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Hidenori Kondo, Ryo Takeda, Kazuo Ohmori, Norio Kunita.

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Development of Size-Free Rolling Technology for Wire Rod and Bar Using 4-Roll Mill*

Hidenori Kondo
Staff Assistant General Manager, Shape & Bar Technology Sec., Shape & Bar Rolling Dept., Mizushima Works

Ryo Takeda
Staff Deputy Manager, Shape & Bar Technology Sec., Shape & Bar Rolling Dept., Mizushima Works

Kazuo Ohmori
Staff Manager, Development & Design Sec., Process Development Dept., Mizushima Works

Norio Kunita
Senior Engineer, Industrial Machinery Design Dept., Sumitomo Heavy Industries, Ltd. (Deceased)

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1 Introduction

Wire rods and bars are used in various industrial fields and quality requirements vary widely depending on the application. The steel industry is required to supply not merely materials; it must supply optimum materials in an integrated manufacturing process all the way to final products. In particular, in the market for special steel products, such as those for automobiles, the supply of medium-size materials that permit the omission or simplification of the working process and materials of high dimensional accuracy is required in addition to high-degree quality assurance across the entire section and along the entire length.

In wire rod and bar mills from which materials are supplied, it has been general practice to use dedicated grooved rolls for each product size and to change these rolls each time the size of rolled product changes. However, frequent size changes increase the rolling downtime necessary for changing rolls and guides. This makes it necessary to secure the manpower for the changing operation and to keep many rolls and guides on hand, thus increasing manufacturing costs. Therefore, the number of producible sizes has been limited. For this reason, the practical application of a rolling method by which products of different sizes can be produced only by changing the clearance between the same rolls (size-free rolling method) is attracting attention as an epoch-making rolling technology that solves the above problems.

The 2-roll and 3-roll methods have already been put into practical use as size-free rolling technology. However, the new 4-roll method is an excellent rolling method that has very high dimensional accuracy and a wide size-free range compared with other methods owing to its characteristics for widening and caliber

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shape. Kawasaki Steel succeeded in developing size-free rolling technology by the 4-roll method that has such excellent features and introduced this technology in the wire rod and bar mill of its Mizushima Works in April 1994.

This report describes the features of this new rolling technology and the equipment with which this technology was put into practical application.

2 Size-Free Rolling Method

2.1 Features of the Size-Free Rolling Method

In size-free rolling, products of any size can be rolled without the limitations of the pass sizes of the rolls held in a mill, as shown in **Fig. 1** (a). Furthermore, the simplification of the pass schedule of an upstream rolling mill enables the frequency of roll changing to be substantially lowered. The wider the range of the product size capable of being rolled with the same rolls (size-free range), the greater the effect of reduced frequency of roll changing.

In addition, size-free rolling is not limited to finishing mills, as it can be effectively applied to prefinishing mills as shown in Fig. 1 (b).

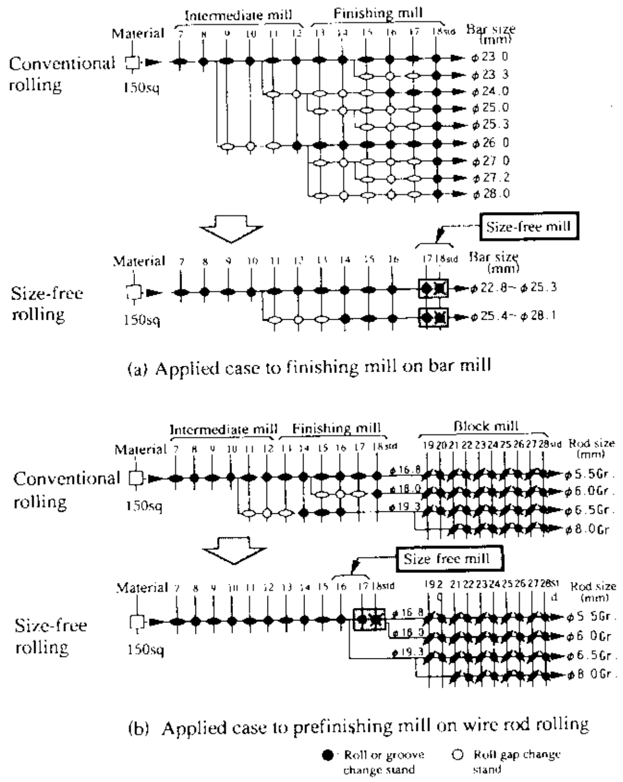


Fig. 1 Comparison of pass schedule between the conventional rolling method and the size-free rolling method

2.2 Kinds of Rolling Methods and Comparison

There are three kinds of size-free rolling as shown in **Fig. 2**. The 2-roll method shown in Fig. 2 (a) and the 3-roll method shown in Fig. 2 (b) have already been put into practical use, and the 4-roll method shown in Fig. 2 (c) is a newly developed technology which will described in this report. As shown in the figure, form rolling is conducted using two passes under the 4-roll method, which has one less forming passes than the other method.

Figure 3 shows the relationship between the change in the gap of the rolls of the same radius, i.e., the size-free range, and the dimensional accuracy of products

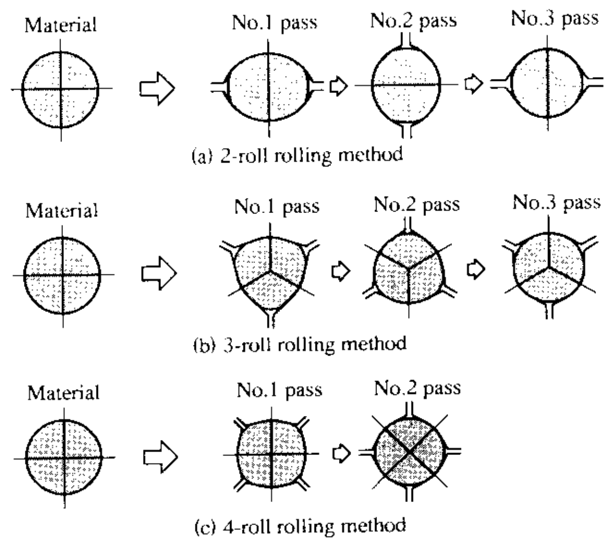


Fig. 2 Size-free rolling methods for finishing passes

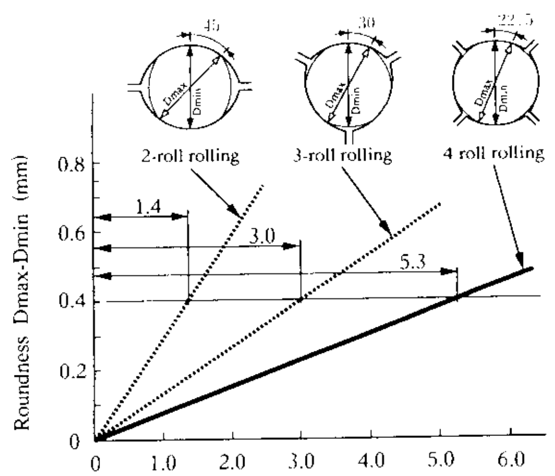


Fig. 3 Comparison of the relationships between roundness of product and amount of roll gap change with rolling methods

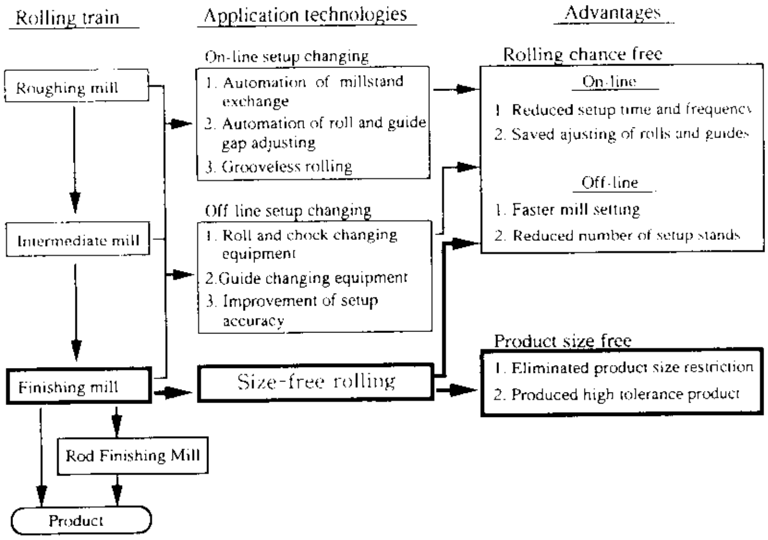


Fig. 4 Advantages of application of size-free rolling

(Dmax − Dmin in the figure) under each of these methods. For example, the size-free range available when products with dimensional accuracy of within 0.4 mm are to be obtained is 1.4 mm under the 2-roll method, 3.0 mm under the 3-roll method, and 5.3 mm under the 4-roll method; hence, the size-free range is the widest under the 4-roll method. Although this is a geometric comparison, it is apparent that the 4-roll method has excellent features as a size-free rolling method.

2.3 Effects of Application to Actual Mills

Figure 4 shows the effects expected when size-free rolling is applied in a general bar mill composed of a roughing mill, an intermediate mill and a finishing mill. The application of size-free rolling in finish rolling is effective not only in eliminating the product size limitations, but also in lessening the rolling chance limitations by reducing the roll-changing time and the frequency of roll changes.

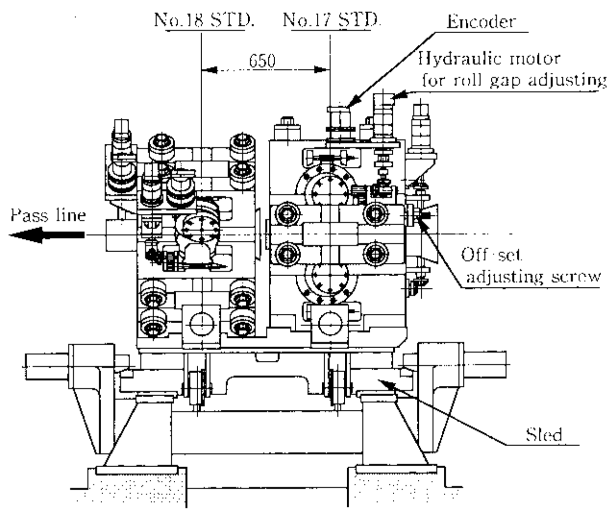


Fig. 5 Outside view of 4-roll mill

3 Development of 4-Roll Rolling Technology

3.1 Development of 4-Roll Rolling Equipment

The greatest reason why the 4-roll method has not been put into practical use despite its excellent characteristics as a size-free rolling method is that generally, the larger the number of rolls, the more complex the mill structure must be, making it difficult to provide the functions required in a compact commercial mill, such as the screw-down mechanism. For this reason, the 4-roll method has so far been limited to laboratory mills[1]. Therefore, the key point in putting the 4-roll rolling method into practical use was to develop simple rolling equipment in which various new technologies are combined.

3.1.1 4-roll mill

As shown in **Fig. 5**, the newly developed 4-roll mill comprises two 4-roll mill stands, which, separated by a short distance of 650 mm, are mounted on one sled. This is a compact mill whose rolls are arranged in such a manner that the No. 17 stand has a cross " + " shaped configuration and the No. 18 stand has an " × " configuration.

The main features of this mill are described below.

(1) 2-Roll Drive

If all four rolls are driven in 4-roll rolling, the mill structure becomes very complex, making it difficult to put the 4-roll method into practical use in terms of maintainability.

Therefore, a method by which only two rolls are dri-

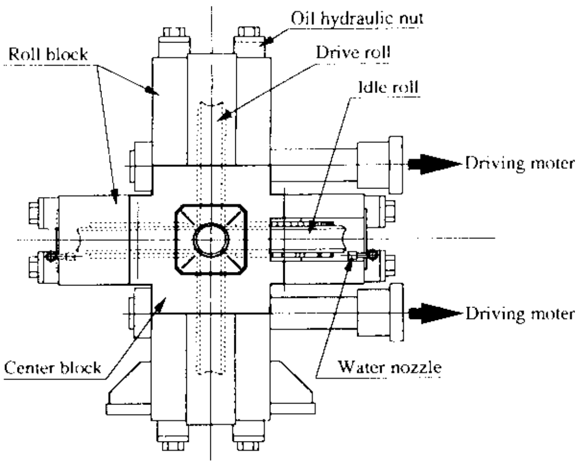


Fig. 6 Construction of 4-roll mill housing

ven by motors as in the 2-roll mill was adopted as shown in **Fig. 6** and the mill was given a simple housing structure so that the 4-roll method can be put into practical use. However, the other two rolls are rotated using pressurized water to prevent the occurrence of surface defects caused by the slippage of both the material being rolled and the rolls themselves when the material enters the roll gap.

(2) Roll Axis Offset

Roll axis offset refers to shifting the axes of the nondriven rolls relative to the axes of the driven rolls in the rolling direction, as described in 3.2.2 to prevent the mutual interference of the rolls. As a result, the roll gap adjustment allowance expands by the amount of offset and the size-free range increases. Furthermore, stable material entry is obtained because the material is first drawn into the driven rolls.

The No. 17 stand was given a mill structure capable of roll axis offset in order to control the material strain described in 3.2.3 in addition to the above objective. The stepless adjustment of offset can be made by loosening the oil hydraulic nut fixing the roll block shown in Fig. 5 and rotating the offset adjusting screw.

Because the No. 18 stand is for the finishing pass, the size-free range is determined by the target dimensional tolerance of the product. The material entry conditions are improved by minimizing the distance from the preceding stand and the roll axes are not offset to obtain a simpler mill structure.

(3) Housing Structure

As shown in Fig. 6, the block construction is such that four roll blocks are fixed to the center block with oil hydraulic nuts through tie rods. This has improved maintainability and achieved high rigidity.

(4) Roll Gap Adjustment

As shown in Fig. 5, the gap between the top and bottom rolls and the gap between the left and right

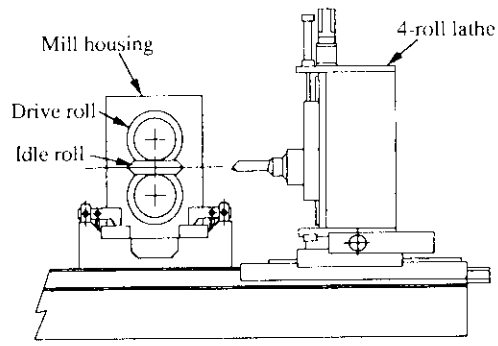


Fig. 7 Outside view of 4-roll conditioning device

rolls can be separately adjusted by remote control using a set of hydraulic motors and encoders for control installed for a pair of rolls.

3.1.2 Off-line equipment

Preparations for the succeeding rolling, such as the changing of rolls and guides of the mill and dressing of worn rolls, are conducted off-line.

The following three methods are available: (1) a method by which a rolling mill is provided for each kind of caliber and a changeover is made to a rolling mill for the next size, (2) a method by which rolls are provided for each kind of caliber and the rolls of a rolling mill are replaced after use with those for the next size, and (3) a method by which the rolls that are kept installed in a rolling mill are remachined to the next size.

Method (3), which allows the equipment costs to be reduced because of fewer rolling mills, does not need complicated roll-changing work, ensuring a short preparation time. Thus it was adopted and an efficient system for making preparations for rolling was established.

(1) 4-Roll Conditioning Device

The device shown in **Fig. 7** is a three-dimensional roll conditioning device provided with an NC unit, developed for use in 4-roll mills only. A power source for rotation is connected to each of the rolls kept installed in the mill housing and the rolls are rotated in a preload condition in order to improve the roll position accuracy. High-efficiency and high-accuracy roll dressing is accomplished by dressing the four rolls at one time.

A method by which only the grooved portion is gradually remachined from the groove for a small size to that for a large size was adopted as the roll dressing method and a system for making preparations for rolling was built accordingly. Therefore, products of a wide size range can be efficiently rolled with little need for changing rolls.

(2) Other Off-Line Equipment

There are off-line operations in addition to roll dressing, that is, maintenance operations such as the replacement of worn rolls, and inspection and replace-

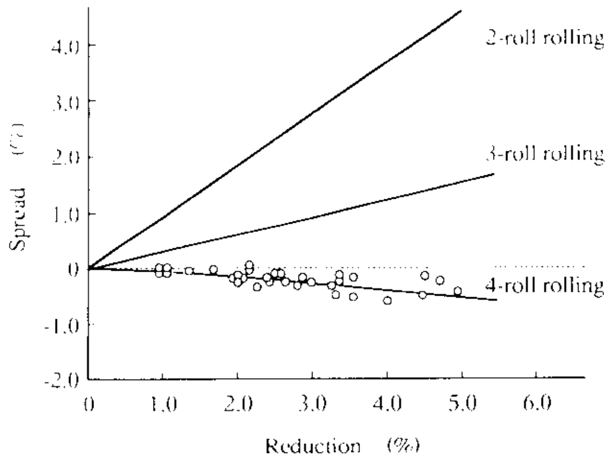


Fig. 8 Comparison of spread by each rolling method

ment of parts. These operations were also thoroughly mechanized in order to increase efficiency. The main equipment developed for this purpose includes a mill-housing dismantling and assembling device and a roll-shaft dismantling and assembling device.

3.2 Rolling Characteristics of 4-Roll Mill

For the width deformation characteristic that is the basics of wire rod and bar rolling, it is known that the rolling characteristic is such that width increases under the 2-roll and 3-roll methods, but narrows under the 4-roll method[1,2]. On the other hand, few studies have been made on the effect of roll axis offset, which was applied in this technology, and strain characteristics affecting the internal quality of products.

Therefore, experiments and studies were conducted in order to incorporate the above characteristics into actual equipment in developing this technology. The following are the results of these studies.

3.2.1 Width deformation characteristic

In wire rod and bar rolling, it is known that the material being rolled is subjected to three-dimensional deformation due to reduction. Therefore, controlling the diameter of the free surfaces that are not constrained by the grooved face of the roll, i.e., the dimension of width, is one of the most important factors that determine the dimensional accuracy of products. This accuracy has been improved by improving the skills of operators and developing control technology. However, the control accuracy has had limits because the width varies depending on such conditions as rolling temperature, steel grade of the material rolled and roll diameter.

Figure 8 shows a comparison of the width deformation conditions affecting the above width variations under various rolling methods. The extent of width deformation is the largest under the 2-roll method while that of the 3-roll method is only half the level. In the case of the 3-roll method, however, the extent of width deformation from the center of a section is almost the same as under the 2-roll method because the width deformation is concentrated on the free surface of one side. In contrast, width deformation scarcely occurs at reductions of 10% or less under the 4-roll method, shattering the conventional concept of three-dimensional deformation. Thus it is possible to treat the width deformation like two-dimensional deformation. Therefore, size control is very easy, eliminating the need for size adjusting operators, who have been indispensable for the conventional methods, while enabling products of high dimensional accuracy to be produced without the influence of rolling conditions.

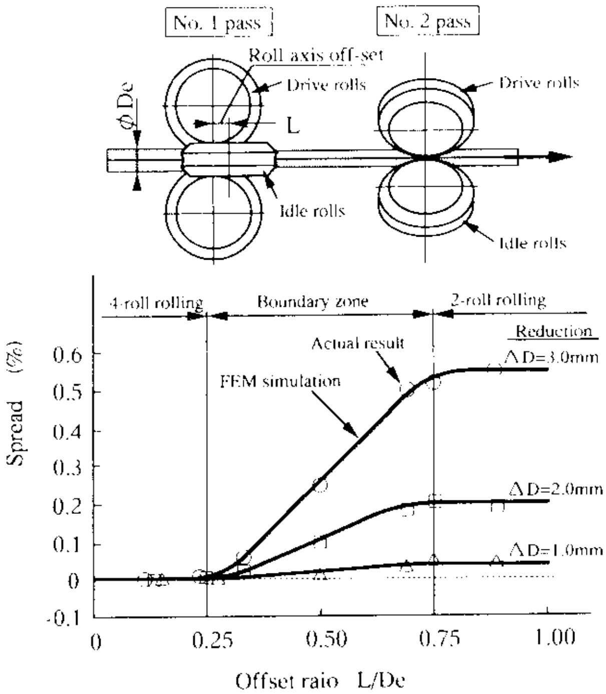


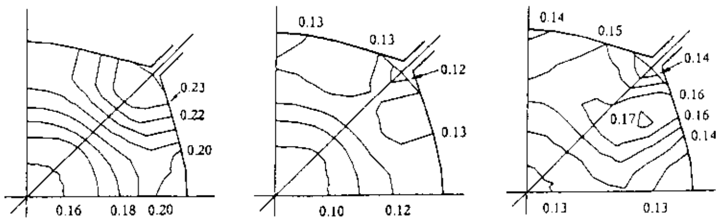
Fig. 9 Effect of roll axis offset on spread of stock rolled by 4-roll mill (where De = 48 mm)

3.2.2 Roll axis offset characteristic

As shown in **Fig. 9**, roll axis offset shifts the axis of the left and right rolls relative to the axis of the top and bottom rolls of No. 1 pass in the rolling direction. This figure shows the results of an analysis of the roll axis offset on width spread conducted by the three-dimensional rigid-plastic finite element method[3].

Spread is very small at offset ratios (amount of offset/material diameter on the entry side) of 0.25 or less and the characteristics of the 4-roll method can be obtained. Spread increases at an offset ratio of 0.25 or above and the characteristics of the 2-roll method are obtained at an offset ratio of 0.75 or above.

Therefore, the offset ratio is set at 0.25 or less when rolling is conducted under the 4-roll method of the width deformation characteristic described in 3.2.1. The offset



(a) De = 21.0 mm
ΔD = 2.0 mm
L/De = 0.0

(b) De = 21.0 mm
ΔD = 1.2 mm
L/De = 0.0

(c) De = 21.0 mm
ΔD = 1.2 mm
L/De = 0.5

Fig. 10 FEM simulation results of sectional strain distribution of the stock rolled by 4-roll mill

ratio ranges from 0.25 to 0.75 when rolling is conducted under conditions between the 4-roll method and the 2-roll method. Thus the offset ratio is set depending on the desired conditions.

3.2.3 Section strain distribution characteristic

The equivalent strain distribution in the section of a material rolled in 4-roll rolling was analyzed by the three-dimensional rigid-plastic finite element method. The results of this analysis are shown in **Fig. 10**.

When the effect of the rolling reduction ($\Delta D/De$) was examined, it was found that strain was lower in the case shown in Fig. 10 (b) where the reduction was lighter than the case shown in Fig. 10 (a) where the reduction was heavy, and that the strain distribution was such that strain was low especially in the center and on the free surface. In the case of Fig. 10 (c) where the roll axis offset was conducted, however, strain increased across the full section.

This suggests that roll axis offset is effective in preventing the coarsening of the material texture, which is said to occur generally when low-reduction, high-temperature rolling is conducted.

4 Application to Actual Operation

4.1 Condition of Application

As shown in **Fig. 11** and **Table 1**, a 4-roll mill is used as the finishing mill of bars and as the prefinishing mill of wire rod in a wire rod and bar mill. Square billets of 150 mm square are used as the material and products 16 to 85 mm in diameter are produced by size-free rolling using 20 kinds of roll grooves.

4.2 Results of Operation

Figure 12 shows a comparison the actual sizes of products produced by the conventional 2-roll method and the new 4-roll method. The example of 42 mmϕ shows regular-tolerance products and the dimensional accuracy is higher under the 4-roll method. The example of 30 mmϕ shows narrow-tolerance products. In this case, products with ultra-high dimensional accuracy of ± 0.05 mm can be rolled by selecting an appropriate groove radius.

The actual results of dimensional accuracy of actual products are summarized in **Fig. 13**. This includes plots of products obtained when only the gap of the same grooved rolls was changed. Here we can see that it has become possible to produce products of high dimensional accuracy of within ± 0.2 mm in the wide size-free range of about 10% of material diameter on the entry side.

Figure 14 shows a comparison of the dimensional accuracy obtained under each rolling method in the size-free range for the rolling of precision-rolled products with dimensional accuracies of ± 0.1 mm and regular-tolerance products with dimensional accuracies of ± 0.2 mm.

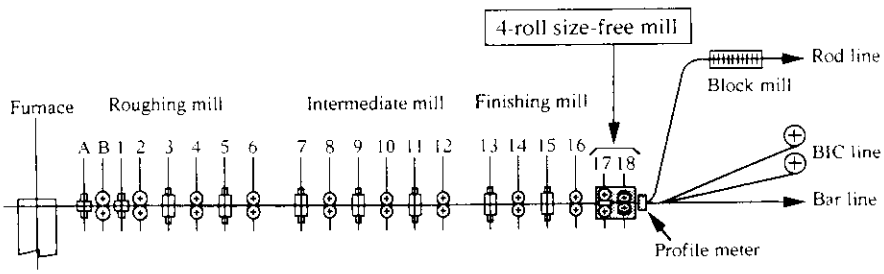


Fig. 11 Layout of bar and rod mill at Mizushima Works

Table 1 Specifications of 4-roll size-free mill for bar and rod at Mizushima Works

Items			Specifications
Mill capacity	Product size range	(mm)	ϕ 16 ~ ϕ 85
	Rolling speed range	(m/s)	0.8 ~ 16.0
	Maximum rolling load	(t)	50
	Mill constant	(t/min)	100
Roll screw down	Screw down range	(mm)	Pitch roll dia. : 400 ± 4.5
	Screw down method		Control : Remote operation
	Accuracy	(mm)	± 0.02
	Time	(s)	3.0
Roll drive	Drive method		2 rolls driven by electric motor 2 rolls rotated by pressurized water
	Motor specification	(kW)	No.17 std. : DC 1 200 − 480/1 200 rpm No.18 std. : DC 450 − 600/1 000 rpm
Stand setup	Exchange method		Automatic operation using sled
	Time	(min)	3.5

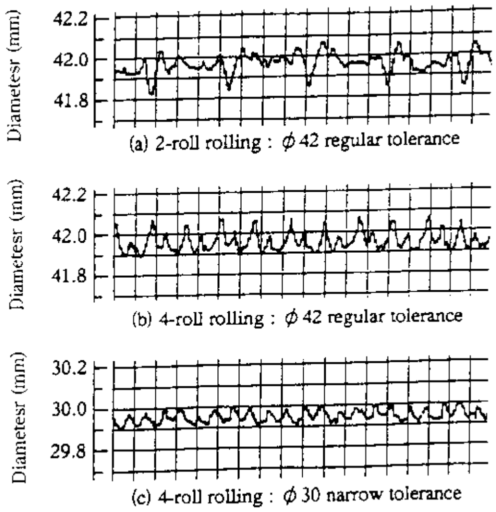


Fig. 12 Results of product diameter measured by profile meter

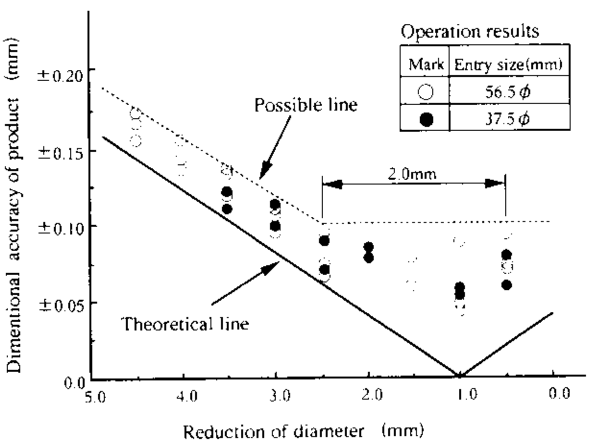


Fig. 13 Actual result of dimensional accuracy of products rolled by 4-roll size-free rolling

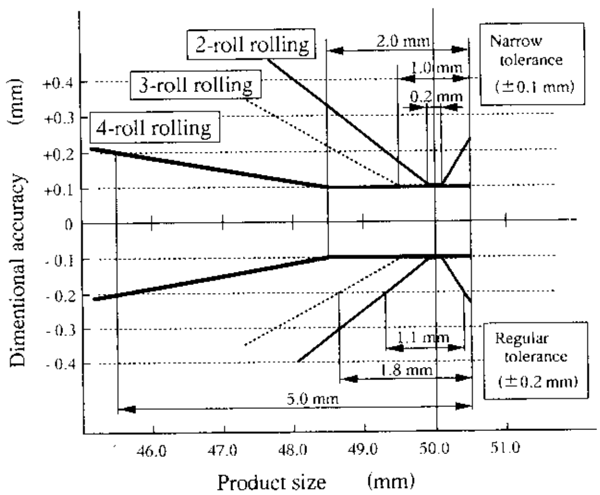


Fig. 14 Comparison of dimensional accuracy of each size-free rolling

4.3 Effects of 4-Roll Mill

The following effects were obtained as a result of the introduction of the 4-roll mill in the wire rod and bar mill:

(1) Production of High Value-Added Products

It has become possible to manufacture products of any diameter suitable for succeeding operations and products of high dimensional accuracy that permit the simplification or omission of drawing and peeling, which are the succeeding operations.

(2) Increase in Production Capacity

As shown in **Fig. 15**, the production capacity expanded by 20% and labor productivity increased to 1.5 times the level before the introduction of the 4-roll mill owing to the improvement in mill working efficiency resulting from a decrease in the frequency of roll changes, etc.

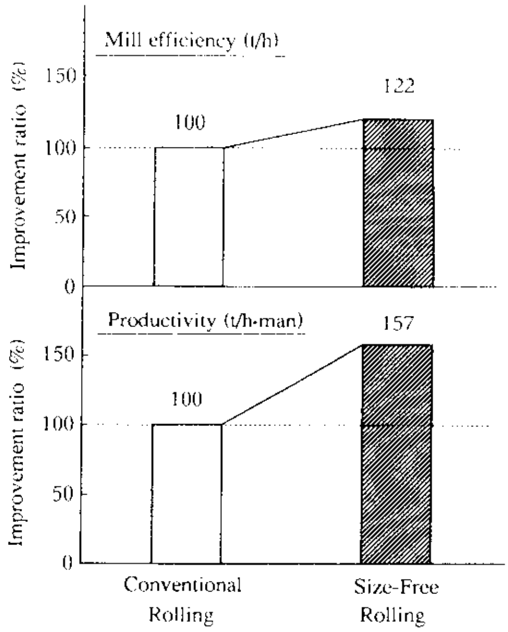


Fig. 15 Improvement of operation by installing 4-roll size-free mill

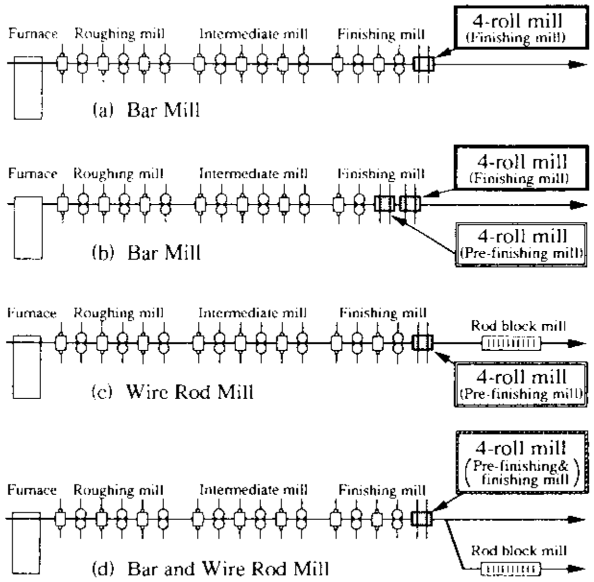


Fig. 16 Application examples of 4-roll mill to bar mill and wire rod mill

(3) Reduction of Manufacturing Costs

In addition to an increase in the production efficiency and an improvement by the reduction of the number of operators for off-line product size adjustment and off-line preparations for the rolling mill, a substantial reduction of manufacturing costs was achieved owing to a decrease in energy and roll consumption.

5 Applications of the 4-Roll Mill

The greatest feature of the 4-roll method is the wide free-size range. Because rolling can be conducted at a wide range of reduction of sectional area, the 4-roll mill can be used as a prefinishing mill that requires reduction of sectional area in addition to the finishing mill that requires the dimensional accuracy described in this report and great economic effects including an increase in productivity due to the integration of pass schedules of upstream rolling mills can be expected.

Figure 16 shows the mill layouts when a 4-roll mill is applied in various bar mills and wire rod mills.

6 Conclusions

Kawasaki Steel has developed size-free rolling technology using the 4-roll method as a new rolling technology in bar and wire rod rolling, the first of its kind in the world.

This 4-roll rolling technology provides better dimensional accuracy of products and uses the size-free range to the fullest extent. At the same time, many new technologies including the 2-roll driving method were incorporated in order to give the 4-roll mill the excellent operability and maintainability that are necessary for a commercial mill.

The 4-roll mill based on this technology was introduced in the wire rod and bar mill at the Mizushima Works in April 1994. It started size-free rolling, which is making great achievements in the production of high value-added products and the reduction of manufacturing costs.

References

1) K. Hiraki, Y. Inami, S. Suzuki, S. Ochi, and S. Kamoto: *Journal of the JSTP*, **34**(1993)3, 253
2) K. Kato: *Journal of the JSTP*, **31**(1990)8, 984
3) K. Omori, A. Karino, K. Kondo, and R. Takeda: The Proceeding of 46th Japanese Joint Conference for the Technology of Plasticity, (1995)9, 383