KAWASAKI STEEL TECHNICAL REPORT
No.7 (March 1983)

Improvements in Cold Rolling of Extra-thin Gage Strip

Yoshi Nakazato, Fumiya Yanagishima, Toshio Tamiya, Toko Teshiba, Hideo Kuguminato, Takuya Araki, Shunji Fujiwara

Synopsis :
At Chiba Works, many kinds of technical improvement have progressed which permitted economical and stable production of extra-thin cold rolled steel sheet for tinplate and galvanized sheets with high quality: (1) In tandem cold mills, "Keyless bearing", hydraulic push-down BISRA-AGC, roll eccentricity control and 6-high mill were adopted for improving gage accuracy and flatness. Moreover the highly efficient rolling lubricant providing method, "Hybrid system", was established. (2) Through hot rolling at low finishing temperature, the material was made softer so that easy cold rolling and good flatness would be attained. (3) In skinpass rolling, both brightness and flatness of strip were improved by selection of suitable roughness of the work roll surface.

KAWASAKI STEEL TECHNICAL REPORT No. 7 March 1983

Improvements in Cold Rolling of Extra-thin Gage Strip*

Yoshio NAKAZATO** Fumiya YANAGISHIMA** Toshio TAMIYA**
Toko TESHIBA** Hideo KUGUMINATO** Takuya ARAKI**
Shunji FUJIWARA**

At Chiba Works, many kinds of technical improvement have progressed which permitted economical and stable production of extra-thin cold rolled steel sheet for tinplate and galvanized sheets with high quality:

(1) In tandem cold mills, "Keyless bearing", hydraulic push-down BISRA-AGC, roll eccentricity control and 6-high mill were adopted for improving gage accuracy and flatness. Moreover the highly efficient rolling lubricant providing method, "Hybrid system", was established.

(2) Through hot rolling at low finishing temperature, the material was made softer so that easy cold rolling and good flatness would be attained.

(3) In skinpass rolling, both brightness and flatness of strip were improved by selection of suitable roughness of the work roll surface.

1 Introduction

Various means have been pursued at the Cold Rolling Department, Chiba Works, to ensure an economical and stable production of high quality extra-thin gage cold rolled steel sheets for such products as tinplates, tinfree sheets and full hard temper galvanized sheets, all known for their great demand and for their difficulty in manufacture.

Technical improvements in the field of coating, printing and can-making for containers led the way for a correspondingly strong demand for tinplates that would meet such technical improvements. For instance, some products are required to have excellent gage accuracy and flatness. Others smaller surface roughness and superior flatness. As for the material for full hard temper galvanized sheet, on the other hand, the one as thin as 0.15 mm or less, which may be regarded as foil, is cold rolled on the tandem mill. Since the material for full hard temper galvanized sheet is to be finished without annealing, its hardness makes it rather difficult to correct the shape after the cold rolling process. It is required, therefore, to manufacture steel strip of excellent flatness by cold rolling.

In response to such growing quality requirements, improvements were made to hardware and software as well as steel material itself for satisfactory results in terms of gage accuracy, flatness and productivity. The present report describes the details.

2 Improvement of Gage Accuracy

Six-stand tandem mill (henceforth abbreviated as 6T) at the Chiba Works is the main mill for cold rolling extra-thin gage steel strip, which is required to have high gage accuracy because of their application. The improvement of equipment and its effect on producing the extra-thin gage strip of high gage accuracy with the 6T are described below.

When the 6T was put into operation in May 1963, the gage control was performed by two methods described below:

(1) The gage deviation is detected by a thickness gage on the delivery side of the No. 1 stand (henceforth abbreviated as 1 Std), and the electric screw-down position of the 1 Std is controlled in accordance with the deviation. The resultant thickness is detected again by the gage, and the screw-down position is further controlled if the deviation is still appreciable. That is, the detection of gage deviation and the control of screw-down position are alternately repeated to control the thickness. This is called the electric screw-down sampling AGC (Automatic Gage Control system).

(2) There is another AGC loop to ensure the gage accuracy of the final products. As a thin and hard strip entering the 6 Std is little affected by the screw-down control, the thickness is controlled by changing the tension through speed control. The thickness deviation is detected by a thickness gage on delivery side of the 6 Std and the rolling speed

---

* Originally published in *Kawasaki Steel Giho*, **14** (1982) 4, pp. 72–83

** Chiba Works

at the 6 Std is controlled in accordance with the integrated value of the gage deviation. Consequently, the tension between the 5 Std and the 6 Std is changed to correct the gage deviation.

These two AGC loops were the latest devices at that time, allowing to control the gage accuracy to ±2.25% (or ±6.8 μm for the finish thickness 0.3 mm). However, it has become difficult to meet the ever-increasing demand of users for higher gage accuracy.

First, in 1975, what was called "Keyless bearing" was developed and adopted in the backup roll (henceforth as BUR) bearing[1-4]. In this system, keys to fix the bearing to the drum of the BUR were eliminated from the pressure-receiving parts. As the pressure-receiving parts include no key, the role eccentricity per turn, that is, the variation of roll-gap is markedly reduced, and the gage accuracy is controlled to ±1.87% (or ±5.6 μm for 0.3 mm thickness).

In order to further improve the gage accuracy, the effects on the final gage of changes in the screw-down position and the speed at each stand were studied. Consequently, it has been recognized that the screw-down and speed changes at the 1 Std and the speed change at the 6 Std have substantial effects. A high gage accuracy would be available, therefore, if these factors could be controlled precisely.

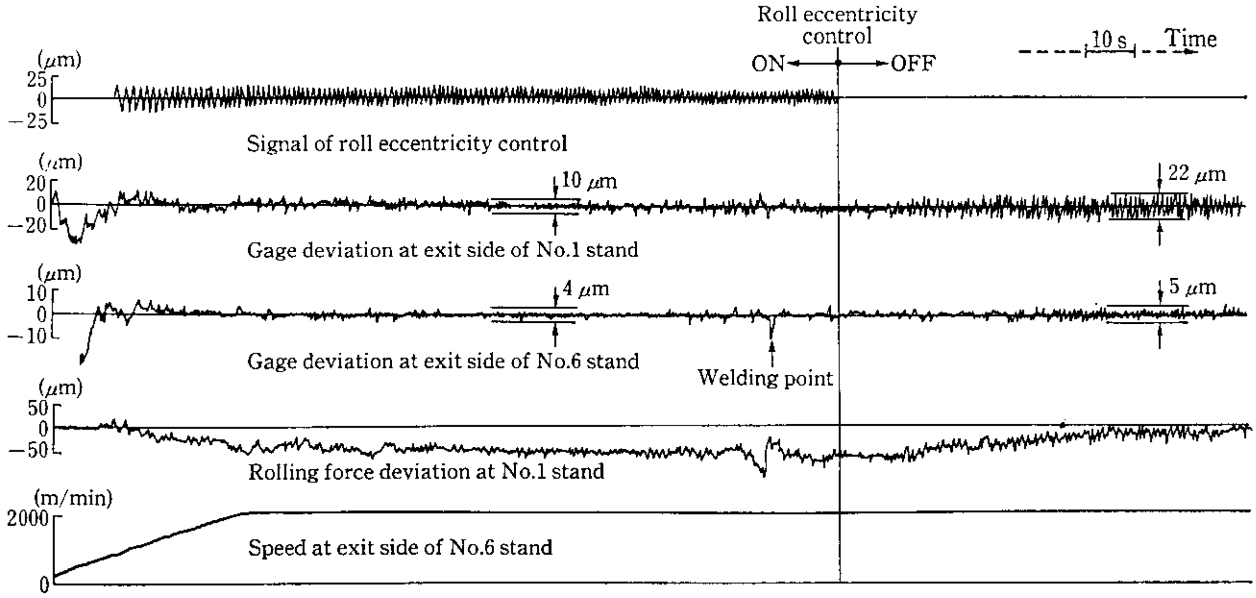
In order to quicken the response of the 1 Std screw-down position control, the screw-down system was switched from the electric screw-down to the hydraulic push-down[5-6], in November 1978. The screw-down response was markedly improved from 0.3 Hz to 17.5 Hz (for 3 dB down). The gage control system was also changed from the sampling AGC mentioned above to the gage meter so-called BISRA-AGC. The BISRA-AGC detects the thickness fluctuation of strip being rolled as changes of the roll force, from which the changes in the screw-down position are derived, and correction is made through the screw-down position control until the gage deviation is eliminated.

In order to detect the change of the roll force exactly, the load cell was changed from that with 37 ms step response to that 3 ms step response. Moreover, in order to correct the deviation from the target, a monitor AGC was adopted at the same time so as to integrate the gage deviation detected by the thickness gage at the delivery side of the 1 Std and to control the screw-down position. The thickness gage at the delivery side of the 1 Std was also replaced with a digital γ-ray thickness gage so as to improve the accuracy in detecting the thickness deviation. Consequently, the gage accuracy was improved in one great stride to ±1.0% (±3 μm for 0.3 mm thickness).

In addition, to renew the electrical equipment and to improve the gage accuracy through the improved accuracy of speed control, the field excitation control system for the main motors and generators was changed from the multi-stage amplifier to the thyristor, and the conventional automatic voltage regulator system was replaced with the automatic speed regulator system (December 1979). The speed AGC for the 6 Std was changed to the direct digital control to improve the control accuracy (March 1980). At the same time, the thickness gage at the delivery side was changed to a digital system. On the other hand, to improve the gage accuracy through the speed control at the 1 Std, the gage deviation detected by the thickness gage at the delivery side of the 1 Std was tracked up to a position immediately before the 2 Std, and the roll speed of the 1 Std was controlled when the strip arrived at the 2 Std to change the tension between the 1 and 2 Stds, so that the target thickness was obtained at the delivery side of the 2 Std (feed forward speed AGC). These improvements led to the gage accuracy of ±0.9% (or ±2.7 μm for 0.3 mm thickness).

In order to achieve further improvement, the roll eccentricity control was introduced in June 1981[7-8]. The load variation at the 1 Std may be attributed either to the entry side thickness variation or the roll eccentricity. Since the BISRA-AGC affects the control on the assumption that the sum of two load variations are due to the gage variation at the entry side alone, the load variation due to the roll eccentricity may cause the error in the gage control. The roll eccentricity is controlled by detecting electrically the load variation occurring periodically in synchronization with the rotation of the BUR and regulating the screw-down so as to eliminate the effect of the roll eccentricity. As the roll eccentiricity is eliminated, the variation in the roll force due to the change in the entry side gage alone is left, allowing to make rolling with high mill modulus by increasing the gain of BISRA-AGC (such as 10 000 tf/mm). An example of rolling chart to indicate the effect of the roll eccentricity control is shown in **Fig. 1**. The peak-to-peak gage deviation at the delivery side of the 1 Std is 22 μm without the eccentricity control, and is reduced by 50% or less, to 10 μm with the eccentricity control. Moreover, the gage deviation at the delivery side of the 6 Std is reduced by 1 μm, demonstrating the adequate control effect. In order to confirm the control effect, the results of the frequency analysis for gage deviation signals are shown in **Fig. 2**. It is evident that the eccentricity frequency component of the BUR (0.83 in. this example) is completely eliminated.

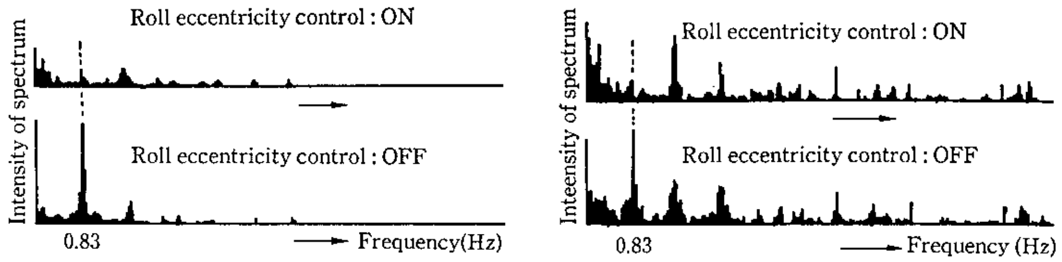
Besides, the roll eccentricity control through speed control has been developed and put into practical use. This system controls the speed of upper or lower work



6 stand tandem mill
Thickness : 2.3→0.201 mm

BISRA-AGC : ON
Monitor AGC : ON
Feed forward AGC : ON

Fig. 1 Effect of roll eccentricity control on gage deviation



(a) Gage deviation at exit side of No.1 stand

(b) Gage deviation at exit side of No.6 stand

Fig. 2 Results of frequency analysis

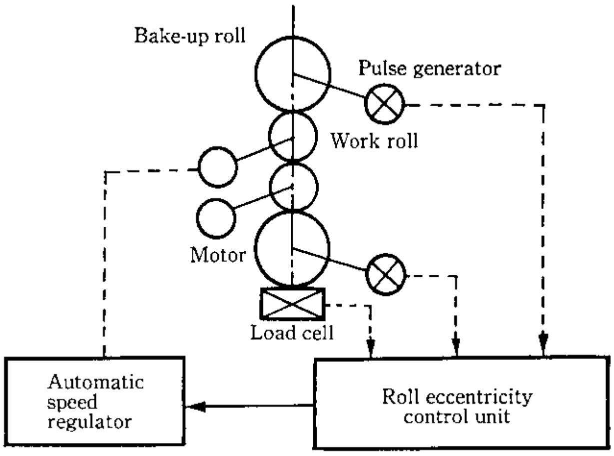


Fig. 3 Diagram of roll eccentricity control system

roll so that rolling is executed at the position of minimum roll force variation, in view of the characteristics that the roll force variation increases or decreases at a certain period owing to the difference in diameters of upper and lower BURs (see **Fig. 3**).

Through the improvements described in the above (see **Table 1**), the 1 Std screw-down control system is an almost complete control system consisting of Keyless bearing, hydraulic push-down BISRA-AGC and roll eccentricity control. The status of the gage control system for the 6T as a whole is shown in **Fig. 4**. Owing to this system, the gage accuracy of rolled strip is ±0.7%, ±2.1 μm for 0.3 mm thickness, which is among the highest in the world.

Table 1 Reconstruction items for improving gage accuracy (6 stand tandem mill at Chiba Works)

Date	Item of reconstruction	Gage accuracy
May 1963	(1) Electric screw-down (All stands) (2) Sampling AGC (No.1 stand) (3) Speed AGC (No.6 stand)	±2.25% (±6.8 μm at 0.3 mm)
Sept. 1975	(1) Keyless back-up roll bearing (All stands)	±1.87% (±5.6 μm at 0.3 mm)
Sept. 1978 Nov. 1978	(1) Load cell (No.1 stand) (2) Thickness gage with digital γ-ray system (Exit side of No.1 stand) (3) Hydrauric push-down (No.1 stand) (4) BISRA-AGC+Monitor AGC (No.1 stand)	±1.0% (±3.0 μm at 0.3 mm)
Dec. 1979 Mar. 1980	(1) Field excitation thyristor Main motors) (2) ASR (Automatic speed regulator) (3) Digital speed AGC (No.6 stand) (4) Digital feed forward AGC (No.1 stand) (5) Thickness gage with digital x-ray system (Exit side of No.6 stand)	±0.9% (±2.7 μm at 0.3 mm)
June 1981	(1) Roll eccentricity control (No.1 stand)	±0.7% (2.1 μm at 0.3 mm)

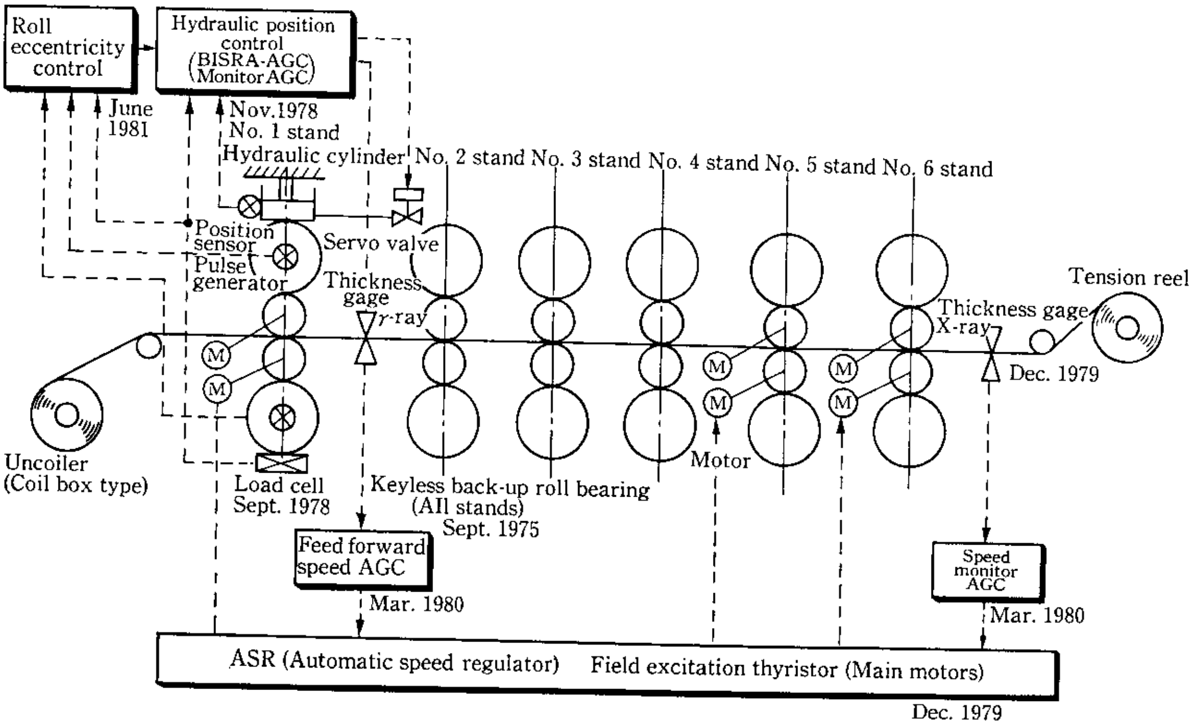


Fig. 4 Schematic diagram of gage control system at 6 stand tandem cold mill

3 Improvement of Hot Roll Conditions

Cold rolling of the extra-thin gage steel strip involves a problem of edge wave generation at the strip edges, since the high cold reduction increases roll force, leading to a marked bending of rolls, causing the roll force to concentrate at strip edges. Another problem is a phenomenon called "heat streak", a surface defect caused by an increased plastic working heat, leading to a frequent roll change. These problems can be solved by an improved cold rolling technique, while the improvement of hot rolled coil itself is also important.

The best suited hot rolled coil is that which has hard and less ductile edges where the roll force is concentrated, with its central area is mild permitting cold rolling under a relatively small roll force. It is desirable that the entire length of the hot rolled strip have such material quality distribution. In manufacturing such materials, continuously cast steel of uniform chemical composition is best suited. It has been said, however, that hot rolled strip worked from continuously cast steel at normal temperature is too hard and inferior in cold rolling properties[12].

By examining the conditions for manufacturing from continuously cast steel extra-thin gage cold rolled steel strip of excellent flatness and cold rolling properties, it has become evident that the hot roll finish at lower temperature is sufficient for this, with added advantages of quality improvement and energy saving.

(1) Method of experiment

A soft-killed steel of lower Al content which was suited for making soft hot rolled strip was continuously cast into a slab and hot rolled to 2.0 mm thickness. The hot roll finish temperature (FT) was set at three levels: high (880°C) and medium (820°C) temperatures in the γ (austenite) singlephase region above the Ar_3 transformation point and low temperature (770°C) in the [α (ferrite) + γ] coexisting region below the Ar_3 transformation point, and the coiling temperature (CT) was set at 580°C in every case. After being air-cooled, test samples were taken to check the hardness distribution in the transverse direction, yield stress, ferrite microstructures at the edge and the center, and their correlations to flatness and to cold rolling properties were compared. Then, cold rolling to 0.15 mm thickness was performed on the 6T to evaluate the cold rolling properties by determining the energy consumed (HHT: horsepower hours/t) in rolling 1 t of hot rolled strip. For the low FT materials, rolls of both the flat and the conventional convex roll curves were used.

(2) Improvement of cold rolling properties

The relationship of yield stress to FT which determines the cold rolling properties as represented by HHT is shown in **Fig. 5**. HHT was small

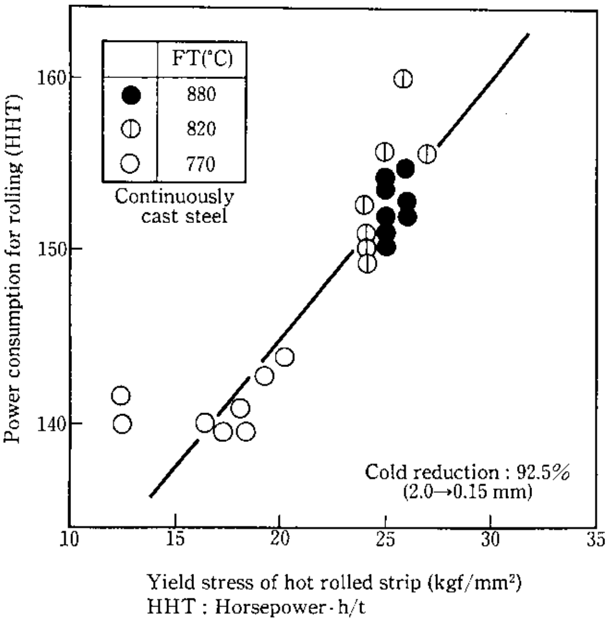


Fig. 5 Relation between necessary power for rolling in 6 stand tandem cold mill and yield stress of hot rolled strip

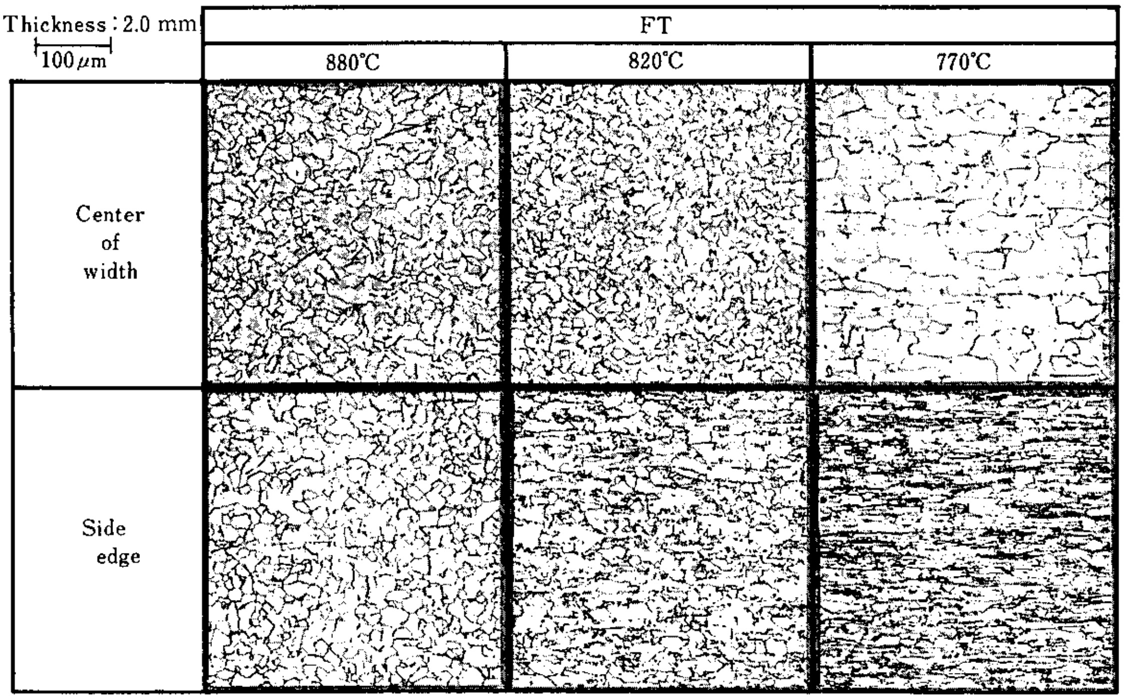
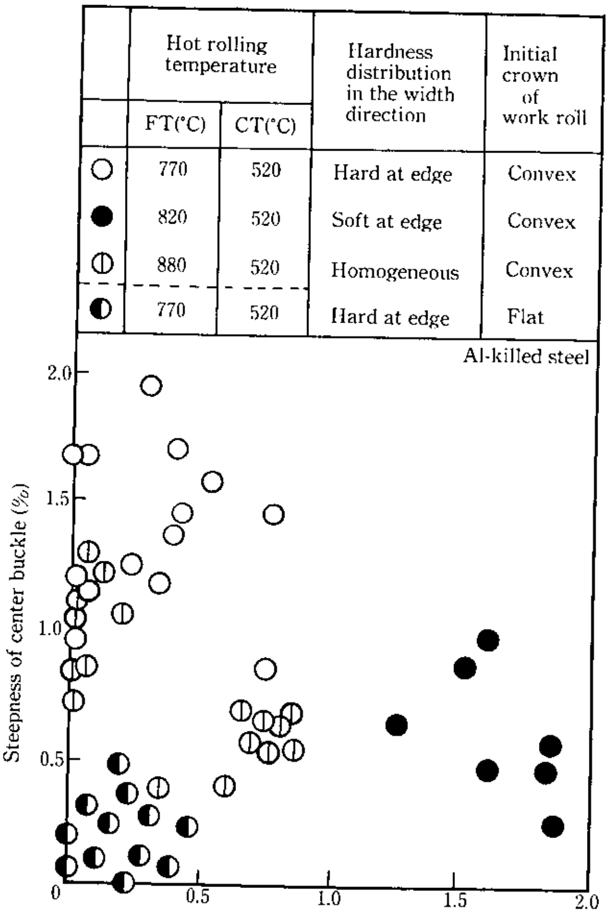


Photo 1 Microstructure of hot rolled strip in relation to finishing temperature

in materials of lower yield stress, and smallest in the low FT materials. With the low FT materials, the high speed roll at 2 200 m/min did not cause seizure. The ferrite microstructure of hot rolled strip is shown in **Photo 1**. The grain size of low FT material was coarser than that of medium and high FT materials, which caused softening to the material. The reason for grain coarsening might be explained as follows: In the high FT materials, rolled at the final stand of the hot finishing mill, γ recrystalizes and transforms into α as the temperature lowers. In coiling, the grain growth proceeds through self-annealing, but fine grains are formed. On the other hand, in case of low FT materials, while γ follows the process mentioned above, α is subjected simply to strain-annealing. That is, if the hot rolled strip under light pressure is coiled, annealing proceeds to result in coarser grains.

(3) Improvement of flatness

The effects of FT and roll curve of the cold rolling mill to the edge wave and center buckle following the cold rolling are illustrated in **Fig. 6**. The edge wave and center buckle are greatly affected by FT, and moreover, in case of low FT materials, the effect of roll curve is noticed. That is, when using the convex roll curve, the edge wave was small while the center buckle large with the low FT materials; the edge wave was large while the center buckle small for the medium FT materials, and both the edge wave and the center buckle wave small in case of high FT materials. However, when the low FT materials were rolled with a flat roll curve, the center buckle was reduced with the edge wave further improved. This effect may be explained as follows. The hardness distribution in the transverse direction of hot rolled sheet is shown in **Fig. 7**. The hardness of low FT materials assumed the concave distribution. This may be attributed to the fact that while the central area is soft because of coarser grain, the edge area is quickly cooled and hardened owing to the more efficient heat dissipation during hot rolling resulting in hot-worked microstructures remained. If steel strip having such hardness distribution is subjected to cold rolling with a convex-shaped roll, the central area which is softer and more ductile is spread extensively to cause center buckle. However, if a flat roll is used, the center buckle is corrected. The hardness of the medium FT strip has the convex distribution. The central area is



	Hot rolling temperature		Hardness distribution in the width direction	Initial crown of work roll
	FT(°C)	CT(°C)		
○	770	520	Hard at edge	Convex
●	820	520	Soft at edge	Convex
⦶	880	520	Homogeneous	Convex
◐	770	520	Hard at edge	Flat

Fig. 6 Effect of hot rolling temperature and initial crown of work roll on flatness in 6 stand tandem cold mill

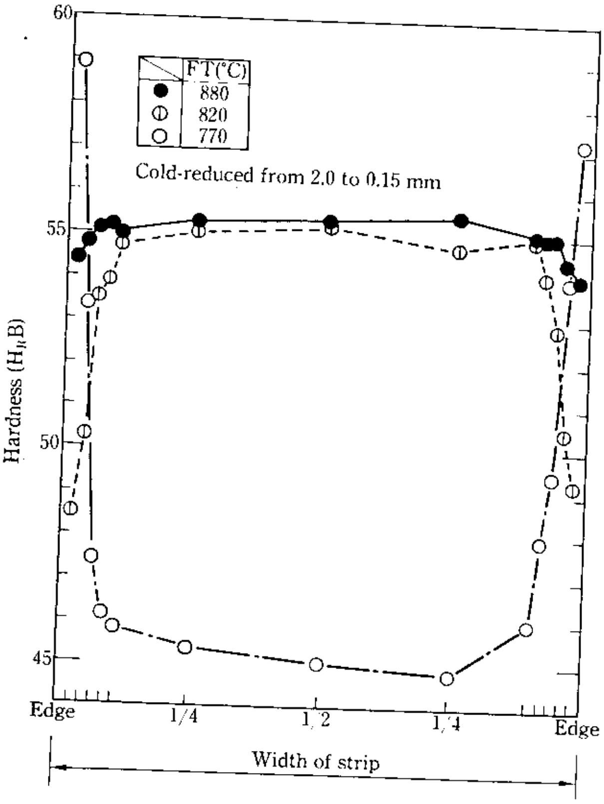


Fig. 7 Hardness distribution in strip width direction

hard with fine grain microstructure as it was hot rolled in the γ region; while the edge area is soft with coarser grain microstructure as the area was hot-rolled at lower temperatures, namely, in the $(\alpha + \gamma)$ region. For this reason, edge wave results. In case of the high FT strip, the hardness distribution was uniform, because the entire width was hot-rolled in the γ region, with both edge wave and center buckle reduced. However, as is evident from **Fig. 7**, the medium and high FT strips are hard and inferior with respect to cold rolling properties. Thus, it seems rather difficult to make industrial production of them even if the flatness is improved in the high FT strip. On the basis of these results, it may be concluded that the low FT strip is best suited for producing extra-thin gage cold rolled steel sheets. This can be achieved readily by keeping the furnace temperature lower, which greatly contributes to energy saving.

4 Effect of Six-High Mill

The five-stand tandem mill (henceforth abbreviated as 5T) has been used for rolling thin-gage cold rolled steel sheet of 0.6–0.3 mm thickness for galvanizing and others. Recently, with an increased demand for extra-thin gage steel strip for tinning and others exceeding the capacity of the 6T, it has been required to roll not only thin strip but also extra-thin gage strip on the 5T. In order to produce steel strip of excellent flatness under these changed conditions, it is essential to use rolls of different curvature for strips of different thickness so that the best results may be ensured. For this purpose, it was necessary to provide a number of rolls and to replace them at high frequency, which depressed the efficiency and was uneconomic.

In November 1980, the 5 Std in the 5T was changed from the 4-high mill to the 6-high mill, which includes an intermediate roll movable transversely between the work roll (henceforth abbreviated as WR) and the BUR. It is possible to ensure uniform roll force in the transverse direction for improving the flatness of strip by setting the intermediate roll at the transverse position best suited for the rolling strip. Moreover, as the WR bender functioned more effectively in the 6-high mill than in the 4-high mill, a powerful WR

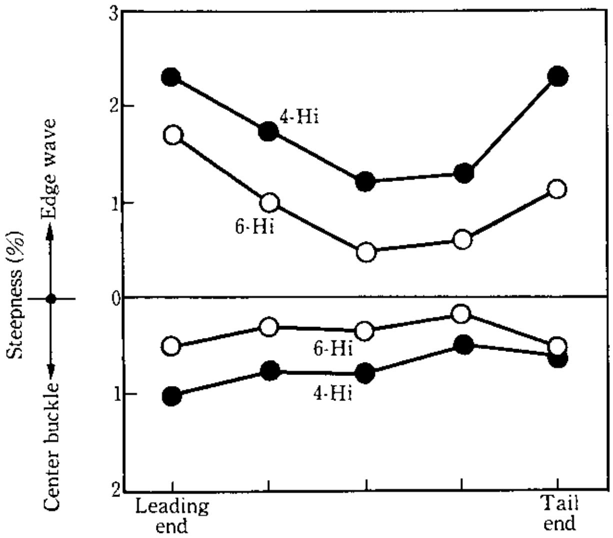


Fig. 8 Comparison of edge wave and center buckle between 6-Hi and 4-Hi mills

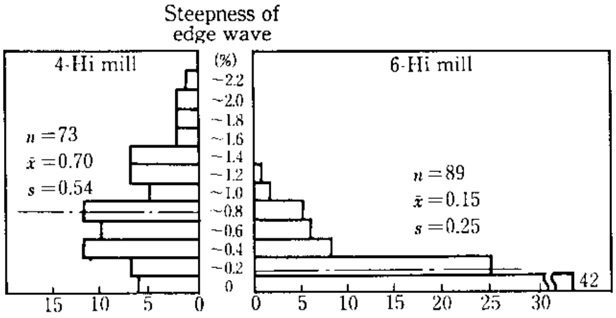


Fig. 9 Comparison of edge wave between 4-Hi and 6-Hi mills

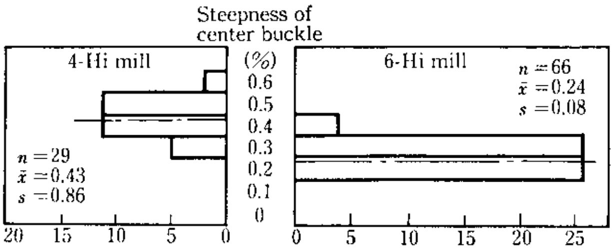


Fig. 10 Comparison of center buckle between 4-Hi and 6-Hi mills

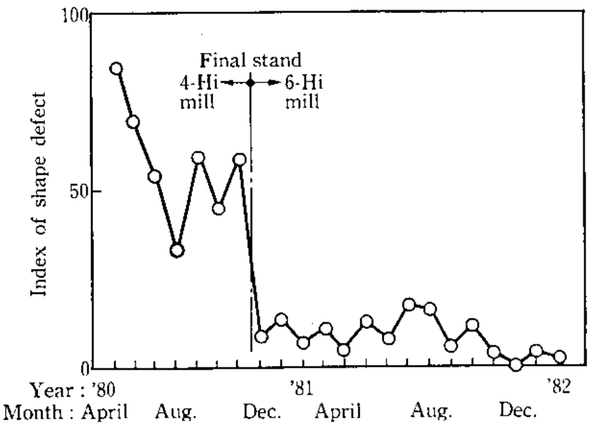


Fig. 11 Decrease of shape defect at 5 stand tandem cold mill

bender (51.5 tf/chock) was installed at the 5 Std. A shape detector of electromagnetic correlation type was installed at the delivery side of the 5 Std to monitor the shape control. Through these changes, the steepness of edge wave was reduced to about 1/4, and that of center buckle to about 1/2, as shown in **Figs. 8–11.** The occurrence of shape failure was reduced as shown in **Fig. 9** through these improvements.

5 Improvement of Temper Rolling Conditions

The temper rolling is performed to give a 0.5–3% elongation for adjusting the mechanical properties of strip, improving the flatness and regulating the surface roughness.

Recently, on the ground of food hygienics, pure tin solder without lead is used in soldered cans for beverages. Moreover, with an improvement in coating technology in plate working, tinplate with smaller amount of tin is used. These altered conditions deteriorate the wetting property of solder with a tendency to reduce the can making efficiency. In order to improve the wetting property, it is intended to improve the technology of can making. It has been required to use glossy, bright-finish tin plate having smaller surface roughness. Since the surface roughness is determined by the roughness of WR for temper roll, WR having roughness corresponding to the required surface roughness is to be used for the temper roll. When WR of smaller roughness is used, the strain pattern occurs at the strip surface, the strip is not rolled adequately and the flatness is deteriorated.

When manufacturing bright-finish tinplate by the 2-stand dry temper roll, a dull-finish WR of larger roughness is generally used in the 1 Std, and a bright-finish WR in the 2 Std. The reason for combining two WRs of different roughness is as follows. The relationship of WR roughness to strip elongation in the temper roll under fixed tension between stands is shown in **Fig. 12**. As the WR roughness is reduced, the strip elongation becomes smaller. When a dull-finish WR is used, the surface roughness of WR is transferred to the strip surface to create a number of origins of plastic deformation uniformly over the strip, which assists the uniform elongation under the tension between stands. Consequently, a large elongation is obtained and the flatness is improved. For achieving the strip elongation with a WR of reduced roughness so as to reduce the surface roughness of the strip, it is necessary either to increase the roll force or to augment the tension between stands. If the roll force is increased, the edge wave tends to occur as stated in the above. If the tension between stands is increased, the strip with a smaller number of origins of plastic deformation is subjected to tensile deformation, causing nonuniform deformation, which in turn results in strain pattern and poor flatness.

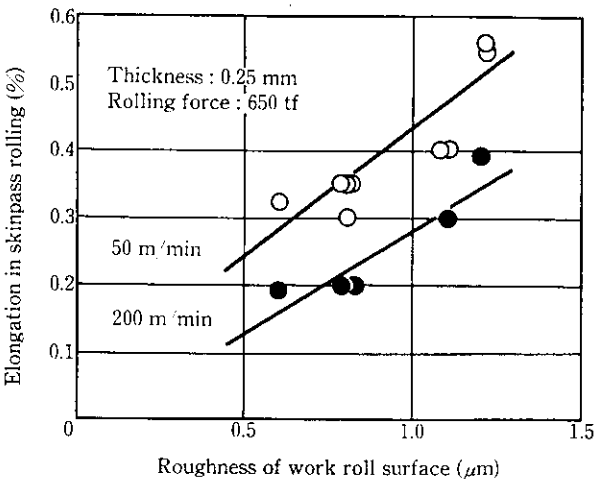


Fig. 12 Relation between roughness of work roll surface and elongation in dry skinpass rolling

Based on these mechanisms thus far known, the selection of the roughness of WR in the 1 Std is important in obtaining strip of excellent elongation and flatness. The effects of 1 Std WR roughness on the flatness, elongation and surface roughness are shown in **Table 2**. If the WR roughness is small, the flatness becomes poor. On the other hand, if the WR roughness is large, the glossiness becomes poor. This may be attributed to the persistence of dull roughness of 1 Std WR transferred on to the strip as a trace after having passed through the 2 Std. As a compromise, the WR roughness was selected to 1.4 μm R_a in order to meet the two contradictory requirements.

On the other hand, for the purpose of energy saving and improving efficiency, the multi-stage printer, of which flatness of tinplate is determined at the correcting stage of temper rolling, technological improvement has been sought for producing strip of excellent flatness at the temper rolling. An example is described below. In the temper rolling, the flatness starts to be deteriorated with time, increasing edge wave, from the

Table 2 Effect of roughness of work roll surface on quality of strip in 2 stand dry skinpass rolling

Work roll of No.1 stand	Strip quality		
Roughness(R_a) (μm)	Rolling elongation	Shape	Roughness
1.0	×	×	○
1.2	×	×	○
1.4	○	○	○
1.6	○	○	×

○ : Good, × : Bad

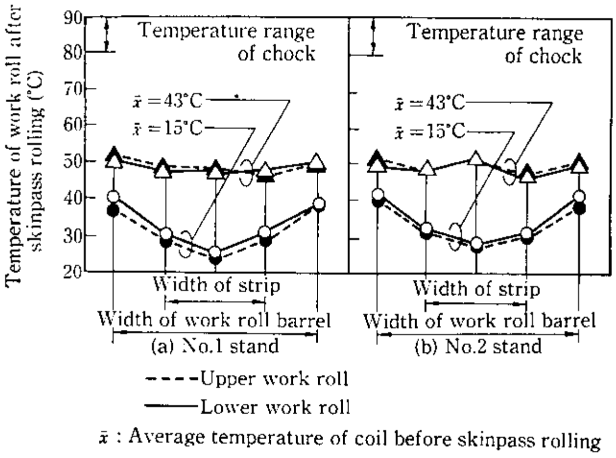


Fig. 13 Effect of temperature of coil before rolling on temperature distribution of work roll after rolling

moment of WR replacement. The cause of this trouble is shown in **Fig. 13**, where the temperature distribution in the transverse direction of WR after the dry temper rolling of strip at low and high temperatures is shown. When the low temperature strip is rolled, the temperature at the roll neck rises and the heat crown becomes concave-shaped. However, when the high temperature strip is rolled, the roll temperature at the strip path is raised by the heat of strip so as to suppress the formation of concave-shaped heat crown. In case of cold rolling, as the rolling work progresses, the heat crown becomes convex through the plastic working heat of strip and the center of the strip tends to expand. In case of temper rolling, however, the effect of plastic working heat on the heat crown is small since the degree of working is small. On the contrary, the effect of heat production at the WR chock part is increased. Accordingly, in order to suppress the concave heat crown in the transverse direction of the WR, it is effective to roll the strip while it is at a higher temperature. The relationship of strip temperature to edge wave after temper rolling is shown in **Fig. 14**. It is evident that if the strip is at a higher temperature, the edge wave is reduced.

6 Improvement of Production Efficiency through New Rolling Oil Feed System

In the 5T, the rolling oil was fed through the recirculating system, and the rolling oil emulsion of low concentration was used for both lubrication and roll cooling. However, for rolling the extra-thin gage strip at a higher speed, the concentration and flow rate of recirculating oil were increased, which was uneconomical. For this reason, a new rolling oil feed system, termed "Hybrid System", has been developed. As shown in **Fig. 15**, the system consists of the Hybrid system designed mainly for lubrication and the coolant system designed for roll cooling. In comparison with the conventional recirculating system, both lubrication and roll cooling efficiencies have been improved. The new system effectively suppresses the development of heat streaks in high speed rolling of extra-thin gage steel strip, and the rolling speed can be improved by about 100 m/min in comparison with the conventional system in case of the 35 % screw-down at the 5 Std, as shown in **Fig. 16**. The Hybrid system is provided with a tank of smaller capacity, so that the concentration can be changed quickly. New rolling oil is supplied to the Hybrid system only, and oil collected from the Hybrid system is fed into the collant system. Consequently, the unit consumption of rolling oil has been reduced to about 1/2 of that in the conventional system, as shown in **Fig. 17**.

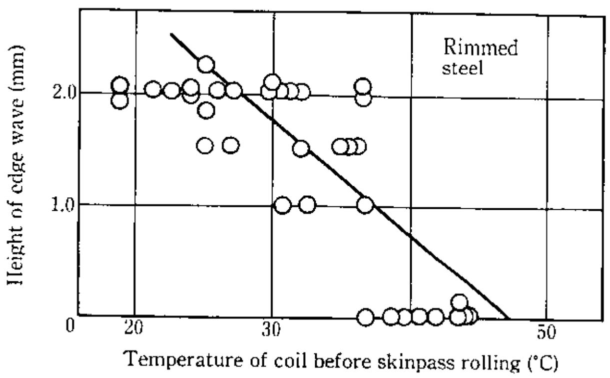


Fig. 14 Relation between temperature of coil before skinpass rolling and height of edge wave

7 Conclusion

A number of improvements designed for manufacturing extra-thin gage cold rolled steel sheet of high quality while maintaining the high productivity brought about the following results:

(1) With regard to gage accuracy, the keyless bearing was developed and the hydraulic screw-down BISRA-AGC and the roll eccentricity control were adopted. Consequently, gage accuracy was improved from ±2.25 % to ±0.7 %.
(2) The cold rolling property and flatness were extensively improved by softening at low FT of the hot rolled steel strip. Consequently, the 6T turned out to be a high efficiency cold rolling mill that rolls strip of mean dimensions 0.23 mm thick and 835 mm wide to 0.145 mm thickness extra-thin gage sheet at the roll speed 2 200 m/min (132 km/h).
(3) With an increase in demand, it became necessary to roll extra-thin gage strip on the 5T. By changing

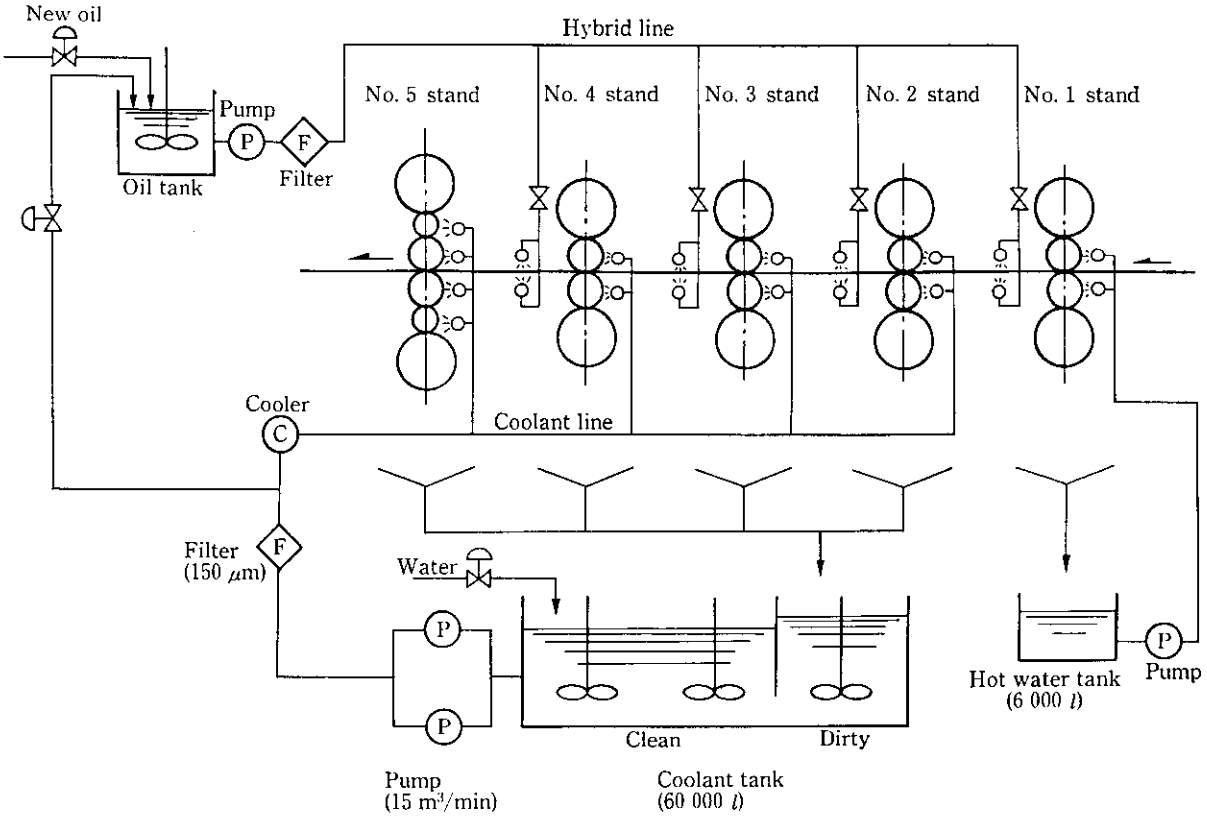


Fig. 15 Rolling oil supply system "Hybrid" in 5 stand tandem cold mill

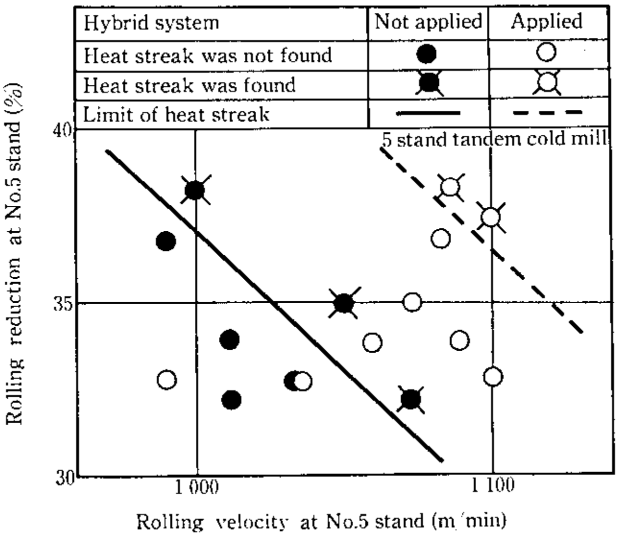


Fig. 16 Effect of Hybrid system for heat streak

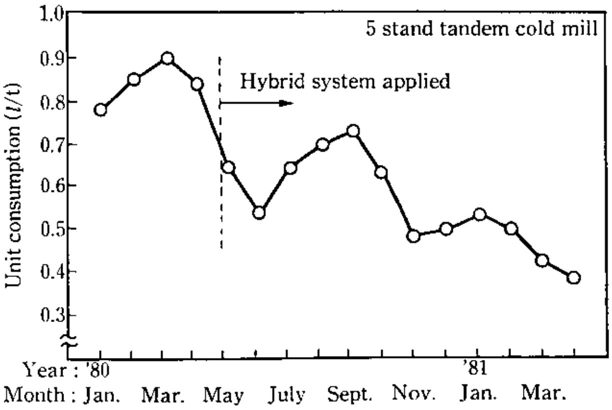


Fig. 17 Change of rolling oil unit consumption

the 5 Std to 6-high mill, the flatness of full hard strip for galvanized sheet was largely improved, to about 1/4 in the steepness of edge wave and about 1/2 in the steepness of center buckle.

(4) With respect to the temper rolling, the WR roughness and the strip temperature were examined. As a result, it was made possible to produce steel sheet of excellent flatness with small surface roughness.

(5) In order to roll extra-thin gage steel strip on the 5T, a new rolling oil feed system, called the Hybrid system, was developed, which suppressed the occurrence of heat streaks, permitting a high speed rolling with the rolling oil consumption almost halved compared with the conventional system.

References

1) F. Yanagishima, et al.: *Kawasaki Steel Technical Report*, **8** (1976) 4, p. 13 (in Japanese)
2) Y. Arimura et al.: *Proc. of the 30th Japanese Joint Conference for the Technology of Plasticity* (1979), p. 97
3) Y. Arimura et al.: *ibid.*, p. 101
4) H. Sunami et al.: "Development of a newly designed oil film bearing", *Proc. AISE*, (1979)
5) T. Teshiba et al.: *Proc. ICSR*, **1** (1980), p. 451
6) Y. Arimura et al.: *Proc. of the 30th Japanese Joint Conference for the Technology of Plasticity* (1979), p. 93
7) Y. Arimura et al.: *ibid.*, (1979) p. 111
8) K. Hashimoto et al.: *Proc. ICSR*, **1** (1980), p. 428
9) K. Kitamura et al.: *Tetsu-to-Hagané*, **65** (1979) 2, A45
10) K. Kitamura et al.: *Proc. of the 30th Japanese Joint Conference for the Technology of Plasticity*, (1979) p. 81
11) I. Yarita et al.: *Tetsu-to-Hagané*, **67** (1981) 14 p. 80
12) T. Jinba et al.: *Proc. of the 1st Joint Conference Technology, Chugoku and Kyushu*, (1980) p. 1