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Synopsis :
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The body can be viewed from the next page.

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Automatic Rolling System of Medium Diameter Seamless Tube by Process Computer Control*

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New automatic billet heating and rolling systems by the use of process computer have been developed in a new seamless tube mill at Chita Works.

Rolling control models consist of the presetting of rolling condition, its adaptive functions and a partial dynamic AGC. Several other new systems, such as for material tracking, operator guidance, data analysis and tool life control, have also been developed for this automatic rolling system.

These systems are applied to the whole rolling line throughout from the billet charging to the finishing of the sizer rolling. The accuracy of the dimensions of the tube, tube-to-billet yield and production efficiency are remarkably improved over the conventional manual rolling by applying the automatic rolling system.

An outline of the rolling system for each mill and an evaluation of the system are discussed.

1 Introduction

A new $16\frac{3}{4}''$ plug mill was put into operation at Chita Works in 1978. For the construction of this mill, it was planned to develop an automatic control system that would permit a computer-controlled rolling line operation. For this purpose, both hardware and software studies were promoted. As for handware, emphasis was placed upon the development and introduction of various kinds of high accuracy sensors such as an outside diameter measuring equipment and upon the development of a perfect tracking system.

Prior to operation, laboratory studies[1-4] by means of various kinds of model mills were made to find optimum rolling conditions, and at the same time, the mathematical models of high reliability were developed. Thus, the automatic gage control system for the overall rolling line from a billet charging table to a sizer rolling was completed. Moreover, the furnace combustion control system to maximize furnace combustion efficiency was developed. This system is the first in the industry. It has remarkably contributed to the satisfactory rating up operation as well as to the stable run, and has a great effect on an improvement in dimensional accuracy of the products, yield rate and productivity as well as saving energy.

In this report, an outline of the automatic gage control system of rolling is described.

2 Mill Layout

The layout of the medium diameter seamless tube mill is shown in **Fig. 1**. Since the details of the equipment have already been published in a supplementary volume[5], a brief description is made here.

The rolling line consists of a rotary hearth furnace, a 2-roll type piercer, a 2-roll type elongator, a plug mill, two 2-roll type reelers, a walking beam type reheating furnace, and 8 stands of 2-roll type sizer.

For rolling, 9 kinds of billets of 175–350 ϕ are used to produce various kinds of seamless tubes of $7–16\frac{3}{4}''$ in diameter and 5.5–40.5 mm in thickness.

Each mill is equipped with various sensors for high accuracy automatic control, and in addition, an outside diameter measuring equipment installed after an elongator, reelers and a sizer as well as a length measuring equipment installed after an elongator, a plug mill and a sizer is provided. The external appearance of the outside diameter and length measuring equipments installed after a sizer is shown in **Photo. 1**.

The rolling information measured by such measur-

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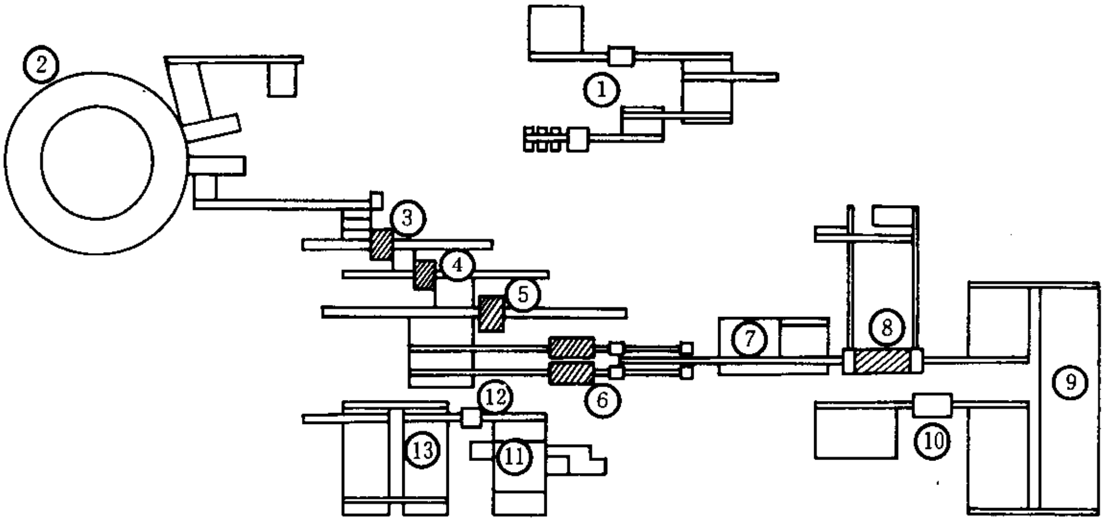
*** Chita Works



① Billet conditioning line
② Rotary hearth furnace
③ Piercer
④ Elongator
⑤ Plug mill
⑥ Reeler
⑦ Reheating furnace
⑧ Sizer
⑨ Cooling bed
⑩ Straightener
⑪ Crop cut & chamfering
⑫ Thickness measuring
⑬ Inspection bench

Fig. 1 Layout of medium diameter seamless tube mill

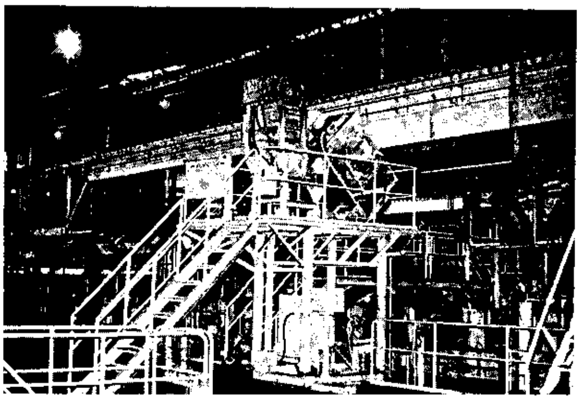


Photo. 1 Outside diameter and length measuring equipments installed after sizer

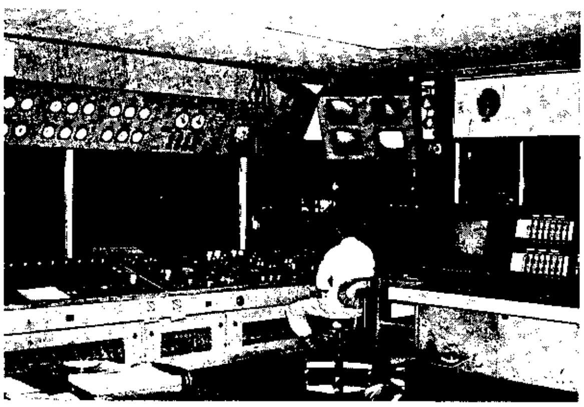


Photo. 2 Sizer operator room

ing equipment is used for computation of rolling control, and displayed on the CRT installed in the operation room of each mill, playing a part as an operator guide. An example of the interior of the operation room is shown in **Photo. 2**. More than 100 sensors are installed in order to maintain complete tracking.

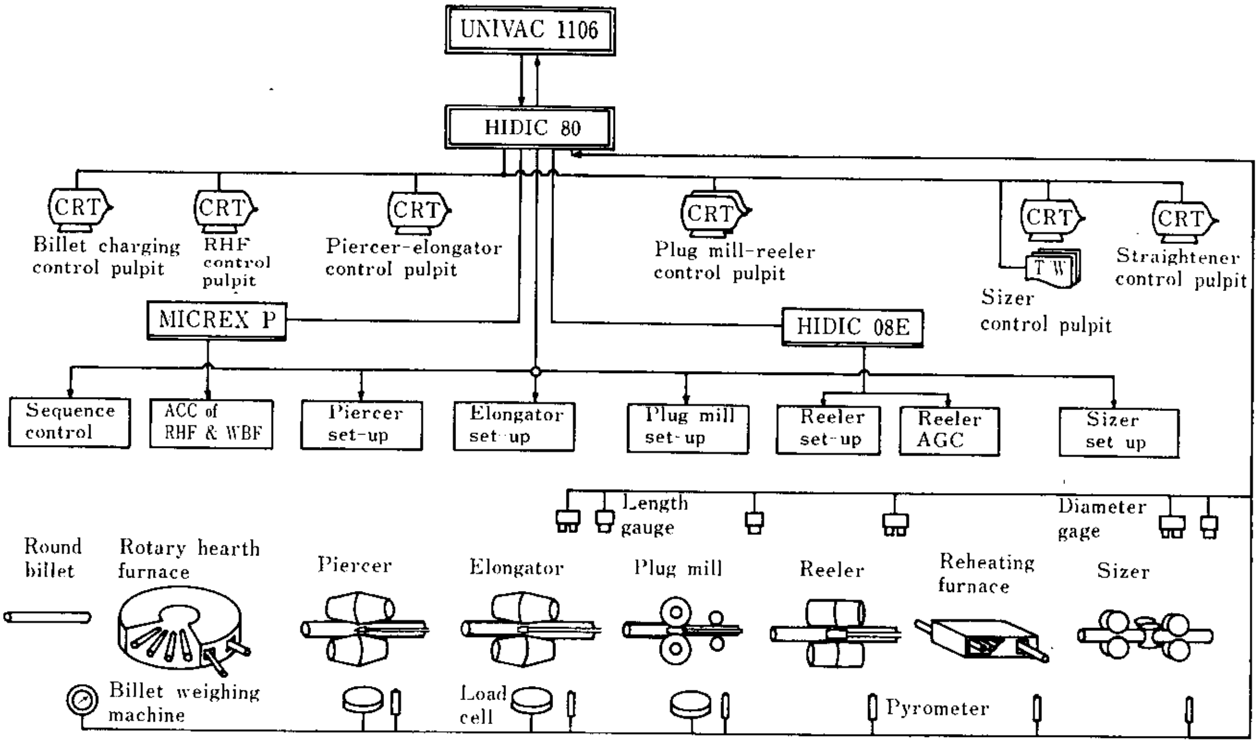
3 Outline of Automatic Gage Control System

The configuration of the system is shown in **Fig. 2**, and the specifications of the computer and its peripheral equipment in **Table 1**. For the control, process computer HIDIC 80 as well as the large size central computer UNIVAC 1106, which has already been installed in Chita Works, is used, and the control functions of each computer are shown in the following:

Central computer:

(1) Decision and instruction of basic rolling schedule.
(2) Mill preset output at the time of lot change.
(3) Calculation for cutting billets in best economical combination to get maximum yield of material.
(4) Filling and long-term storage of various rolling result data.
(5) Analysis of accumulated data.
(6) Life control and stock order control of tools.

Process computer:



ACC : Automatic combustion control RHF : Rotary hearth furnace
WBF : Walking beam furnace

Fig. 2 Basic configuration of computer control system

Table 1 Specifications of computer and peripheral equipment

Central computer		
UNIVAC 1106	Magnetic core	262 kW (1W : 32 bit+2 parity), Cycle time 0.75 μs
	Magnetic disk unit	238 M bit
	Magnetic tape unit	9 truck 1 600 bpi 60 ips 4 sets
	Line printer	1 000 line/min 2 sets
	Card reader	1 000 card/min 1 set
	Cathode ray tube	12 in 1 024 characters 1 color (green) 1 set
Process computer		
HIDIC 80	Magnetic core	64 kW (1W : 16 bit+1 parity), Cycle time 0.65 μs
	Magnetic disk unit	26 M bit
	Magnetic tape unit	9 truck 1 600 bpi 25 ips 1 set
	Line printer	200 line/min 1 set
	Logging typewriter	40 character/s 3 sets
	Card reader	300 card/min 1 set
	Cathode ray tube	20 in 960 characters 7 colors 9 sets
DDC		
TOSMATIC-12A	IC memory	
	12 bit micro processor	10 sets
PROSEC-2000	Wire memory	
	16 bit micro processor	10 sets
U-100	IC memory	
MICREX	8 bit micro processor	4 sets

(1) Tracking from billet charging table to straightener outlet side.
(2) Preset calculation of each mill and output of its results.
(3) Adaptive control calculation of each mill and output.
(4) Combustion control of rotary hearth furnace and reheating furnace.
(5) Logging of various kinds of rolling information.
(6) CRT display and typewriter output of logging data.
(7) Sequence control of rolling line.

4 Automatic Rolling Control

The control model of each mill is roughly divided into two parts; the calculation of initial presetting values to be applied at the first rolling of each lot, and the adaptive control which calculates the optimum presetting values of the next rolling material on the basis of the results of the previous rolling material. The concept of the adaptive control is illustrated in **Fig. 3**. The billet weight is measured, the scale loss weight estimated from the actual holding time in the rotary hearth furnace is corrected, and the target dimensions at each mill are calculated from piece to piece. Moreover, the mean wall thickness is calculated from actual measurements of outside diameter and length of material just after rolling, and the proper correction value of the presetting is obtained by comparing the mean wall thickness with the target dimension, and it is output for the rolling of the next material. In this case, tool expansion caused by tool wear, deformation resistance and mill spring back quantity calculated from the type of steel and rolling temperature are corrected.

4.1 Piercer and Elongator

The piercer and the elongator are cross roll mills having the same functions except that the shapes of plugs and guide shoes as well as roll cone angles are different. Therefore, the method of control can be regarded as basically identical. The outside diameter and wall thickness of the hollow shell after rolling can be represented by eqs. **(1)** and **(2)** on the basis of the distance between rolls, the plug advance and the distance between guide shoes[1,6]. (Refer to **Fig. 4**.)

$$D_H = \gamma\{H + 2(L_p - L)\tan\beta_3\} + \gamma'\{E + 2(L_P - L)\tan\beta_2\} + \Delta D \quad \cdots\cdots (1)$$

$$t_H = \{E - D_P + 2(L_P - L)\tan\beta_2\}/2 + \Delta t \quad \cdots\cdots (2)$$

D_H, t_H: Outside diameter and wall thickness of hollow shell after rolling

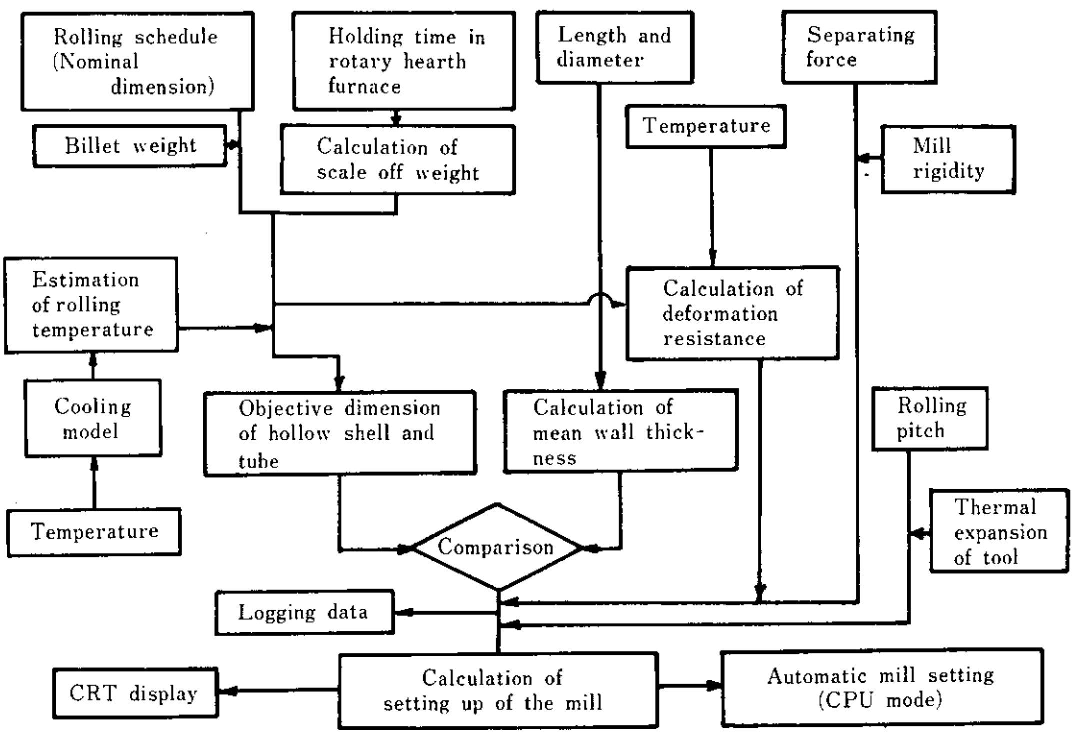


Fig. 3 Concept of automatic gage control system

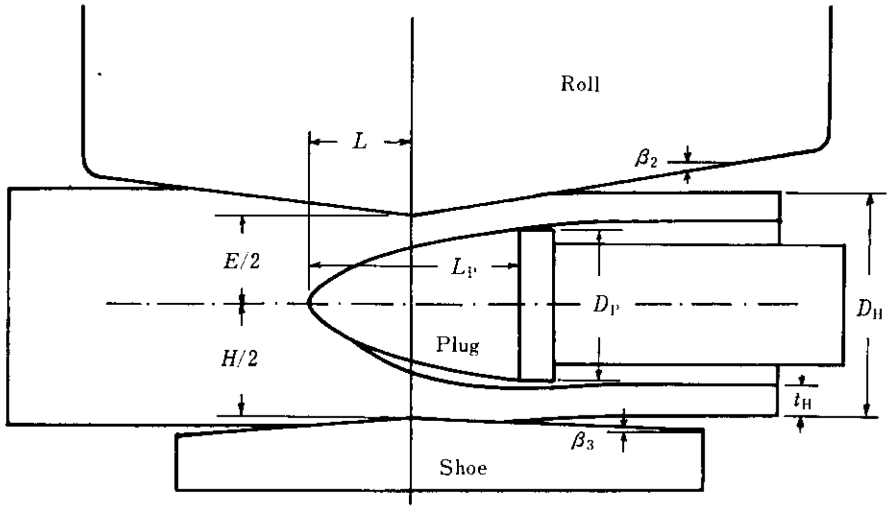


Fig. 4 Notation of piercer and elongator

D_P, L_P: Diameter and working length of plug
E : Distance between rolls
L : Plug advance
H : Distance between guide shoes
β_2 : Outlet cone angle of roll
β_3 : Outlet taper angle of guide shoe
γ, γ' : Coefficients varying according to outside diameter and wall thickness
ΔD, Δt: Adaptive factors

Solutions of the setting conditions for obtaining the objective dimension are within the range which satisfies eqs. **(1)** and **(2)**, and it is an essential subject in providing an initial presetting of mill to select an optimum solution from them. In order to set up optimum rolling conditions, laboratory investigations by means of a model mill were performed, and the range of optimum conditions which satisfied the following restrictive conditions at the same time was determined:

(a) Inlet material should not come into contact with the end of a roll.
(b) Top end sticking should not be caused.
(c) Bottom end sticking should not be caused.
(d) The conditions should not develop an internal crack due to the Mannesmann effect.
(e) A sufficient reeling part should be provided behind the roll gorge in order to minimize the wall thickness variation of rolling material.
(f) A proper distance should be maintained between a roll and the side of the guide shoe.
(g) The H/E ratio should be within a optimum range.
(h) Clearance in a proper range should be secured between the inside diameter of the hollow shell after rolling and the diameter of the plug.

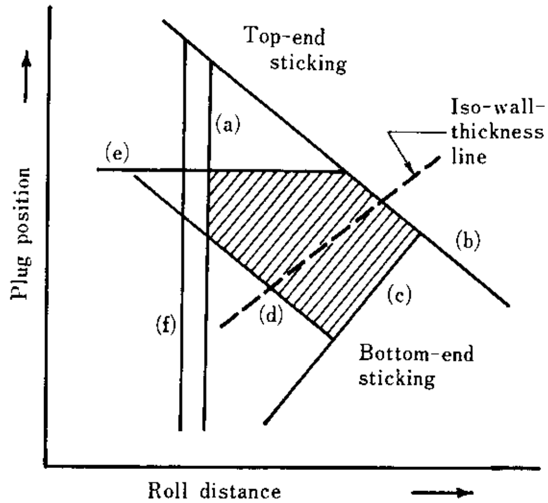


Fig. 5 Optimum setting condition of piercer

A proper range which satisfies these conditions at the same time is restricted to the shadowed area schematically illustrated in **Fig. 5**. The proper conditions thus obtained were applied to the actual mill.

They were partially corrected after sufficient investigations of the correspondence with the pipe quality, and a model formula for obtaining proper conditions for every dimension was prepared. The central computer calculates and outputs the initial presetting of the piercer and the elongator by means of this model.

The adaptive control model basically consists of eqs. **(1)** and **(2)**, and besides, the correction for the

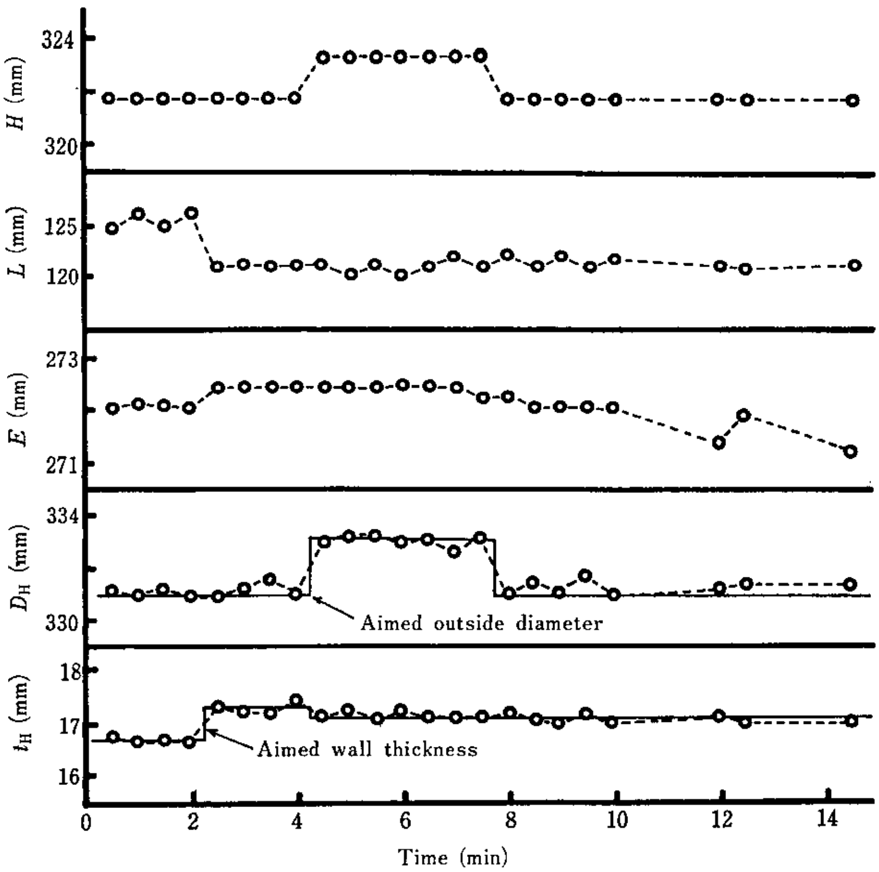


Fig. 6 Variation of dimensions of outgoing hollow shell at elongator rolled by the mode using CPU

deviation of plug bar expansion due to the change of rolling pitch as well as for the deviation of the dimensions of the plug and the guide shoe and for the quantity of wear (which is important at the time of replacement of tools in particular) is made to improve the accuracy of adaptive control. In the case of the piercer, however, practically sufficient accuracy can be obtained only with the initial presetting partially because the wall thickness is so large that trifle variation of the wall thickness does not affect very much the variation of the length.

An example of the results obtained when elongator rolling is carried out in the automatic control mode using CPU is illustrated in **Fig. 6**[7]. The set-up value automatically changes not only at a lot change but also when the rolling pitch has varied, so that the hollow shell of sufficient accuracy can be obtained.

4.2 Plug Mill

The plug mill normally circulates through 4 plugs to carry out 2-pass rolling. It may be a mill having exceedingly important meaning for deciding the elongation length of final products. Accordingly, effort was made to improve the accuracy by adding several features as shown in the following to the control model of the plug mill.

(1) The actually measured dimensions of the hollow shell after elongator is fed forward to correct the target wall thickness reduction.
(2) The roll gap at the time of 1st pass is calculated so that the wall thickness variation of the tube after 2nd pass rolling may be minimum.
(3) The adaptive control model is separated from plug to plug in order to eliminate the errors due to the variation of the plug dimensions and the wear.
(4) The separating force at the time of plug mill rolling is estimated from the temperature of the hollow shell after elongator and from the type of steel in order to correct the mill rigidity. In addition to this, the model formula for force estimation is corrected on the basis of the resulting separating force.
(5) The quantity of adaptive factors at the time of previous plug change is stored in memory in order to prevent deviation of adaptive control at the

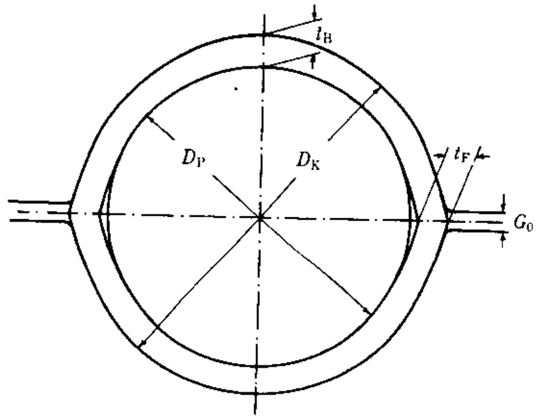


Fig. 7 Roll groove and plug at plug mill

time of plug changes, and the adaptive factors in the control model is corrected by actually measured plug dimensions.

Among these features, the distribution of rolling reduction of 1st and 2nd passes which minimizes wall thickness variation is as follows[6].

In **Fig. 7**, wall thickness (t_F) of the roll flange side which is not subject to virtual reduction is tensioned by the longitudinal elongation of the forcibly rolled part (t_B) at the groove bottom, and the wall thickness (t_F) is reduced, compared with the initial wall thickness (t_E) of the hollow shell. Now, the ratio of the wall thickness reduction of the flange side to the wall thickness reduction at the groove bottom is represented by C values:

$$C_1 = \lambda_1'/\lambda_1 \text{ for 1st pass rolling} \quad \cdots\cdots(3)$$

$$C_2 = \lambda_2'/\lambda_2 \text{ for 2nd pass rolling} \quad \cdots\cdots(4)$$

$\lambda_1' = (t_E - t_{F1})/t_E$
$\lambda_1 = (t_E - t_{B1})/t_E$
$\lambda_2' = (t_{B1} - t_{F2})/t_{B1}$
$\lambda_2 = (t_{F1} - t_{B2})/t_{F1}$

t_E : Thickness of hollow shell after elongator.
t_B, t_F: Wall thickness at groove bottom and roll flange side
Suffixes 1 and 2 stand for 1st pass and 2nd pass, respectively.

The following condition should be satisfied to minimize wall thickness variation.

$$t_{B2} = t_{F2} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots(5)$$

Therefore, the proper wall thickness reduction of the 1st pass can be decided by the following formula from eqs. **(3)** and **(4)**:

$$\lambda_1 = \frac{-Y - \sqrt{Y^2 - 4XZ}}{2X} \quad \cdots\cdots\cdots\cdot(6)$$

$X = C_1(1 - C_2)t_E$
$Y = (C_1 - C_2)t_{B2} - (1 + C_1)(1 - C_2)t_E$
$Z = (1 - C_2)(t_E - t_{B2})$

C_1 and C_2 are obtained experimentally by means of a model mill beforehand, and further, they are given as the functions of the hollow shell dimensions after confirmation in the actual mill.

The automatic gage control system of the plug mill is shown in **Fig. 8**. The basic formula of adaptive con-

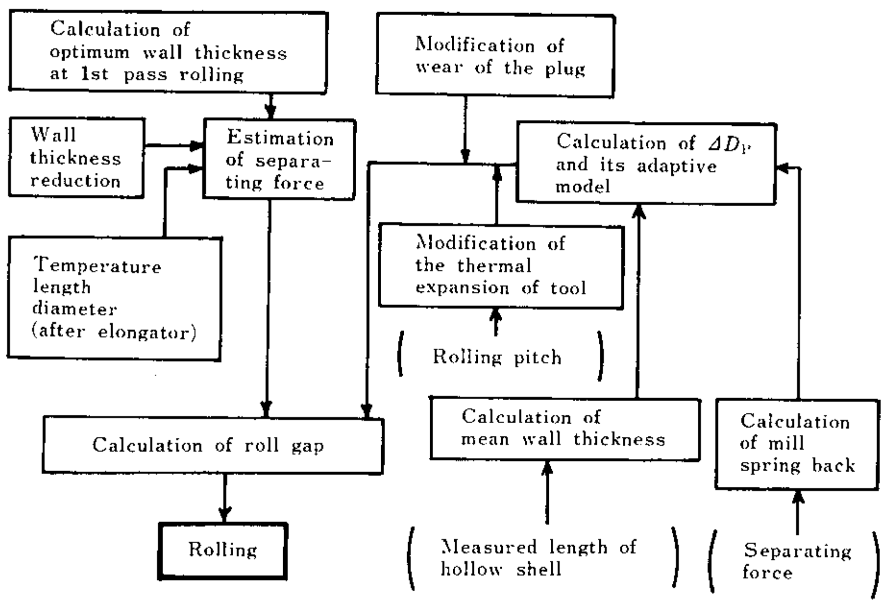


Fig. 8 Block diagram of gage control model for plug mill

trol is given by the following equation:

$$G = G_0 - D_K + D_P + 2t_B + \Delta D_P - P/M \quad \cdots\cdots(7)$$

G : Roll gap
G_0 : Reference roll gap
D_K : Nominal diameter of groove of roll
D_P : Diameter of plug
t_B : Wall thickness at groove bottom of material after rolling
ΔD_P: Adaptive factor
P : Separating force
M : Mill rigidity

It should be noted that it is necessary in improving the dimensional accuracy to treat adaptive factor ΔD_P by the quadratic processing, regarding it as the area of the material passing between roll and plug, not by the linear processing as the clearance between roll and plug, namely the error of t_B. In this model, the area of material after plug mill piece by piece, so that the length control of high accuracy would be carried out with the wall thickness variation in the circumferential direction suppressed to the minimum.

As the rolling control of plug mill, two control systems of exact length mode control (constant length control) and random length mode control (constant wall thickness control) are provided, and these modes are properly used according to purposes.

An example of the effect of plug mill rolling control upon the deviation of the wall thickness of tube is shown in **Fig. 9**[8]. This figure shows the case of random length mode control, and it is clear from this figure that the deviation of wall thickness is remarkably reduced by this gage control system.

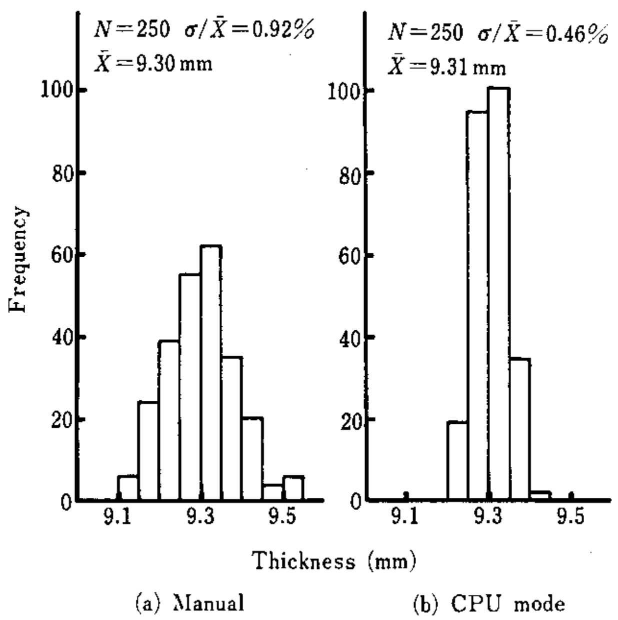


Fig. 9 Comparison of wall thickness deviation of pipe rolled by CPU mode and manual one at plug mill

4.3 Reeler

Unlike the case of other mills, the control of the reeler is provided with the functions of presetting and AGC. The presetting model is used for the calculation of the mill presetting value at the start of rolling, and eqs. **(1)** and **(2)** are used as the basic formulas as in the cases of the piercer and the elongator. For the calculation of presetting, the wall thickness distribution in the top end non-steady section of the hollow shell on the reeler inlet side is estimated from the measured mean wall thickness of the hollow shell after elongator, the measured mean wall thickness at each pass of plug mill and the C values given by eqs. **(3)** and **(4)**, and the mill presetting is calculated so that the outside diameter of the hollow shell after reeler may coincide with the objective value. Needless to say, the model formula of high accuracy; which was obtained by investigating the relationship between the reduction of wall thickness and the expansion of outside diameter of hollow shell during the reeler rolling beforehand, is used for the calculation. Thus, the system of calculating the presetting by estimating the distribution of the wall thickness of material brings about a great effect not only on the improvement of the dimensional accuracy from the very top end of rolling material but also on the prevention of top end sticking.

In the AGC control system, on the other hand, the transformation resistance is derived from the rolling temperature of material (while the measured rolling temperature of plug mill is applied to the cooling model formula to estimate the reeler rolling temperature piece by piece, the estimation formula is modified by means of the previous rolling temperature measured in order to improve the accuracy) and the type of steel, the actual wall thickness of hollow shell after reeler rolling is calculated from the rolling torque of the roll driving motor during the rolling, and the mill is controlled so that the measured wall thickness reduction may coincide with the objective value. The formula of the wall thickness reduction and the rolling torque is constructed by transforming the rolling of the plate rolled between the roll and the plug to be applied to pipe rolling, and further by modifying it by means of the measured value at the actual mill.

The relation between the longitudinal variation of the outside diameter of the material measured by the outside diameter measuring equipment installed after the reeler and the variation of the torque during rolling is shown in **Fig. 10**[9]. Close relation can be recognized between the rolling torque and the outside diameter of

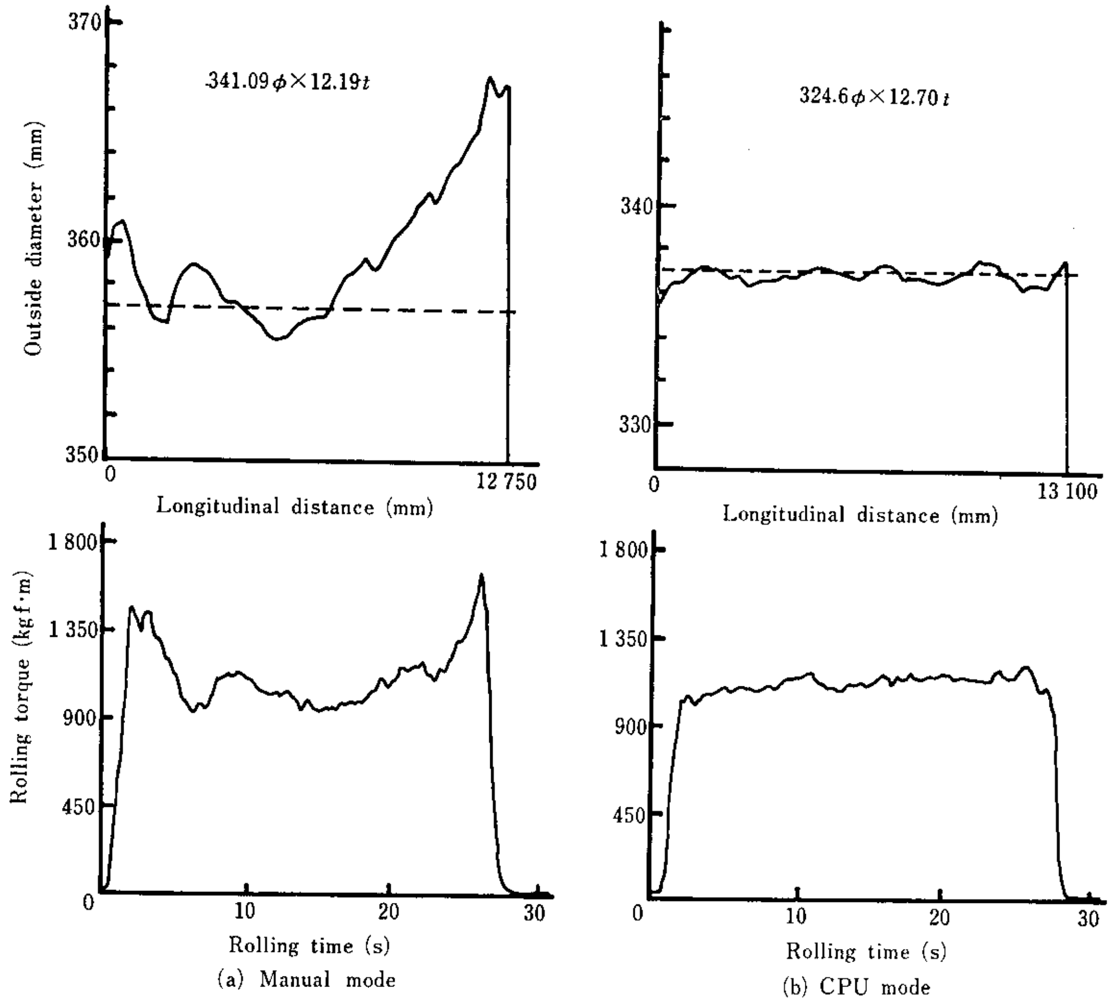


Fig. 10 Relation between outside diameter of outgoing shell and rolling torque at reeler

material, and it is clear that the AGC control is exceedingly effective for obtaining the hollow shell of uniform dimensions in the longitudinal direction. In addition to this, the non-steady rolling section of the material at the very bottom end shows a tendency of a remarkable expansion in outside diameter even with the same wall thickness reduction, compared with the steady section. In this control system, the relation of wall thickness reduction and outside diameter expansion in the rolling bottom end section is previously patterned, the bottom end section is controlled so that a proper wall thickness reduction pattern may be obtained, and consideration is taken so that the tube of uniform dimensions up to the tube end section may be obtained.

One of the outstanding features of reeler rolling is the function of calculating the longitudinal distribution of the target wall thickness reduction by feeding forward the hollow shell information after plug mill rolling. This system has allowed the deviation of the length of the material after plug mill rolling to be corrected by reeler rolling and the deviation of the product length has remarkably been reduced. **Fig. 11** shows an example. It is clear from this figure that the deviation of the tube length after sizer rolling has been improved considerably, compared with the deviation of the hollow shell length measured after plug mill rolling.

4.4 Sizer

Unlike the length control at other mills, the sizer controls the outside diameter directly. Moreover, a control model differing from that of other mills is required since the sizer has multiple stands. The control system of the sizer consists basically of the following six models[10].

(1) The thermal contraction modulus is derived from

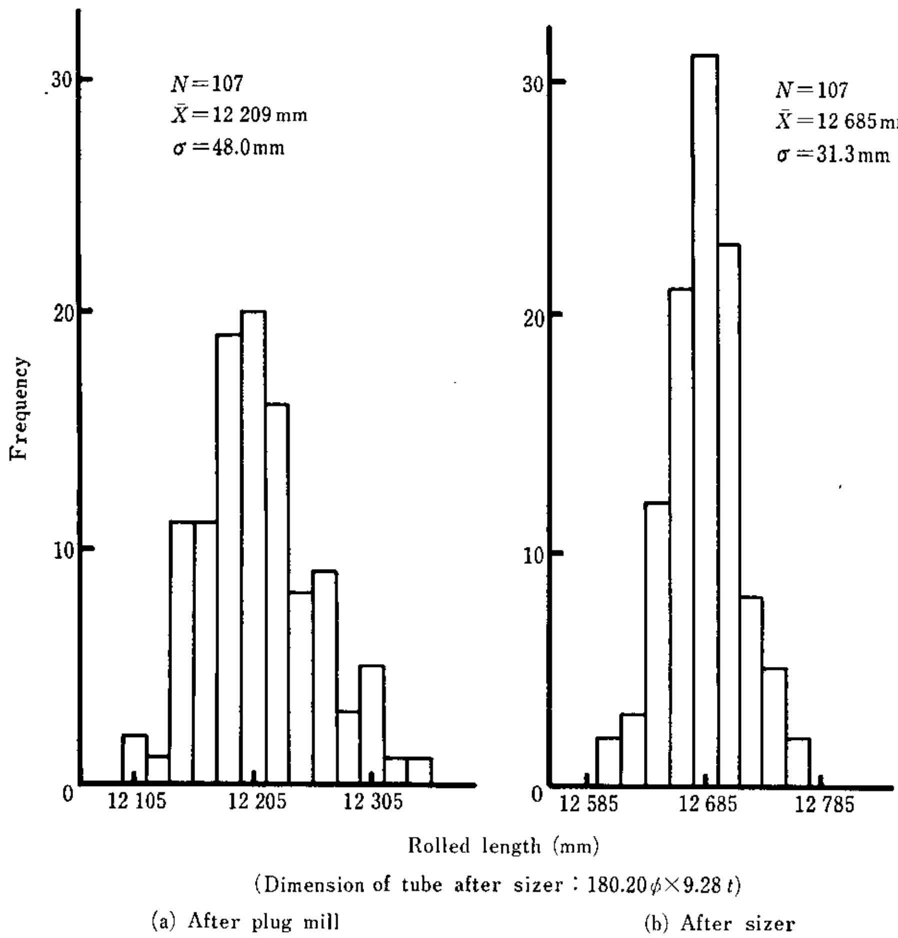


Fig. 11 Comparison of length of rolled materials after plug mill and after sizer

tube to tube from the target dimensions of product at the cold state, the type of steel and the hot rolling temperature, to calculate the target outside diameter at the hot sizer rolling.

(2) The dynamic control of the tube in the longitudinal direction is not carried out, but the presetting system is employed. The initial preset value for the 1st tube after the roll change is calculated by the previously stored basic constant and the roll wear. Moreover, the value for the 1st tube after the lot change is calculated from the measured roll gap of the previous lot as well as from the target change value of the outside diameter and wall thickness.

(3) The rolling of the 2nd and the succeeding tubes of the same lot is adaptive-controlled by the measured values of the two outside diameter measuring equipment installed after the sizer (which are arranged at right angles respectively, so that the outside diameter in the groove bottom direction can be measured). The basic formulas for control are as follows:

$$D_{\mathrm{I}} = a_{\mathrm{I}} + \sum_i b_{\mathrm{I}i} \cdot G_i \quad \cdots\cdots\cdots\cdots\cdots (8)$$

$$(i = 1, 2, \ldots, N)$$

$$D_{\mathrm{II}} = a_{\mathrm{II}} + \sum_i b_{\mathrm{II}i} \cdot G_i \quad \cdots\cdots\cdots\cdots\cdots (9)$$

D_{I}, D_{II}: Outside diameter of the hot tube in the diagonal direction
G_i : Roll gap at the i th stand
N : Number of stands
a, b : Coefficients

(4) When calculating deviation from the target outside diameter so as to determine (or preset) optimum roll gap for the next rolling material, a roll gap change should be given larger in the downstream stands, namely smaller in the upstream stands.

(5) The function of obtaining the coefficients of eqs. **(8)** and **(9)** during rolling and automatically modifying them is added to improve the convergence accuracy of control.

(6) The hollow shell temperature before the sizer is

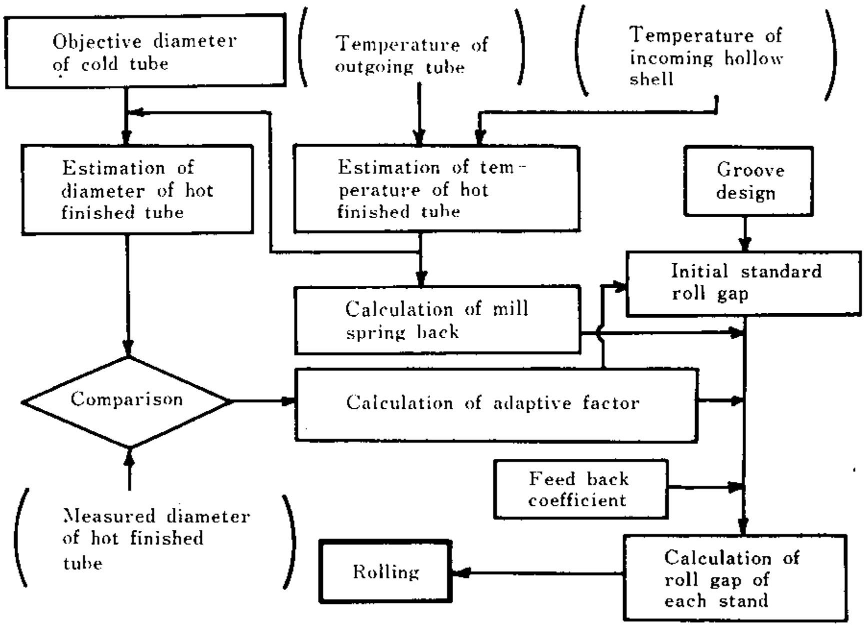


Fig. 12 Block diagram of gage control system for sizer

measured, and the quantity of mill spring back is estimated, whereby it is fed forward to the roll gap presetting.

The automatic rolling system for the sizer is shown in **Fig. 12**, and an example of the outside diameter variation included in the automatic rolling is shown in **Fig. 13**. As shown in **Fig. 13**, the outside diameter deviation converged within 0.2 mm at the 1st to 2nd tube after the start of the automatic rolling by the use of CPU mode, with little variation of the outside diameter during rolling.

This model has a number of outstanding features such as an improved hit rate of outside diameter after lot change since the roll wear is calculated and memorized based on the preset roll gap and the measured outside diameter value, and as quick the convergence of the outside diameter because of the self-learning function of coefficients as described above.

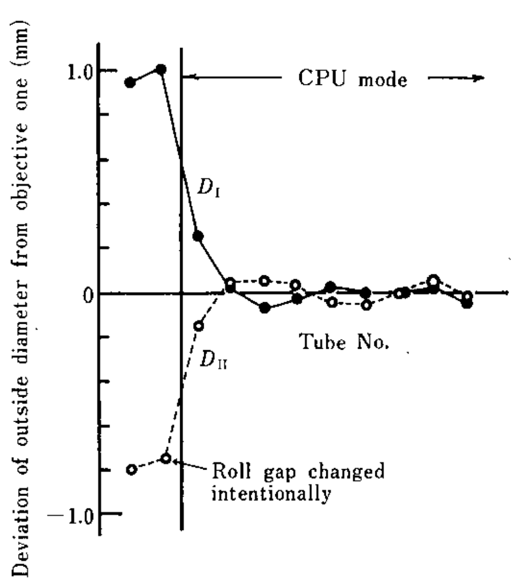


Fig. 13 Change of outside diameter of pipe rolled by the mode using CPU at sizer

5 Operator Guide and Data Logging System

Every kind of information obtained in each process from the billet charging table to the sizer outlet side is temporarily stored in the disk of the process computer. This information is displayed in the CRT in the operator room. The display has different forms such as material tracking information, lot control information, rolling results, and proper presetting of the next rolling material. The operator can choose any of them.

Photo. 3 shows the tracking information of the rolling line, **Photo. 4** the rolling information of the sizer, and **Photo. 5** the graphic display of the actual outside diameter and length after sizer rolling.

Among these informations, data necessary for routine control, such as measured dimensions at each mill, the deviation from the target value, rolling time, rolling temperature at each mill, and holding time in

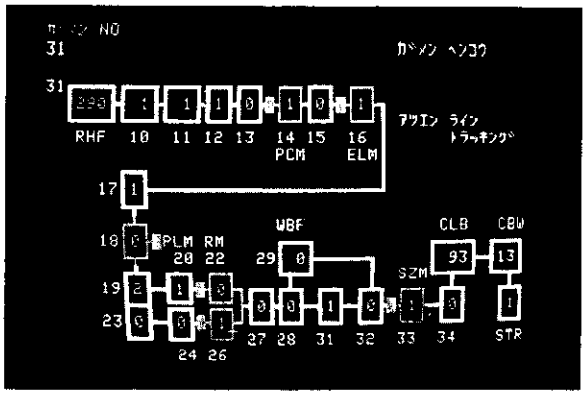


Photo. 3 Graphic display of material tracking at rolling line

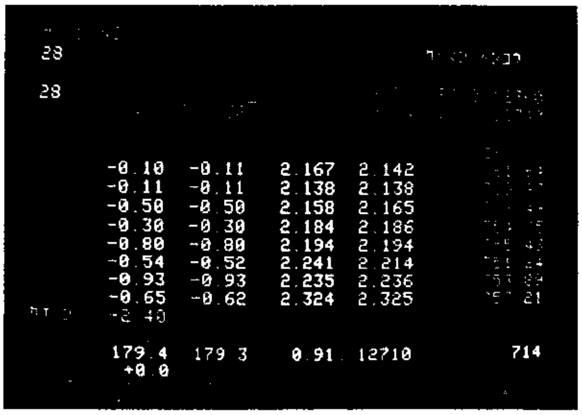


Photo. 4 Numerical display of rolling condition at sizer

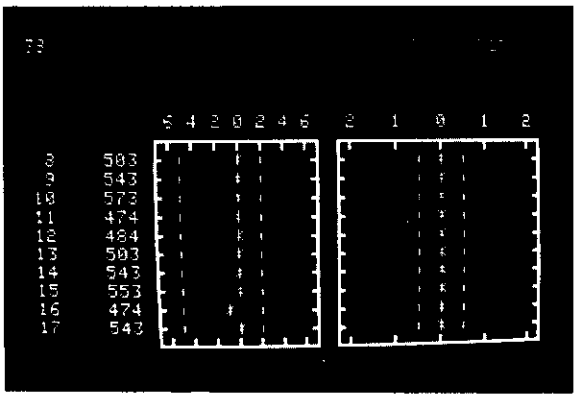


Photo. 5 Measured dimensions of hot rolled pipe displayed on CRT graphically

the rotary hearth furnace, are typed out from piece by piece.

The output forms of the logging data are as follows:

(1) Mill engineering logging
(2) Furnace control logging
(3) Piece data logging
(4) Lot data logging
(5) Shift data logging

On the other hand, the information temporarily stored in the disk of the process computer is sent to the central computer, and after being put in order, the data necessary for long term preservation (410 data per pipe) are stored in a magnetic tape. These preserved data can be taken out at any time and easily analyzed. Such data logging and analysis system are very effective not only for the quality control of products but also for the improvement of the accuracy of the rolling model.

6 Effect of System Application

This automatic rolling system is applied to the overall rolling line, and great effects have been seen in improvement of dimensional accuracy, yield and productivity of tubes as well as in energy saving, and so on. At present, the percentage of the application of this system to the total rolling time has reached 98% on an average, and it is being further improved. By the application of this system, a number of effects as shown below have been recognized:

(1) The wall thickness variation has been improved by approximately 1% through the introduction of models for calculating distribution of reduction to 1st and 2nd passes of the plug mill.
(2) The occurrence of defects as well as the dispersion of crop length has been reduced and the yield has been improved 3%, thanks to the effects of the automatic setting of proper rolling conditions and the length control model.
(3) Energy consumption has been reduced 10% by the practice of furnace control.
(4) Productivity has been improved 5% by the automatization of initial presetting and conveyance, and the practice of lot control and material tracking.
(5) Remarkable labor savings has resulted from the automatization of mill setting, the concentrative control of furnace combustion and the practice of the life control system of tools.

7 Conclusion

This system that automatically controls the overall rolling line of a seamless tube mill can be regarded as an exceedingly effective system not only because it is useful to the improvement of dimensional accuracy and the stabilization of product quality but also because it greatly contributes to the improvement of productivity, the stabilization of operation, and saving of labor and energy. However, it is needless to say that the effect of the system depends to a considerable extent upon the accuracy and reliability of the control model. The authors have carried out investigations for the purpose of improving the accuracy and reliability of the control model, and intend to continue further detailed study to establish a control system which will bring about more achievements. In conclusion, the authors refer to the fact that the development of this system has been made by a project team consisting of the related sections of Chita Works and Research Laboratories, and acknowledge the associated persons of Hitachi Co., Ltd. who have been in cooperation with them throughout the development.

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