KAWASAKI STEEL TECHNICAL REPORT
No.37 (October 1997)
Rolling Technology and Modernization of Chiba Works

Technologies for High Speed Rolling and Gauge Control in Cold Tandem Mill for Ultra-Thin Gauge Strip

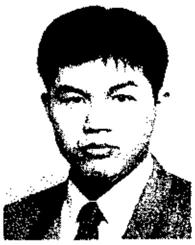
Tomohiro Kaneko, Hiroaki Masuda, Kohei Takezawa

Synopsis :
High productivity and gauge accuracy are required of a tandem cold rolling mill that produces ultra-thin gauge strip, such as a tin mill black plate. Until now, the authors have improved lubrication for cold rolling by developing a new direct rolling oil and a Ti-enhanced work roll having high wear resistance for No. 2 TCM of Chiba Works. As a result, it has been made possible to conduct rolling at an ultra-high speed, that is 2 800 m/min, and productivity has been remarkably improved. Furthermore, in order to achieve a major increase in gauge accuracy at high rolling speed cold tandem mill the authors applied a roller bearing to back up roll for high speed rotation and replaced mill motors with high response AC motors. As a result, the gauge accuracy during rolling has been improved to ±1.0% at a steady rolling speed and ±1.5% in acceleration and deceleration.

KAWASAKI STEEL TECHNICAL REPORT No. 37 October 1997

Technologies for High Speed Rolling and Gauge Control in Cold Tandem Mill for Ultra-Thin Gauge Strip*

Tomohiro Kaneko
Staff Assistant Manager, Cold Rolling Sec., Cold Rolling Dept. I, Chiba Works



Hiroaki Masuda
Cold Rolling Plant Control Sec., Plant Control Dept., Chiba Works

Kōhei Takezawa
Staff Deputy Manager, Maintenance Control Sec., Equipment Technology Dept., Chiba Works

Synopsis:

High productivity and gauge accuracy are required of a tandem cold rolling mill that produces ultra-thin gauge strip, such as a tin mill black plate. Until now, the authors have improved lubrication for cold rolling by developing a new direct rolling oil and a Ti-enhanced work roll having high wear resistance for No. 2 TCM of Chiba Works. As a result, it has been made possible to conduct rolling at an ultra-high speed, that is 2 800 m/min, and productivity has been remarkably improved. Furthermore, in order to achieve a major increase in gauge accuracy at high rolling speed cold tandem mill the authors applied a roller bearing to back up roll for high speed rotation and replaced mill motors with high response AC motors. As a result, the gauge accuracy during rolling has been improved to ± 1.0% at a steady rolling speed and ± 1.5% in acceleration and deceleration.

1 Introduction

In order to increase productivity, the maximum rolling speed of tandem cold mills for ultra-thin gauge strips, such as tin mill black plates, is commonly designed to be higher than that of sheet-gauge mills. However, surface defects are sometimes generated as a result of poor lubrication and cooling.

Various measures have been taken to improve lubrication at the No. 2 tandem cold rolling mill in No. 1 cold rolling plant of Chiba Works which is the main rolling mill for producing the tin mill black plates at Kawasaki Steel. These efforts have made it possible to produce more than 100 000 t/month at present. Although the maximum rolling speed had been specified as 2 260 m/min, the equipment was modified in July 1995 so that the maximum speed could be increased up to 2 813 m/min.

In addition, the gauge of tin mill black plates has been becoming lighter and demands for higher gauge accuracy have increased in recent years. In order to meet customers' demands, roller bearings were adopted for the back-up rolls at every stand of the mill in July 1993[1], and the mill motors were remodeled in July 1995 to improve responsiveness. As a result of these modifications, the gauge accuracy during steady rolling, acceleration and deceleration has been markedly improved.

This paper gives a brief description of the technologies used for high-speed rolling and for improving gauge accuracy in this operation.

2 Outline of Equipment

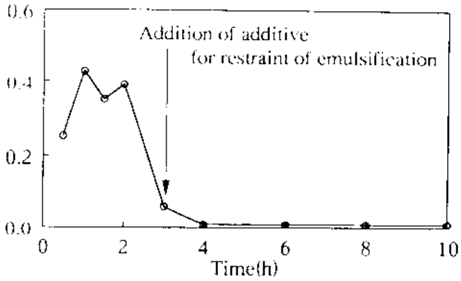
The No. 2 tandem cold mill, constructed in 1963, was revamped into a fully continuous rolling mill in 1984. Extensive automation was incorporated in the mill as part of this conversion. In addition, gauge accuracy was improved at the leading and tail ends of strips. The major specifications of the No. 2 tandem cold mill are shown in **Table 1**. The most important feature of the mill is that ultra-thin gauge strips (average delivery thickness = 0.23 mm) for both tin mill black plates and tin-free steel, as well as strips for galvanized steel, can be rolled at the high speed of 2 813 m/min. Another special feature of the mill is that a direct application method has been adopted to supply rolling oil so that strips can be rolled at higher speeds.

---

* Originally published in *Kawasaki Steel Giho*, **28**(1996)2, 108–113

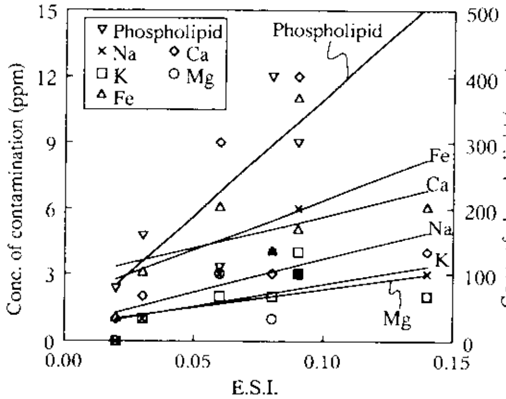
Table 1 Specifications of No. 2 tandem cold mill

Type	Fully continuous 6 stand tandem mill (4-Hi)
Rolled material	Mild steel (for tin plate, TFS, GI)
Max. mill speed (m/min)	2 813
Delivery thickness (mm)	0.1 ~ 1.0
Strip width (mm)	508 ~ 1 295
Work roll diameter (mm)	495 ~ 610
Backup roll diameter (mm)	1 270 ~ 1 427
Application	Direct



E.S.I. = (Conc. of lower 100cm^3) / (Conc. of upper 100cm^3)
Sampling 400 cm^3 emulsion and leaving sample as it is for 2 min

Fig. 1 Transition of ESI



E.S.I. = (Conc. of lower 100cm^3) / (Conc. of upper 100cm^3)
Sampling 400 cm^3 emulsion and leaving sample as it is for 30 s

Fig. 2 Concentration of contamination by ESI

3 High-Speed Rolling Technology

3.1 Development of a New Direct Rolling Oil

3.1.1 Application of a new additive for restraining emulsification of the rolling oil

In tandem cold mills which are provided with a direct application of rolling oil such as the No. 2 tandem cold mill, the efficiency of plating-out is very important for good lubrication. The plating-out properties of rolling oil are strongly affected by its emulsification conditions, which are commonly indicated by an emulsion stability index (ESI). It is desirable to suppress any emulsification of rolling oil and to make its ESI as close to zero as possible in order to increase the plating-out of the oil. The praticle size of emulsion is reduced by mechanical agitation and shearing. Moreover, the surface of the rolling oil particles is charged negatively and electrical repulsion works between the particles. As a result, emulsification becomes steady. However, the properties of plating-out become worse with this stability. In the past, crude and regenerated palm oil were emulsified and used as rolling oil in the No. 2 tandem cold mill. These oils had a rather high ESI value of between 0.3–0.8 and were unstable.[2)] As a result, the rolling lubrication changed from time to time, affecting productivity.

Under such conditions, it is possible to increase particle sizes by neutralizing emulsified particles that are negatively charged. For this purpose, a cation polymer coagulant was developed as an additive for restraining emulsification. The results of tests to confirm the effect of the additive in the actual mill showed that the ESI became nearly zero immediately after the additive had been added and stabilized without any further changes as shown in **Fig. 1**. In these tests, the sample of rolling oil was allowed to settle for 2 min before the measurements.

3.1.2 Improvement of base oil for rolling oil

While the additive successfully decreased the ESI and lubrication was thus stabilized, additional studies were also carried out from the view point of base oil in order to reduce ESI and to improve lubrication performance even further. In an actual mill, the plating-out of rolling oil onto strips occurs almost instantaneously. In order to simulate the actual plate-out phenomenon, the period before measurement was shortened from 2 min to 30 s. Under these conditions, it was found that the effect of the additive differs depending on the concentration of the inorganic contaminants and phospholipid in the rolling oil. The change of ESI is shown in **Fig. 2**. The variations of the effect of the additive resulted from the degree of its coagulation. This is because inorganic contaminations in crude palm oil are tied with free fatty acid while phospholipid is tied with the additive itself. The additive should have electrially neutralized the rolling oil drops by being tied with free fatty acid in the rolling oil.

In order to resolve this problem, a new rolling oil based on a refined, bleached and deodorized palm oil was developed. The additive works effectively only when free fatty acid exists. When inorgainc contaminants and phospholipid are removed from the crude palm oil, the additive acts in a sensitive fashion so that ESI fluctuates in response to even slight changes in the quantity of the additive and the concentration of the con-

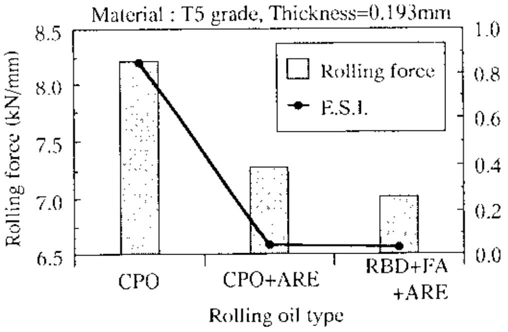


Fig. 3 Effect of improvement by rolling oil

taminants. For these reasons, the optimum fatty acid and the optimum quantity of the additive were determined so that the plating-out properties of the oil would not be affected by the above-mentioned factors and the coagulation effect would be kept high.

3.1.3 Effect of new direct supply rolling oil

The new rolling oil was developed by selecting the proper amounts of the additive, base oil and fatty acid as described in the preceding paragraphs. When the rolling oil was tested in actual mill operations, the properties of the rolling oil lubrication were found to have been inproved as shown in **Fig. 3**. This oil is currently being used for actual production and contributes to high productivity[3].

3.2 Development of a High Wear-Resistant Work Roll

3.2.1 Introduction

Work rolls which possess excellent wear resistance are required for cold rolling mills as a means of improving rolling efficiency and reducing product cost. High Cr forged rolls (5–10% Cr) and semi high-speed steel rolls (tool rolls) are being used in other mills, but these kinds of rolls have some problems such as difficult grinding and high cost of roll manufacturing compared to conventional Cr-type rolls.

The microstructure of the cold rolling work roll mainly consists of a martensitic matrix and distributed Cr-carbides. It is obvious that enrichment with hard carbides effectively improves the wear resistance of work rolls. However from the view point of roll ductility and grindability, it is important that the carbides be as minute and uniformly distributed as possible. Ti has strong affinity with carbon and nitrogen, and minute titanium carbo-nitrides precipitate during solidification. For these reasons, Ti was selected as the element to improve the wear resistance of work rolls. The authors developed a new Cr steel work roll containing minute and uniformly distributed titanium carbo-nitrides. This has increased wear resistance at small additional cost[4]. This chapter describes the performance of the Ti-enhanced work roll in a cold rolling mill.

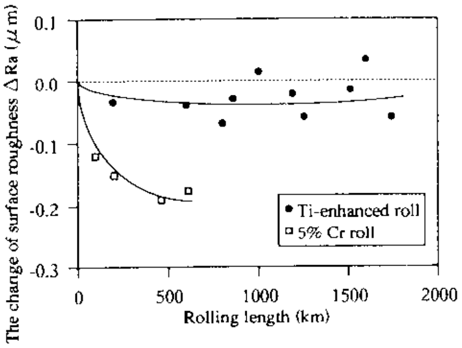


Fig. 4 The change in surface roughness of work roll at finishing stand

3.2.2 Application to an actual rolling mill

(1) Grindability

A common problem with work rolls is their grindability. When the newly developed work rolls were ground using a conventional whet stone, scratches appeared which were caused by titanium carbo-nitride particles. However, the grindability was improved by improving the whet stone and grinding techniques. It thus became possible to use the newly developed roll at the finishing stand of a rolling mill for tin mill black plates.

(2) Evaluation of Wear Resistance

Figure 4 shows a comparison of changes in the surface roughness of work rolls when 5% Cr rolls and Ti-enhanced rolls were used on the finish stand of an actual cold rolling mill. In the figure, initial wear is clearly observed with the conventional 5% Cr roll. However, initial wear was very small when the Ti-enhanced roll was used. In addition, almost no changes in roughness could be observed even after the new rolls were used for a rolling length twice that of conventional rolls. It can also be seen that roughness was somewhat stabilized[5].

(3) Improvement in Rolling Efficiency

Usually the initial roughness at the grinding stage is specified so that the most suitable friction coefficient can be obtained after the initial wear. As a result, the rolling speed could not be increased just after the work rolls were changed because lubrication of rolling was inferior at the beginning. However, because there is little initial wear of the surface in the Ti-enhanced work rolls, initial surface roughness of the work roll can be adjusted to make the friction coefficient most suitable for rolling from the very start of use. Moreover, the roughness of such rolls remains relatively unchanged for a long time. As a result, the frequency of changing work rolls can be reduced, making it possible to operate the rolling mill continu-

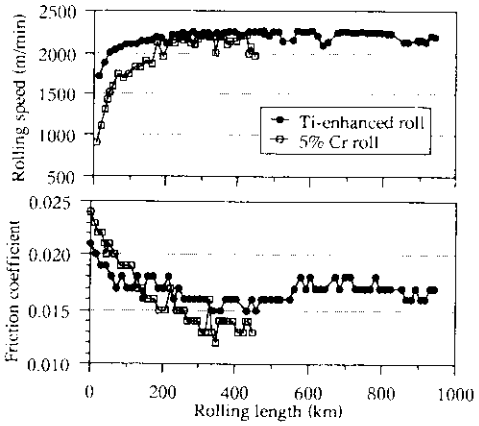
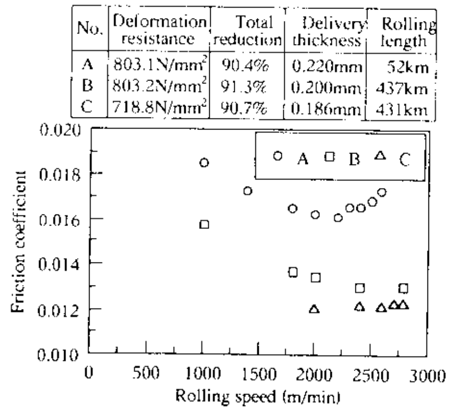


Fig. 5 The change in rolling speed and friction coefficient during rolling length



No.	Deformation resistance	Total reduction	Delivery thickness	Rolling length
A	803.1N/mm²	90.4%	0.220mm	52km
B	803.2N/mm²	91.3%	0.200mm	437km
C	718.8N/mm²	90.7%	0.186mm	431km

Fig. 6 Relation between rolling speed and friction coefficient

ously with the most suitable coefficient of friction.

Figure 5 shows the changes in the relation between rolling length and rolling speed at a finishing stand. We can see that the use of the Ti-enhanced work roll makes it possible to start operating the rolling mill at nearly the maximum rolling speed immediately after rolls are changed. Furthermore, roll life is extended, resulting in an increase in the ratio of the maximum rolling speed, and rolling efficiency is dramatically improved.

3.3 Behavior under Ultra-High-Speed Rolling

Generally speaking, rolling oil at the inlet of the roll bite tends to be drawn into the bite due to the wedge effect, and the coefficint of friction decreases as rolling speed increases. However, the temperature of the roll bite rises under high-speed rolling conditions causing the rolling oil temperature at the inlet of the roll bite to increase as well. As a result, the viscosity of rolling oil decreases and the coefficient of friction tends to increase. For this reason, the behavior of the coefficient of friction in the roll bite has become important in determining rolling speed in the operation of rolling mills.

Nevertheless, high-speed rolling at speeds as high as 2 800 m/min has become possible due to the effects of various measures to improve rolling lubrication as mentioned above. **Figure 6** shows the relation between rolling speed and the coefficient of friction in a roll bite at the finishing stand. By improving rolling lubrication, the friction coefficient at over 2 000 m/min becomes small enough even under the severe conditions of high deformation resistance and a high reduction in strip thickness, while the roughness of work roll remains high.

3.4 Improvement in Productivity though the Establishment of Ultra-High-Speed Rolling Technology

As described above, the productivity of rolling could be improved by the development of high-wear work rolls and a rolling oil that has superior properties of plating-out despite the lightening of the strip gauge, as shown in **Fig. 7**. As a result, it has become possible to maintain highly stable levels of production of ultra-thin gauge strips.

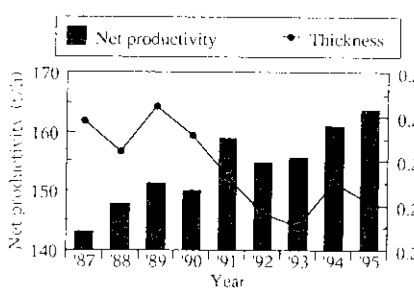


Fig. 7 Change of net productivity

4 Technologies for Improving Gauge Accuacy

4.1 Estimated Effect of Measures to Improve Gauge Accuracy

Figure 8 shows the results of fast Fourier transform (FFT) analysis of the gauge thickness at the outlet of the rolling mills while oil film bearings were in use as back-up rolls. It was concluded that fluctuations in the gauge thickness during steady operation were caused by eccentricities in the back-up rolls of each stand. On the other hand, the major causes of gauge fluctuations during acceleration and deceleration were understood to be due to fluctuations in speed and tension resulting from changes in the coefficient of friction as well as poor speed matching.

Based on this analysis, studies of modifying back-up roll bearings were conducted in order to reduce gauge fluctuations during steady operation. The speed response (ω_c) of the drive system was studied in order to reduce

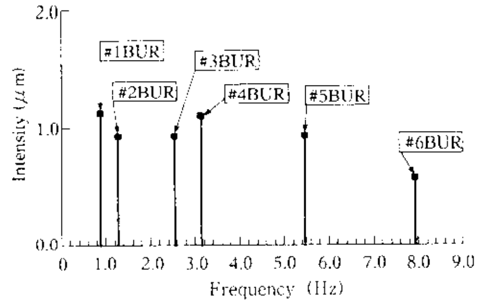


Fig. 8 FFT of delivery gauge with all stands oil film journal BUR

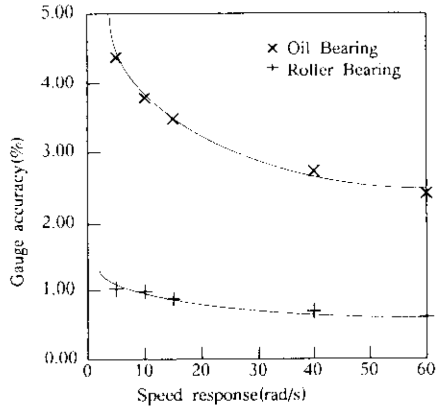


Fig. 9 Effect of gauge accuracy by speed response at uniform speed part

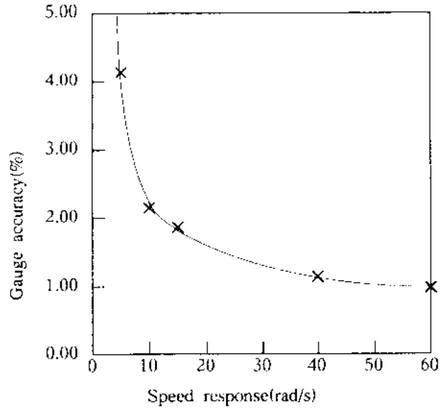


Fig. 10 Effect of gauge accuracy by speed response at speed reduction part

gauge fluctuation during steady operation, acceleration and deceleration. The effects of these measures were evaluated using dynamic simulation of the mill.

First, two cases were studied to evaluate the improvement in gauge accuracy during steady operation. That is, the back-up roll bearings were remodeled as (1) oil film bearings and (2) roller bearings. Oil film bearings have tapered necks and the position on the roll that is pressurized during rolling operation does not coincide with the supported position when the roll was ground. Consquently, eccentricity remains to some extent. On the other hand, roller bearings have straight necks and the position that is pressurized during rolling operation coincides with the supported position at grinding, thereby making it possible to reduce the eccentricity to a considerable extent.

The results of simulation analysis for steady operation are shown in **Fig. 9**. The gauge accuracy was improved by the increase of the speed response ω_c. However, it was more than ± 2.5% in the case of oil film bearings. On the other hand, the gauge accuracy could be improved to less than ± 1.0% in the case of roller bearings.

The eccentricity and torque disturbance were smaller when roller bearings were used. Moreover, the gauge accuracy improved without regard to the response of the motors. Thus, converting the back-up roll bearings into roller bearings is very effective in improving the gauge accuracy during steady operation.

Next, simulation studies were carried out to improve the gauge accuracy during acceleration and deceleration. The disturbance due to eccentricity was not given in order to clearly show the effects of acceleration and deceleration alone on gauge fluctuations.

A speed control system becomes robust against disturbances in torque when its speed response is improved. Consequently, fluctuations in speed due to changes of the coefficient of friction during acceleration and deceleration can be reduced by improving speed response, which in turn helps to reduce changes in tension due to poor speed matching at each stand.

The results of simulation studies are shown in **Fig. 10**. From these simulations, it became clear that the gauge accuracy was improved remarkably to less than ± 1.5% during acceleration and deceleration when speed response was higher than 40 rad/s. It is apparent that improvements in the speed response of the speed control system were effective in improving the gauge accuracy during acceleration and deceleration. Based on these results, it was concluded that gauge accuracy of better than ± 1.0% during steady operation, and of better than ± 1.5% during acceleration and deceleration through the adoption of roller bearings for the back-up bearings and by using AC motors which enable the speed control system, would have a high-speed response of better than 40 rad/s.

4.2 Application of Roller Bearings to Back-up Rolls

4.2.1 Design of back-up roll bearings

(1) Estimation of Roller Bearing Life

At the No. 2 tandem cold mill in the No. 1 cold rolling plant of Chiba Works, the rolling speed at the finishing stand reaches as high as 2 800 m/min. As a

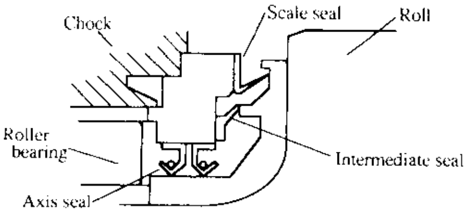


Fig. 11 Structure of seal in roller bearing BUR

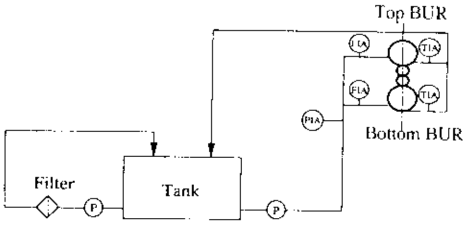


Fig. 12 Lubrication system of roller bering BUR

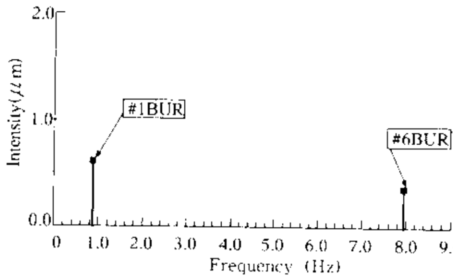


Fig. 13 FFT of delivery gauge with all stands roller bearing BUR

result, the life of back-up roll bearings is likely to be extremely short if standard roller bearings are used. The life of a roller bearing can be calculated using the following formula.

$$L_h = (Cr/F)^{10/3} \cdot 10^6/(60 \cdot N) \cdots\cdots\cdots\cdots (1)$$

where L_h: Life of bearing (h)

F: Radial load of bearing (kgf)

N: Revolutions (rpm)

Cr: Fundamental standard load

$Cr = f \cdot (4\cos\alpha)^{7/9} \cdot Z^{3/4} \cdot D^{29/27} \cdot l^{7/9}$

f: Coefficient

α: Nominal contact angle

Z: Number of rollers per line

D: Average diameter of rollers (mm)

l: Effective length of rollers (mm)

From this equation, it is necessary to increase the fundamental standard load, Cr, by increasing the size of the bearings and thereby extend their life. The difference between the inner and outer diameters of the bearings was made greater. At the same time, the outer diameter and the width of the bearings were also made larger in consideration of the strength of the roll neck. Also, on the problem of decreased strength of the chock, the size of each part of the chock was designed by FEM analysis.

(2) Construction of Sealing

In order to ensure the bearing life and expected performance, the sealing must perform well. In addition, the seals of back-up rolls in No. 2 tandem cold mill are working under severe conditions and the peripheral speed at the sealing of back-up rolls reaches 30 m/s. Consequently, many studies were carried out on the material and lubrication of the shaft and sealing. As a result, the sealing was designed to have a triple structure as shown in **Fig. 11**. Fluoride rubber was used for all seals, and the wear resistance of the shaft was increased by applying hard chromium plating on the shaft surface around the fillet rings. These modifications helped extend the life of the sealing to four times that of conventional designs.

(3) Lubricating System for the Bearings

An adequate bearing lubricating system is necessary to prevent excessive heat generation at the roller bearings of high speed mills. Therefore a forced lubricating system was adopted. In addition, a large capacity filter and a bearing surveillance system were installed at the mill to improve the reliability of the facilities.

The purpose of the filter is to purify the lubricating oil and to prevent the life of the bearings from becoming shorter, because no matter how well the sealing of bearing parts is designed, it is inevitable that foreign matter will get into the lubricating oil due to various reasons, such as the generation of wear particles in the bearings themselves. There are also bearing surveillance systems, which are designed to monitor the condition of each chock continuously. These systems consist of bearing thermometers, lubricating oil supply pressure gauges and flow meters at all chocks. A schematic of the lubrication system is illustrated in **Fig. 12**.

4.2.2 Gauge accuracy after alteration of roller bearings

Figure 13 shows the results of FFT analysis done on the delivery gauge of the strip rolled by No. 2 tandem cold mill after alteration of roller bearings. The revolving frequency of the back-up rolls almost diminished completely, and the occurrence of gauge fluctuations dropped by one half.

4.3 Improvement of Gauge Accuracy during Acceleration and Deceleration through the Adoption of AC Motors

4.3.1 Modifications to the drive system

Compared with DC motors, AC motors have no restriction with respect to rectification because of their design. Consequently, it is possible to achieve speed response ω_c of more than 40 rad/s using AC motors. AC

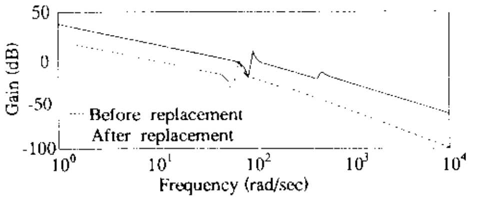


Fig. 14 Bode diagram of No. 2std speed control loop

motors are also easier to maintain.

Gate turn-off thyristor (GTO) inverters were adopted for the drive system of the motors. This system enables independent control of the phase of the voltage and electric current, making it possible to control the power factor at 1.0. In addition, because the high harmonics have a constant frequency, the harmonic filter can be simplified. Further, the mill speed can be increased because control using inverters makes it possible to determine the operating frequency for the motor independent of the frequency of the power supply.[6]

4.3.2 Examination of items for high response

(1) Modification of the Drive Mechanism

Although a twin drive electrically-tied system had been used for the driving mechanism of the No. 2 tandem mill, its intermediate shaft was too rigid to improve speed response. Consequently, a single-drive, mechanically-tied system was adopted by changing the pinion stands and the intermediate shaft so that the drive system could have a higher speed response. The frequency response characteristics (Bode diagrams) of the No. 2 stand before and after the modification are shown in **Fig. 14**. By increasing the rigidity of the mechanical system, the mechanical resonance frequency and the antiresonance frequency could be increased to 1.5 times their respective values measured prior to the modification.

(2) Torque Ripple

GTO inverters generate a torque ripple which is characteristic of pulse width modulation (PWM). In adapting a GTO inverter system, therefore, the effect of torque ripple on gauge accuracy was the most important matter to be examined. A simulation study confirmed that if torque ripple generated from motors is kept less than 0.5%, its effect on gauge accuracy can be less than ± 0.06% at the maximum, and can be less than ± 0.01% at normal speed[7].

(3) Backlash

A certain degree of backlash exists at pinion stands and couplings. If the gears are intermittently disengaged due to the effect of backlash, motor torque is not transmitted to the rolls while the gears disengaged. The speed response during acceleration and deceleration and the behavior of the driving system during rolling were analyzed using a simulator designed to take this phenomena into consideration.

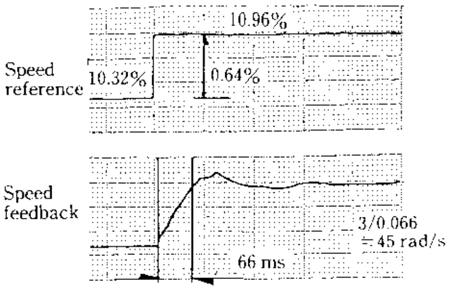


Fig. 15 Speed response of No. 2std

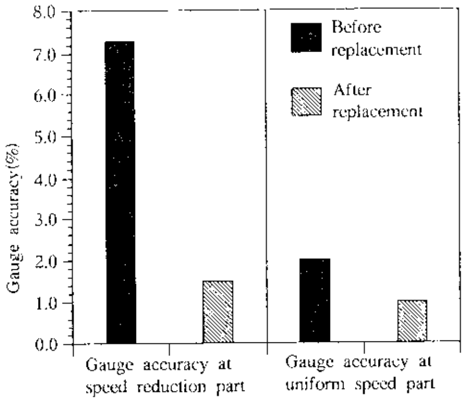


Fig. 16 Gauge accuracy at each speed part before replacement and after replacement

This analysis confirmed that no effects due to backlash appeared during rolling under heavy load conditions. However, the speed response did become delayed by the effect of backlash occurring from the disengagement or re-engagement of the gears under light load conditions such as idling. As a result, excessive torque was applied on the motors when the gears were re-engaged. Based on this analysis, the permissible amount of backlash was calulated and reflected in the design to prevent excessive current. Furthermore, since a certain degree of delay occurs in the speed response in general when the rigidity between gears is low, the rigidity between the gears was increased to a level sufficient to achieve the target value of speed response, that is, $\omega_c = 45$ rad/s, while limiting the value of overshooting to less than 10%.

4.4 Results Confirmed through Operation

The results of the effectiveness of these modifications using the No. 2 stand as an example showed that speed respones ω_c could be improved from 8 rad/s to the target value of 45 rad/s as shown in **Fig. 15** by incorporating these modifications. As a result, mismatching of speed (non-synchronicity of speed and operation) between each stand was reduced to less than 1%, while gauge accuracy was improved considerably as shown in **Fig. 16**.

5 Conclusion

(1) In order to improve the plating-out of rolling oil, an additive for restraining emulsification and a base oil were developed that could remarkably improve rolling lubrication.

(2) By developing Ti-enhanced work rolls with excellent grindability at a reasonable cost, it was possible to roll at the most suitable roughness of work roll surface and operate at maximum rolling speed irrespective of rolling length.

(3) By introducing high lubrication rolling oil and wear-resistant work rolls, no remarkable increase was observed in the coefficient of rolling friction, and even high speeds of 2 800 m/min could be realized.

(4) It was confirmed that converting the back-up roll bearings into roller bearings is more effective in improving gauge accuracy during steady operation than the use of high-response motors. It has subsequently become possible to achieve a gauge accuracy of better than ± 1.0%.

(5) Modification of mill motors for higher speed response was found to be effective in improving gauge accuracy during acceleration and deceleration. A gauge accuracy of better than ± 15% could obtained with a speed response of 45 rad/s.

References

1) T. Saito, Y. Yamada, F. Kosumi, K. Takazawa, and Y. Kuga: *CAMP-ISIJ*, **7**(1994)2, 446

2) Y. Muramoto, T. Yasumi, S. Matsumoto, Y. Seino, Y. Shinoyama, T. Ohnishi, T. Minabe, and A. Okamoto: *CAMP-ISIJ*, **1**(1988)2, 539

3) T. Kaneko, Y. Yamada, S. Matsumoto, T. Henmi, T. Naruke, and K. Tanaka: *CAMP-ISIJ*, **8**(1995)2, 1230

4) M. Kobayashi, Y. Yamada, F. Kosumi, K. Ueda, and K. Aoki: *CAMP-ISIJ*, **4**(1991)2, 470

5) S. Shimizu, K. Aoki, M. Kobayashi, T. Saito, Y. Yamada, and F. Kosumi: *ISIJ International*, **32**(1992)11, 1238

6) T. Chonan, M. Matsutake, M. Yamashina, J. Takahashi, and S. Motoyama: *Hitachi Hyoron*, **75**(1993)5, 31-34

7) H. Masuda and T. Chonan: IEEE Industry Application Society, Tokyo Chapter (1995), MID-95-30, IEA-95-8