep itself at the technical forefront of the wire rod production in the country. One of the latest principal modifications is the introduction of a mini block mill (MBM) in August 2000 to increase the rolling speed and reduce the number of mill strands. As a result, it is presently operating as a two-strand, high-speed, high-efficiency wire rod mill for producing high-end products typically such as steel tire cord materials.

4.1 Background

As shown in **Table 4**, the Kamaishi wire rod mill was initially constructed by then Schloemann as a four-strand mill to produce 500 kg coils and commissioned in 1961. Then in 1976, the reheating furnace was modified to increase the coil weight to two tons, non-twist mills were installed to increase the rolling speed to 61 m/s, and the number of strands was decreased from four to two. Thereafter, a third strand was added in 1981 to increase the production capacity. The additional strand, No. 3 Course, was equipped with an in-line heat treatment facility called the Slow Cooling System (SCS) to produce wire rods that would enable a secondary manufacturer to skip or simplify part of annealing processes. During the 1980s, techniques for simultaneous rolling of different sizes and steel grades

Table 4 History of Kamaishi wire rod mill

	Event	Strands	Speed	Coil weight
1961	Beginning operation (Schloemann type)	4	30 m/s	500 kg
1976	Non-twist mill	2	61 m/s	2000 kg
1981	Slow cooling system	2	↓	↓
1989	Walking beam type reheating furnace	3		
2000	Mini block mill	2	100 m/s	

were introduced, and in 1989, the reheating furnace was modified into a walking-beam furnace to decrease problems due to decarburization and scratches. These equipment improvements have successfully enhanced the quality competitiveness of the mill.

In the meantime, other steelmakers constructed wire rod mills of higher and higher rolling speeds, and it became necessary to increase the rolling speed of the Kamaishi wire rod mill. Among a variety of solutions studied, the installation of a two-stand mini block mill (MBM) was found effective for increasing the rolling speed with a minimum capital investment.

4.2 Increased rolling speed

4.2.1 Outline

Before the revamping, the roughing mill (nos. 1 to 8 stands/passes) and the first intermediate mill (nos. 9 to 12 stands/passes) were common to the three strands, then the strands followed three different courses, each consisting of the second intermediate mill (nos. 13 to 16 stands/passes) and the non-twist mill (nos. 17 to 26 stands/passes). Since it became clear that, after increasing the rolling speed, two strands would be enough for keeping the same production capacity with three strands, it was decided that one of the three strands (courses) would be shut down. Two units of the two-stand MBM were installed behind the respective non-twist mills of the two courses, as shown in **Fig. 9**. As a result, it became possible to dramatically increase the rolling speed from 61 to 95 m/s. This was made possible by skipping the first two passes (nos. 17 and 18) of the non-twist mill and shifting the roll pass schedule by two passes in the downstream direction, as seen with **Fig. 10**.

4.2.2 Equipment configuration

Before the revamping, the non-twist mill used 8 in. rolls for the nos. 17 and 18 stands, and 6 in. rolls for the no. 19 and thereafter. As a consequence to skipping nos. 17 and 18 passes, the no. 19 stand was modified for using 8 in. rolls, and the no. 20 was revamped to withstand higher rolling loads.

Table 5 shows the main specifications of the MBM; it is a two-stand, Vee-type block mill built by Morgan. In each of the two courses, the MBM was installed behind the non-twist mill with a water-cooling box in between but without loopers. To minimize the unit consumption of rolls, the MBM units were designed to use discarded rolls after use on the non-twist mill. To secure smooth threading from the non-twist mill to the MBM and stable rolling on these mills, the electrical system of the MBM was so designed as to allow control in synchronization with the non-twist mill; such control functions included impact drop compensation control at the threading of the top end, lead ratio control between the two mills during the stable-state rolling and slowdown control at the tailing-off.

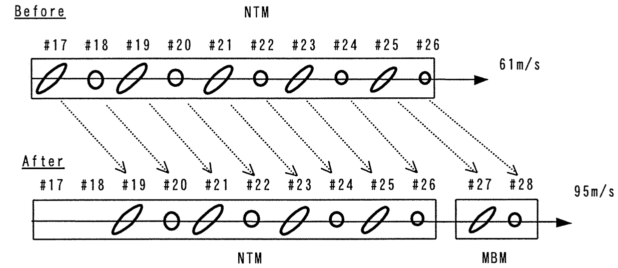

Fig. 10 Pass schedule (ex. 5.5 mm ϕ)

Table 5 Specifications of Mini Block Mill

Type	Vee Mini-Block
Motor capacity	AC 1300 kW
Rolling pass	2 pass
Roll diameter	140 mm ϕ (146.7 mm ϕ - 131.5 mm ϕ)
Rolling speed	95 m/s (Max 110 m/s at 5.5 mm ϕ)
Manufacturer	Morgan

Pinch rolls with screw-down control for both the upper and lower rolls were selected to secure stable feeding of rolled wore rods at high speeds, and auger-type laying heads with a deflector plate were selected. As a result of the higher rolling speed and consequent larger heat input, it was feared that the cooling capacity of the Stelmor conveyers would be insufficient, and as a countermeasure, blowers were moved from the shut-down course to the two remaining courses. With respect to the roughing and first intermediate mills, the increase in required power due to the higher rolling speed was offset by the decrease in the number of strands from three to two, and no modifications to the mill drive system was necessary.

The decrease of strands led to the decrease in the maintenance costs, manpower, unit consumption of energy and rolls, the inventory of guides, etc., significantly improving productivity.

4.3 Decreased number of strands

Taking the advantage of the fact that the MBM was a two-stand mill independent from the non-twist mill, the possibility of size-free rolling was studied. As a conclusion, a two-speed gear multiplying transmission, shown in **Fig. 11**, having two stages corresponding to

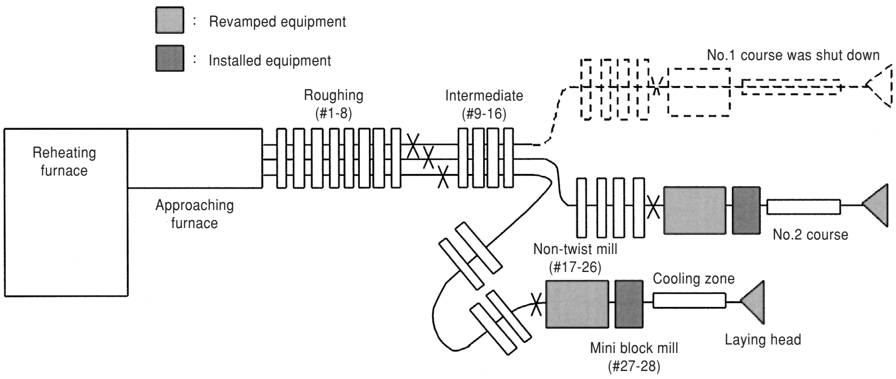

Fig. 9 Layout of Kamaishi wire rod mill

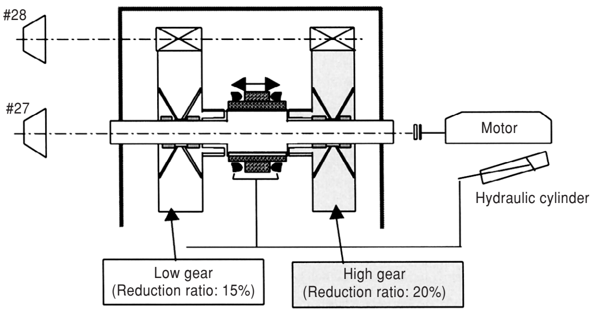

Fig. 11 MBM with two-speed transmission

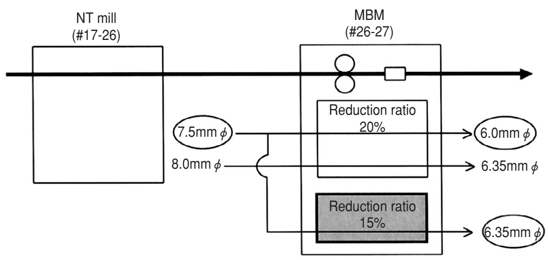

Fig. 12 Example of rolling by low gear

normal and low area reduction ratios (20 and 15%, respectively) was provided for the nos. 27 and 28 stands of the MBM. Thanks to the use of this transmission, it became possible to unify one pass family with another.

Fig. 12 schematically shows an example of low-area-reduction rolling. By normal rolling, the material diameter at the exit from the non-twist mill was 7.5 mm to obtain a final product diameter of 6 mm, and it was 8 mm to obtain a final product diameter of 6.35 mm, which means that it was necessary to change the rolls of the non-twist mill to change the final product size from 6 to 6.35 mm. The two-speed transmission has made it possible to do that simply by switching to the speed for the low area reduction ratio of 15%, without having to change the rolls of the non-twist mill.

The use of the two-speed transmission for the MBM simplified roll pass schedule, and reduced the inventory, unit consumption and changing time of the rolls for the non-twist mill.

4.4 Closing

The introduction of the MBM to the Kamaishi wire rod mill brought about a dramatic increase in the rolling speed with a minimum capital investment for equipment modification. The result was significant decrease in maintenance costs, manpower, unit consumption of energy and rolls, inventory of mill accessories, and roll changing time.

5. Productivity Enhancement of Kimitsu Wire Rod Mill Plant

5.1 Outline

The wire rod mill of Kimitsu Works was commissioned in 1971. Since then, no major revamping has been done to the main equipment of the rolling line, and there have been many problems due to the aging of the equipment such as frequent operation troubles and increasing repair costs. The related people were aware that the plant was inferior to the wire rod mills of other steelmakers in terms of productivity and equipment performance.

In view of the above, renewals of obsolete facilities began with that of mill drive motors in 2001, whereupon their capacities were increased to enhance productivity making the best of the capability of the existing equipment. The following subsections present the outlines and main technical points of the mill motor renewal and other revamping of the mill. For reference, **Fig. 13** shows the layout of the Kimitsu wire rod mill line and major revamped equipment (figures in black).

5.2 Renewal of electrical equipment for finishing mills

5.2.1 Background

Each of the finishing mills (non-twist mills built by Morgan) were driven by two 1150 kW DC motors at a maximum rolling speed of 54 m/s, but after 30 years of operation, they posed frequent problems such as failures due to degradation of insulation and the difficulty in the supply of spare parts and availability of experts due to the old equipment type, and therefore, they were at the top of the list of the electrical equipment that required renewal.

What is more, although the rolling speed of the Kimitsu wire rod mill was among the fastest in the world when it started operation, as the equipment technology advanced and rolling speed of 90 to 100 m/s became commonplace in the field of wire rod rolling, the Kimitsu mill was one of the slowest among the wire rod mills equipped with non-twist mills in the recent years. For this reason, in spite of being a mass production mill with four strands, the productivity of the Kimitsu wire rod mill was not especially competitive over other similar mills in Japan and abroad, and an increase in the rolling speed was strongly required.

5.2.2 Outline of improvements

The main motors of the finishing mills were renewed in October,

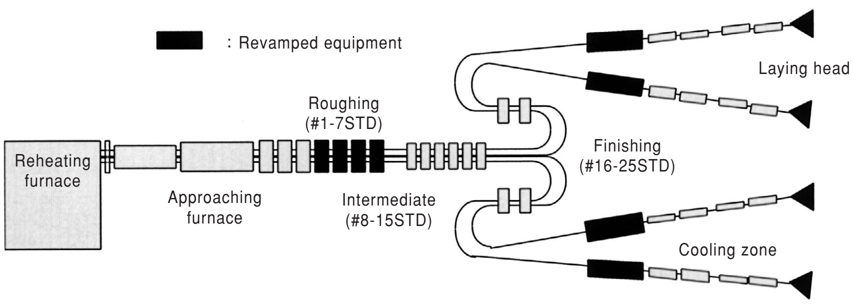

Fig. 13 Layout schematic of Kimitsu wire rod mill

Table 6 Main specifications of finishing mill motor

	Capacity	(rpm)	Supplier
Former	DC1150 kW× 2	600 / 1000	Toshiba
Present	AC 3000 kW	600 / 1000	Toshiba

2001 as a first-priority item. **Table 6** compares the old and new motors. Although the initial intention was simply to replace obsolete motors with new ones, the most advanced AC motors introduced through the renewal required less manpower and cost for maintenance, and made it possible to increase the finishing rolling speed by roughly 20% from 54 to 65 m/s thanks to increased motor capacity (from 2 × 1150 kW to 1 × 3000 kW per strand).

5.3 Renewal of winders

5.3.1 Background

The original winders of the plant, which are shown in **Fig. 14**, were of the so-called wheel-guide-and-laying-cone type, whereby a wire rod immediately after rolling is bent at a right angle, and then formed into rings and put on a cooling conveyer. While the winders of this type are reliable in terms of the shape of the rings, after 30 years of operation, they frequently posed operation and maintenance problems related to the deformation of the cone and deterioration of the holder of the spiral laying pipe.

In addition, their threading performance was insufficient at rolling speeds exceeding 65 m/s, and for this reason, the rolling speed increase was only about 20% although the new mill drive motors allowed higher speeds.

At that time, the rolling speed of many wire rod mills of other works of Nippon Steel and those outside the company was as high as 90 to 100 m/s, and most of them used winders of the so-called pinch-roll-and-laying-head type, whereby a wire rod is bent downward at an angle of 10 to 20° near the exit from the final rolling pass, and then formed into rings and put on a cooling conveyer. The old winder of the wheel-guide-and-laying-cone type was a rare item at that time, and it was obvious that the winders would constitute a bottleneck in further improving the productivity of the mill.

5.3.2 Outline of improvements

The winders were renewed in two stages from 2003 to 2004, and the work was completed in November, 2004. As a result of the renewal of the winders, various additional effects were obtained such as improved control of the top end position on the cooling conveyer and more stable ring shape. The new winders of the laying-head type allowed a rolling speed of 74 m/s, and consequently, the rolling efficiency of the mill was raised by 30% from what it was before the renewals of the mill drive motors and winders.

5.3.3 Problems and solutions

Because of the construction of the old winders, the pass line of the finishing stands was approximately 3 m above the entry to the cooling conveyer. Since it was impractical to reduce this difference in height by raising the cooling conveyers in consideration of the large cost involved, and veering the pass line at a large angle would pose a problem in the threading of the material, it was necessary to limit the turn-down angle before the laying heads within the range of precedent cases, and finally, it was set at 15°, the most common angle among similar mills. To make up for the shorter length of the cooling box behind the finishing mill due to the shallow slope to the laying head and to maintain the same total length of the cooling boxes, an additional cooling box (no. 4) was provided in the slope before the pinch roll stand.

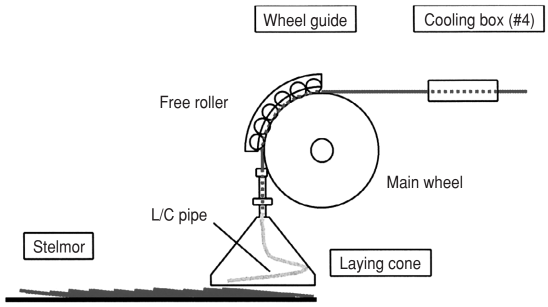

Fig. 14 Wheel guide and laying cone

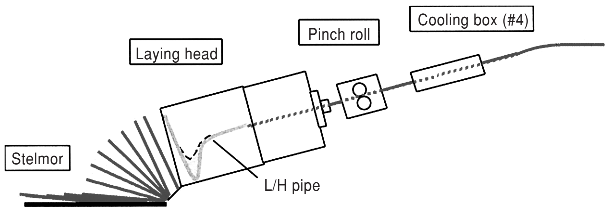

Fig. 15 Laying head

Fig. 15 shows a new winder of the laying-head type and the pass line before it. The equipment arrangement with a slanted cooling box after the turn-down point is rather rare, but this configuration proved effective and posed no problem to product quality.

5.4 Others

After the renewal of the drive motors of the finishing mills, the electrical equipment for the nos. 4 to 7 roughing mill stands, which was most problematic among the electrical facilities for the roughing stands because of degradation due to aging, was renewed in November, 2004. As with the case of the finishing mills, the DC main motors were replaced by the latest AC motors to reduce maintenance costs, and their capacities were increased. Although these roughing mill stands constituted a bottleneck in rolling of some particular sizes, the capacity increase has solved the problem. Besides the above, minor improvements such as a decrease in the extraction pitch and an increase in the draft capacity were introduced to the reheating furnace so that the advantages of the increased mill capacity could be fully enjoyed.

5.5 Closing

The latest measures to improve the rolling efficiency of the Kimitsu wire rod mill have been presented. These renewals and other minor modifications successfully improved the rolling efficiency of the mill significantly making the best of existing equipment and without requiring large-scale replacement of the main facilities.

6. End Remarks

This article presented examples of refurbishments of rolling lines for bars and wire rods. Obviously, these rolling lines will have to undergo further revamping and improvement to remain at the forefront of the market in terms of productivity and cost competitiveness, in response to increasingly stringent customer requirements for higher product quality and performance.