OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

This document has been produced without formal United Nations editing. The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as "developed", "industrialized" and "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO.

FAIR USE POLICY

Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

pk

D04702

Distr.
LIMITED

ID/WG.146/11
8 March 1973

ORIGINAL: ENGLISH

United Nations Industrial Development Organization

Third Interregional Symposium
on the Iron and Steel Industry

Brasilia, Brazil, 14 - 21 October 1973

Agenda item 7

AUTOMATION AND COMPUTER CONTROL OF HOT AND COLD STRIP MILLS[1]

by

T.Okamoto and Y.Misaka
(Sumitomo Metal Industries Limited)

---

[1] The views and opinions expressed in this paper are those of the authors and do not necessarily reflect the views of the secretariat of UNIDO. This document has been reproduced without formal editing.

SUMMARY

Sumitomo Metal Industries Ltd has two hot and two cold strip mills. No. 1 hot strip mill, built in 1962, is the first mill in Japan to which a computer control system designed and built in Japan was introduced. No. 2 hot strip mill, which started operation in 1969, is a fully automated and computerised mill with many special features, such as closely coupled roughing stands, closely coupled downcoilers, etc.

No. 1 cold strip mill was constructed in 1963 at the Wakayama Steel Works and No. 2 mill began operations in 1971 at Kashima Steel Works. No. 2 mill is a hydraulic tandem cold mill, with technical features such as interstand tension control, automatic gauge control, and computer control.

In this paper, the different forms of local automation and computer control of these mills is explained in detail.

1 Automation of Hot Strip Mill

The details of equipment of two hot strip mills in Sumitomo are shown in Table 1. The one in Wakayama Steel Works which began its operation in 1962 was one of the most modern hot strip mills in the world at that time. Ever since, various automation systems have been added in accordance with the progress of technology. The authors are proud of the fact that the mill is the first one in Japan on which a computer control system accomplished by native technology was successfully introduced, after the several years of joint research with Hitachi, Ltd., the manufacturer of the electrical equipment of the two hot strip mills.1)

No. 2 hot strip mill was brought into operation in April, 1969. In the construction of this latest type hot strip mill, the company incorporated a variety of technical innovations of a noteworthy character in recent years. The computer control system was naturally introduced making effective use of experience in Wakayama and it has been controlling the rolling of all slabs, including plain carbon steel, low-alloy steel and stainless steel, from the very first bar after roll change.2)

first.

1-1 Local Automation

1-1-1 Furnace area automation

The slab located in correct position is pushed off the charging tables onto the furnace apron where it can be picked up by the walking beam and transported into the furnace. It is necessary to know the position of the slab pushed in and transported just before in order to determine the pusher stroke of this time "L" (Fig. 1). From the previous pusher stroke "l1" and distance transported by walking beam "l2", L can be calculated by the following equation,

$$L = (l1 + l2) - (W + D)$$

where, W is slab width and D is intervals of slabs, both of which are given by decade thumb wheel switch or by computer. Information of l1 and l2 is calculated by detecting the movement of pusher and walking beam.

When a slab reaches the furnace exit, it is detected by a photo-cell sensor and pauses to move and wait for discharging. The extractor forward stroke "L1" can be calculated by the following equation,

$$L1 = l1 + W - \alpha$$

where, l1 is the distance between the backward end of extractor and the leading end of the slab at the exit (Fig. 2). After completion of going forward, the extractor lifts the slab and withdraws it. This backward stroke "L2" is calculated by the following equation,

$$L2 = l2 + \frac{W}{2}$$

where, l2 is the distance between the leading edge of the slab and the center of table roller.

Table 1 Specifications of Sumitomo's Two Hot Strip Mills

( ) shows extension already accomplished.

ITEM		Wakayama	Kashima
TYPE		80" semi-continuous	70" full-continuous
Reheating furnaces		2-120 t/h pusher type (2-120 t/h pusher type)	2-300 t/h walking beam
Rougher	Mills	1-VSB 1-2 high mill, Two pass 1-4 high mill	1-VSB 3-2 high mills 3-4 high mills
	Gages	(Width gage)	Width gage Thickness gage
Finisher	number	6-4 high mills	7-4 high mills
	power	1 ~ 6 std - 4500 kw Mercury Ward Leonard	1 6 std - 8100 kw 7 std - 6075 kw Thyrister
	max speed	747 m/min	1325 m/min
	screw down motor #1	DC 55kw × 2 CP (Thyrister)	DC 75kw × 2 Thyrister
	#2	DC 55kw × 2 CP (Thyrister)	DC 75kw × 2 Thyrister
	#3	DC 55kw × 2 CP (Thyrister)	DC 75kw × 2 Thyrister
	#4	DC 55kw × 2 Ward Leonard	DC 75kw × 2 Thyrister
	#5	DC 55kw × 2 Ward Leonard	DC 75kw × 2 Thyrister
	#6	DC 55kw × 2 CP (Thyrister)	DC 75kw × 2 Thyrister
	#7		DC 75kw × 2 Thyrister
	Work roll change	porter bar (double C-hook)	Turn table type #1~#7
	AGC	#4, #5, (#2, #3, #6)	#2 #3 #4 #5 #6 #7
	Gages	1 - Width gage 1 - Thickness gage (1 - Thickness gage)	1 - Width gage 2 - Thickness gage
	Looper	hydraulic	pneumatic
	Crop shear	manual control	automatic control
Down Coiler		2-two wrapper roll type (1-two wrapper roll type)	4-three wrapper roll type
Automatic Position Control		(6-Finisher screw position) (6-Finisher speed) (2-Xray gage) (1-Width gage) (6-Side guide)	REFER TO Table 2
Computer Control		(Finisher set-up)	Set-up & Control of all the equipment

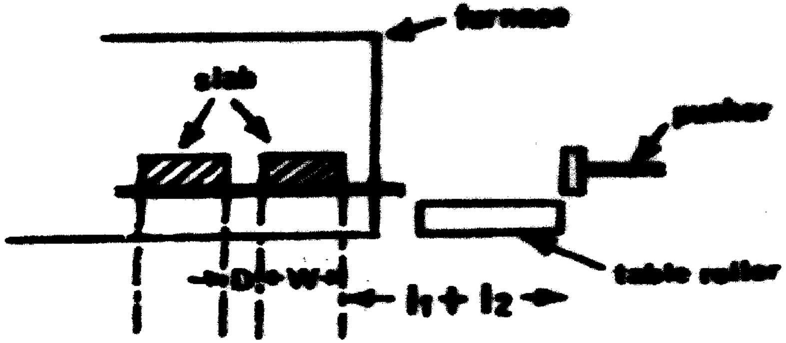


Fig.1 Furnace Pusher System

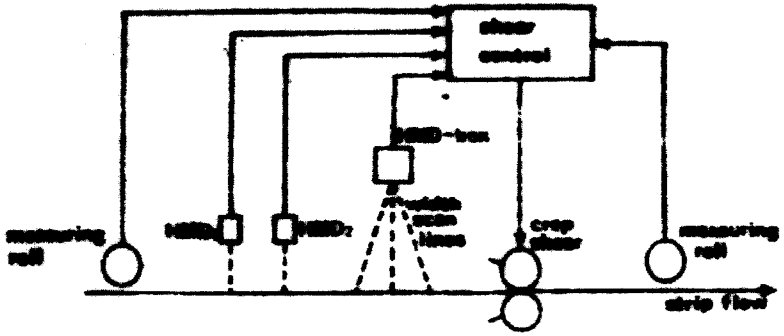


Fig.3 ARRANGEMENT OF CROP SHEAR SYSTEM IN KASHIMA

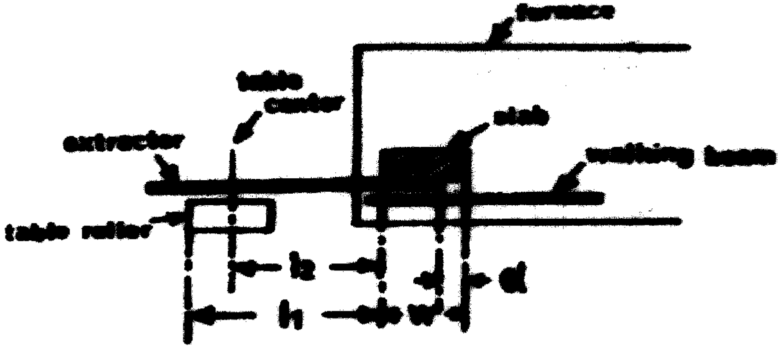


Fig.2 Furnace Extractor System

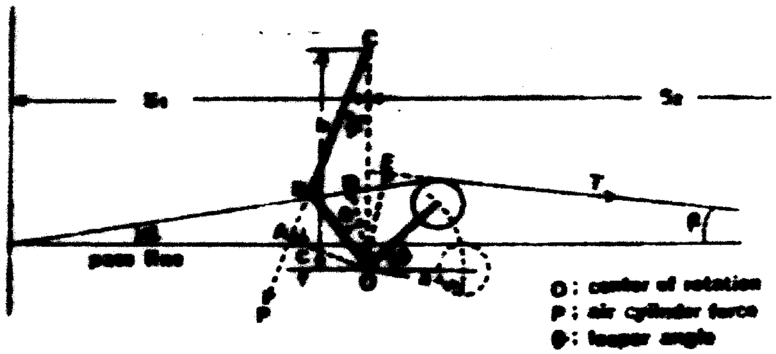


Fig.4 HYDRAULIC CONSTANT TENSION LOOPER IN KASHIMA

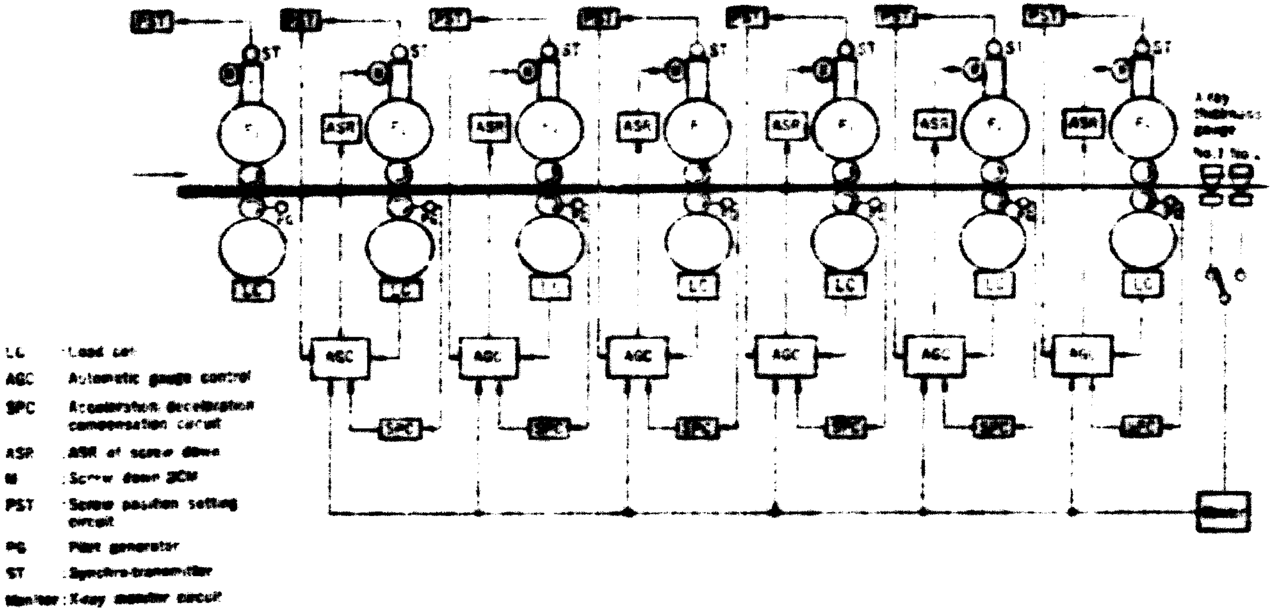


Fig.5 AGC SYSTEM OF HOT STRIP MILL IN KASHIMA

1-1-2 Rougher automation

The rougher at Kashima is fully automated, while the reversing roughing mill of Wakayama is operated on semi-automatic. Though the mill at Wakayama had been equipped with card program control system from the first time, it was abandoned because the handling of cards was very troublesome and the automatic reversing time was long compared with manual operation. The control system was revised so that the screw positions, edger positions and table speeds for three or five passes can be previously given by decade thumb wheel switches and the initiation of the position control was left for operator's work.

The R-5 and R-6 roughing mill in Kashima are closely coupled having a looper between them. But the operation is usually carried out under Automatic Current Regulating system without using the looper.

1-1-3 Automatic crop shear

The general arrangement of the system is shown in Fig. 3. Two selectable modes of automatic control are provided ; one operates on a pre-set length of cut basis and the other on a width deviation basis. Usually the length of cut mode is used.

1-1-4 Looper

Both hot strip mills in our company have pneumatic constant tension loopers. The one in Kashima is shown in Fig. 4. Refering to the Fig. 4, the ratio of tension "T" to the force of air cylinder "P" is derived as follows,

$$T/P = \overline{OA}/(\overline{OE} - \overline{OD})$$

where, $\overline{OA} = b\cdot\sin\phi$, $\overline{OE} = (S_2\cdot\tan\beta + C)\cos\beta$, $\overline{OD} = (S_1\cdot\tan\alpha + C)\cos\alpha$. The value of T/P is equal to 1.5 regardless of the looper angle θ. There are a number of different designs of loopers available and electric type is often used in Japan.

1-1-5 Automatic gage control

The gaugemeter type automatic gauge control (AGC) is applied to six among seven of the finishing mill stands, F2 through F7 (Fig. 5). It operates on the so called "Lock-on" mode with following compensator circuits such as, (a) Monitor by X-ray thickness gauge installed at the delivery of F7 stand, (b) Oil film compensator on each stand, (c) Tail end compensator, (d) Gauge vernier. Fig. 6 is the gage traces of this system showing that strip gage veriation is controlled within the limit of ± 20 μm.

Though the assumed mill stiffness "C" which is used in the control circuit and is shown in the block diagram of Fig. 7 should be, as is well known, equal to actual mill stiffness "M", "C" is often set up a little larger than "M" for the sake of stabilization. (Theoretically speaking, the system is within stability boundary if only "C" is not smaller than $M\cdot Q/(M + Q)$, where Q shows the gradient of plastic curve of strip.) Since the response of screwdown should be as high as possible in order to make

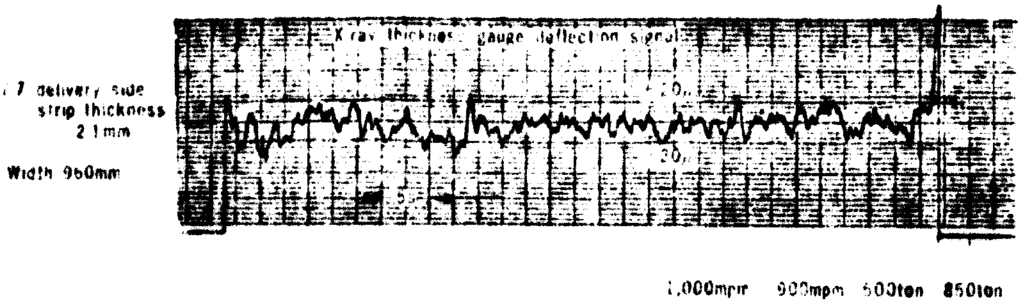


Fig.6 AGC ADJUSTMENT OSCILLOGRAM

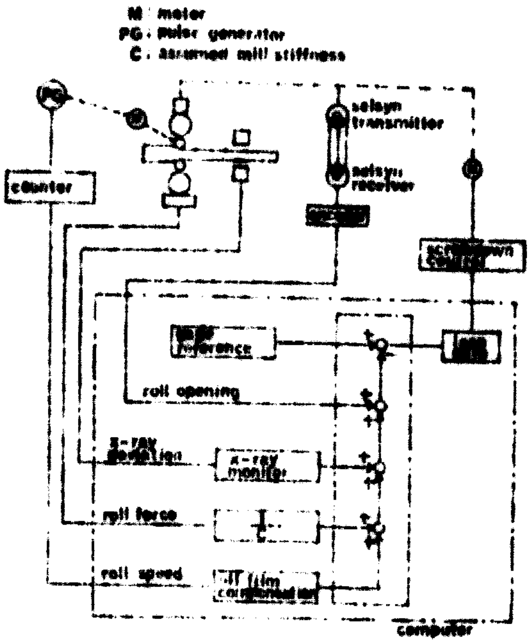


Fig.7 AGC BLOCK DIAGRAM

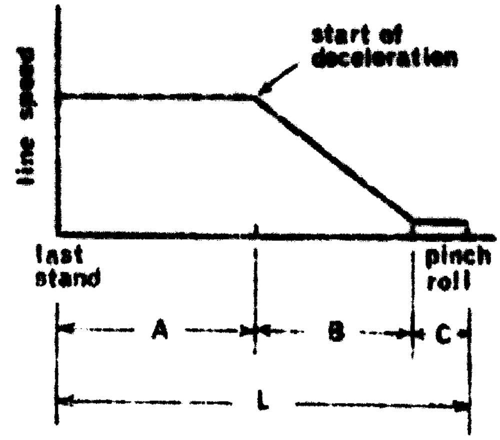


Fig.8 AUTOMATIC DECELERATION OF DOWN COILER

maximum use of Gagemeter AGC system, hydraulic screwdown system will be, in the future, installed in hot strip mills. There are some examples of hydraulic hot strip mills in Japan.[3)]

The AGC system of Kashima was provided in hardware equipment, while the AGC of hot strip mills recently constructed have been provided in programmed software (Fig. 7).

1-1-6 Down coiler area automation

The automatic initiation of coiler deceleration can be done as follows. As is shown in Fig. 8, the following equation exists,

$$L = \int V dt + \frac{(V - V_C)^2}{2\alpha} + C$$

where, L is equal to the distance between the last stand of finishing mill and pinch roll, V is line speed of strip, α is deceleration rate, Vc is creep speed of down coiler and C is a constant. When the tail end of strip just left the last stand, the integration in the above equation commences and the deceleration is initiated when the value of the right hand side of the equation just became equal to "L" (Fig. 9). The method of automatic stopping the coil tail end at a fixed point is as follows. Firstly, during the period of tail end of strip traveling from the position "P" to "A" in Fig. 10, the coil diameter can be calculated by counting pulses developed from pulse generator (1) and (2). Secondarily, the coiler revolutions which correspond to the distance between the position "A" and "S" are determined, which permits automatic stopping.

The banding of a hot coil is automated but the coil marking is still hand-operated in Kashima, though there are a few reports in Japan that the marking has successfully become automated.

1-1-7 Position regulator

The preset control system is used to set up roll speed, roll opening, side guide opening, and other various auxiliary drives in mills. The preset system in Kashima consists of three groups for roughing mills, finishing mills, and down coiler (Table 2). Table 2 lists the items which is preset by this system. These preset items are, when classified by control system, driven into two systems. In one (Table 2-1), the set value which is output of a digital switch or set-up computer is provided with setting change-over timing (such as setting the speed). In the other (Table 2-2), the set value is received and positioning is controlled with this set value (such as setting the roll opening). This system uses both digital and analogue computing systems. Specifically, the digital system (Fig. 11) is adopted for positioning machines which require highly precise positioning, and the analogue system (Fig. 12) is used for other purposes. Actually, the digital system is adopted in positioning the roll opening of finishing mills. The preset control system is being operated very effectively and satisfactorily at Kashima. Especially, the position control system maintains high speed and high accuracy controls, improving smooth setting change-over operation, reducing required manpower, and ameliorating rolling mill quality.

Recently, the use of computers in automation systems is being

Table 2-1 Position regulators at Kashima

	Item	Q'ty	Setting Range	Pitch
Roughing Mill	Draft compensation	2	0 - 50 %	5 %
	Width gauge	1	580 - 1,780 mm	1 mm
	Thickness gauge	1	10 - 50 mm	0.1 mm
Finishing Mill	F 1 threading speed	1	0 - 211 MPM	1 MPM
	F 2 threading speed	1	0 - 345 MPM	1 MPM
	F 3 threading speed	1	0 - 456 MPM	1 MPM
	F 4 threading speed	1	0 - 655 MPM	1 MPM
	F 5 - F 7 threading speed	3	0 - 800 MPM	1 MPM
	Maximum speed	1	0 - 1,320 MPM	10 MPM
	No.1 and No.2 acceleration rate	2	0 - 62 MPM/Sec	2 MPM/Sec
	Deceleration rate	1	0 - 130 MPM/Sec	10 MPM/Sec
	F 1 draft compensation	1	0 - 55 %	5 %
	Width gage	1	508 - 1,780 mm	1 mm
	Thickness gage	1	0.5 - 15 mm	0.01 mm
Down Coiler	Wrapper roll	2	1, 2, 3	1 knotch

Table 2-2 Position regulators at Kashima

	Item	Q'ty	Setting Range	Positioning System	
				Digital	Analog
Roughing Mill	R1 - R3 screw down	3	50 - 300 mm		O
	R4 - R6 screw down	3	0 - 100 mm		O
	VSB housing adjust	1	508 - 1,780 mm		O
	E2 - E6 housing adjust	5	508 - 1,780 mm		O
	VSB, R1 side guide	2	508 - 1,780 mm		O
Finishing Mill	FCS side guide	1	508 - 1,780 mm		O
	F1 - F3 screw down	1	-3 - 37 mm	O	
	F4, F5 screw down	3	-3 - 17 mm	O	
	F6, F7 screw down	4	-5 - 15 mm	O	
	F1 - F7 side guide	7	500 - 1,720 mm		O
Down Coiler	No.1, 4 D/C side guide	2	508 - 1,780 mm		O
	No.2, 5 D/C side guide	2	508 - 1,780 mm		O
	No.1, 2, 4, 5 pinch roll gap adjust	4	0 - 15.3 mm		O

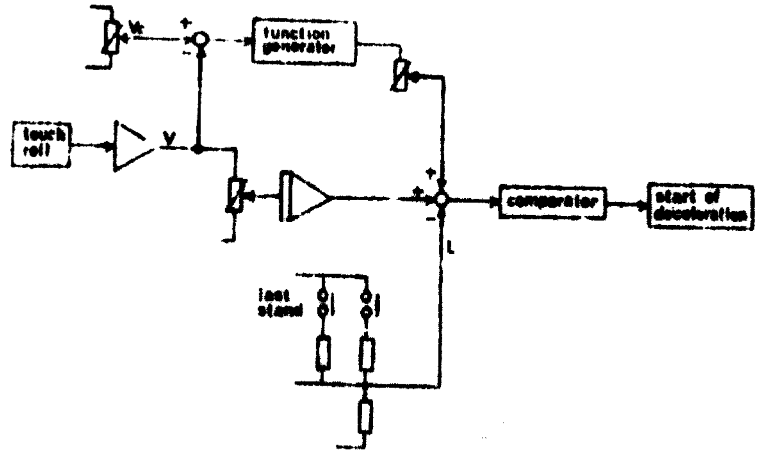


Fig.9 AUTOMATIC DECELERATION OF DOWN COILER IN KASHIMA

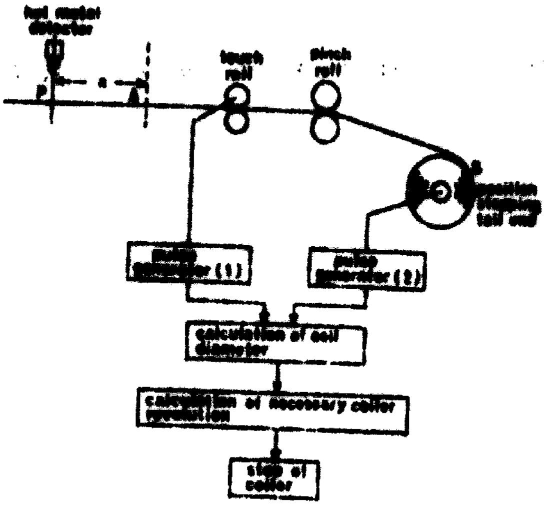
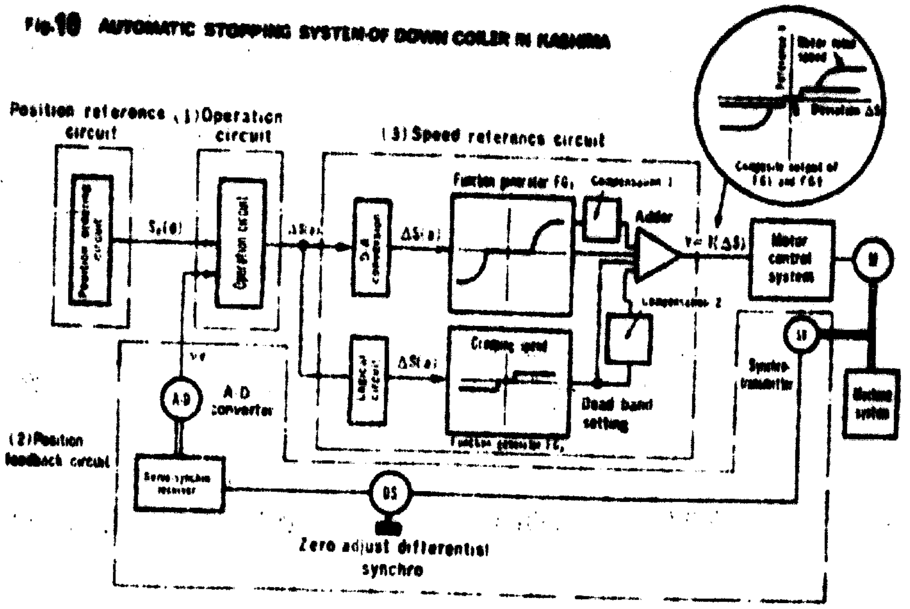


Fig.10 AUTOMATIC STOPPING SYSTEM OF DOWN COILER IN KASHIMA



(d) is digital value ; (a) analog value

Fig.11 DIGITAL POSITIONING SYSTEM BLOCK DIAGRAM

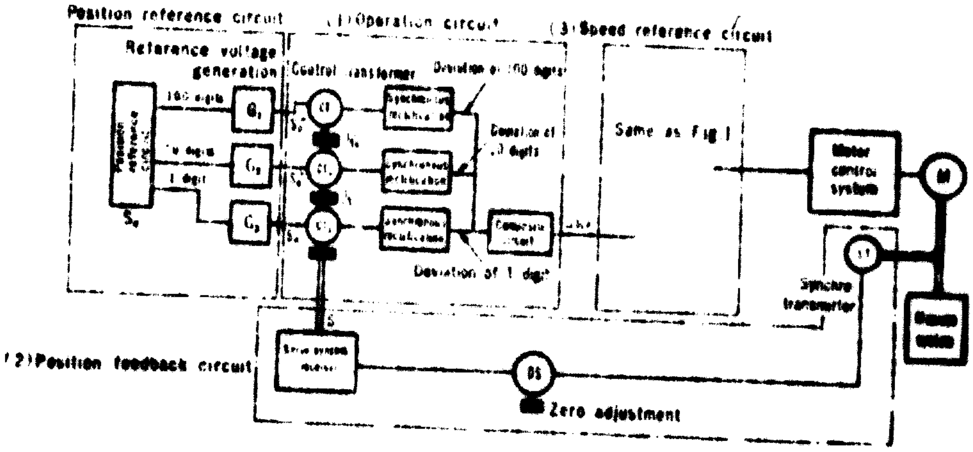


Fig.12 ANALOG POSITIONING SYSTEM BLOCK DIAGRAM

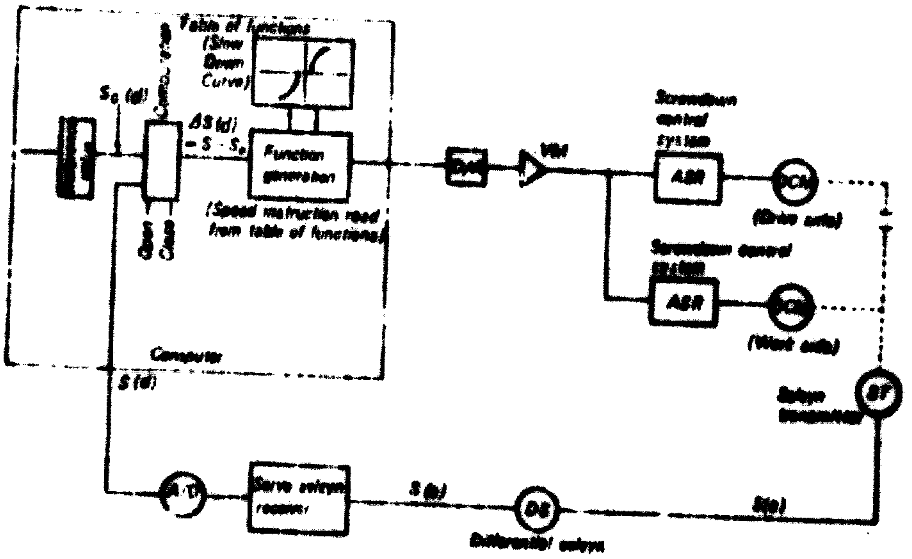


Fig.13 CONTROL BLOCK FOR SCREWDOWN POSITION CONTROL

actively studied and the position controls are often carried out using minicomputer (Fig. 13). Position control is effected by the following procedure. Computation is made for the equation below in which So denotes the command value and Sd the feedback value.

$$\Delta S = So - Sd$$

Then computation is made for motor speed Vs as follows and speed instruction is given to the motor control system.

$$Vs = K\sqrt{\Delta S}$$

where K is a constant dependent on the motor rating, the gear ratio of motor and mechanical drive, and the inertia moment of the mechanical system.1)

1-2 Computer Control

1-2-1 Experience in Wakayama.1),5)

The computer control system for the hot strip mill of the Wakayama Works, was completed in August, 1968. After debugging for four months at the Hitachi Works, Hitachi, Ltd., the HITAC 7250 control computer system (core 16384 words, drum 98304 words) was delivered in March, 1968. Only five months in the field were required to operate the full system. Our experience at that installation revealed that careful preparations to reduce the engineering and programming effort were absolutely necessary for shortening the field term. These preparations included the unique checking method for finishing mill setup calculation and the support programs. One of the most important items which must be considered in the application of a computer control system is how to reduce the time element as much as possible. Initially, the plan, scope, and specifications of the control system are clarified. System designs are drawn up deliberately and their results are recorded in documents and on flow charts for the subsequent job of coding programs. Coding is to be started only after a complete check of all documents and flow charts, and this is undertaken separately for each application program or task. On completion of coding, work is started on debugging the tasks and testing the system. Testing the computer control system involves many processes. First, the unit operation test checks whether or not each task is coded as recorded on the flow chart. Second, the general operation test examines whole programs which exhibit their functions as software systems, and finally the quality of all control systems is judged from actual operation. It is highly beneficial for both the vendor and the user of a computer control system to reduce the lengthy period of testing and adjusting the programs, software systems, and control systems. To accomplish this purpose and to obtain appreciable results, many intentional preparations are required at the early stage of the system design.

A computer control system is usually constructed in the order of system design, production of hardware and software, and system testing. In the first half of the system design, a decision should be made on organization of the control computer system and other hardware specifications which will realize the plan. In the latter half of the system design, A software system is planned to construct programs which will function with the predetermined hardware. After determining the hardware system, concrete plans are drawn up for the hardware and software systems separately. Drawing the flow charts, coding and debugging the programs, and testing the system are done subsequently to planning the software system. Each step in the construction of the software system is discussed below. Results of the system design concerning software are documented and converted to a general flow chart which shows the overall configuration of the system and is used to check specifications of the system as well as to check operational requirements and constraints that may not be clarified. After the overall configuration of the system is cleared up on the general flow chart, it is divided into units of application programs (also termed tasks), each of which is separately described by a flow chart. Every flow chart for each task is assembled to make up the master flow chart. In computer control of rolling mills, each task is conducted in connection with interrupt signals transmitted from various types of sensors such as load sensing relays, pyrometers, and hot metal detectors, and with a request signal from the timer built into the computer. Various tables are designed, to which many tasks refer, and each task is assigned either to a resident area of the core storage or to its non-resident area where any task may be swapped with an external memory such as the magnetic drum. Meanwhile, more determination is required, such as what levels should be assigned to an external priority interrupt and to a task, respectively, and what kinds of format and processing should be used for the outputs of typewriters and card punch. Our experience in the construction stage of the master flow chart has revealed that it is extremely useful in reducing later troubles to scan various functions of the computer control system from all angles. For example, desk simulation of information processing for assumed states of the mill line may resolve many doubtful problems in processing. A check on backup processing, skipped under normal conditions, should be conducted at this stage to reduce troubles which may occur later in on-line processing. After exercising care in the work mentioned above, program coding is started.

Various types of debugging and testing are begun on the completion of coding. Testing of the application programs usually starts with a first unit test of one program segment and builds up to testing the fully developed system. Testing of the computer control system for the rolling mill also progresses in this manner. After completion of coding for a task, its debugging is started, with the Unit Operation Test (UOT). The test process subsequent to the UOT is the Single Operation Test (SOT) which tests a single function performed among tasks. An example of the SOT is checking the data linkage between the tasks in conjunction with the task of data input, task of calculation using input data, and task of output sending the calculated results. The UOT and SOT, not carried out in real-time, are conducted under the Non-Process Monitor System (NPMS) of the HITAC 7250's system program. Some of the effective support programs in these tests are various types of dump subroutines and the process input-output simulator. Programs in a real-time style are supervised under the Process Monitor System (PMS) of the HITAC 7250's system program. The first stage of debugging under the PMS is the General Operation Test (GOT) which accepts manual pseudoexternal interrupts and causes corresponding tasks to start one by one successively as a first step in testing the complete system. In the GOT, all programs are stored in memory storages to work in real-time, and are initiated with manual pseudointerrupt signals transmitted from snap-switches instead of external interrupt signals. A Real-Time Simulation Test (RTST), subsequent to the GOT, uses pseudointerrupts created by the mill line simulator instead of manual interrupts for the special purpose of testing the problem of timing. The objective of the GOT is to test a processing of one slab on the entire mill line, simulating the external interrupt signals with manual signals.* The objective of the RTST is to simulate several slabs in a situation similar to an actual rolling operation. The above-mentioned tests are off-line tests because the computer is not linked to the actual rolling mill line, and their objectives are to test programs and linkages between computer and its peripheral input-output devices such as typewriters, card reader, and card punch. After introducing the control computer system into the mill, field adjustment of the hardware and a reappearing test of the software are conducted by using the GOT and the RTST. After the reappearance of functions of the system, a linkage test is begun with various types of sensors, output devices, and position regulators installed along the mill line. After completing the linkage test at least once, an On-Line Test (OLT) is begun. In the initial period of the OLT, output linkage from the computer to the mill line is open, and the test for slab tracking is undertaken. When tracking is completed, computer control of the rolling line may be recognized to be more than fifty percent complete. Support programs which prove especially useful in the real-time test are the on-line monitor and the mill line simulator, which are described below.

Main functions of on-line computer control of a mill are activated in response to interrupt signals generated through sensors by slabs moving on the mill line. Since a series of programs actually moves in accordance with them, the interrupts must occur at correct times. The system must conduct many operations for several slabs continuously. In such a system, errors can result after many programs have been executed. It is quite impossible to test such a system manually. The system needs to be capable of inspecting its own actions as far as possible and to log significant data that can be analyzed later. For this purpose, a monitoring program called On-Line Monitor (OLM) has been developed. The OLM is a sort of subroutine connected with the system program or the PMS. It monitors tasks at those times requested, start and end, and prints out the type of actions, program number, name, and time of the task. Practical uses of the OLM are clarifying results of interrupt timing, sensor failure, impropriety of a task and among tasks, sequences of task movements, waiting state of a task, conditions of loading and storing tasks and processing time, and in considering various kinds of timings, leveling of tasks, and core sharing. In addition, the entire history of task processing and operating time is recognized and analyzed with the aid of the OLM, resulting in the modification of sequencing and processing of the critical parts of the time cycle. Timing is one of the big problems involved in the on-line real-time system and, what is even worse, it is carried over to the field test. Even if all tasks and the task linkages were checked out thoroughly in off-line debugging, it would give no clue to problems caused by timing. Once a timing problem occurs, there may possibly arise such a fundamental problem as priority level of interrupts, level and sequence of programs, and core sharing. The Mill Line Simulator (MLS) is a task which induces a change of events and starts corresponding tasks successively.

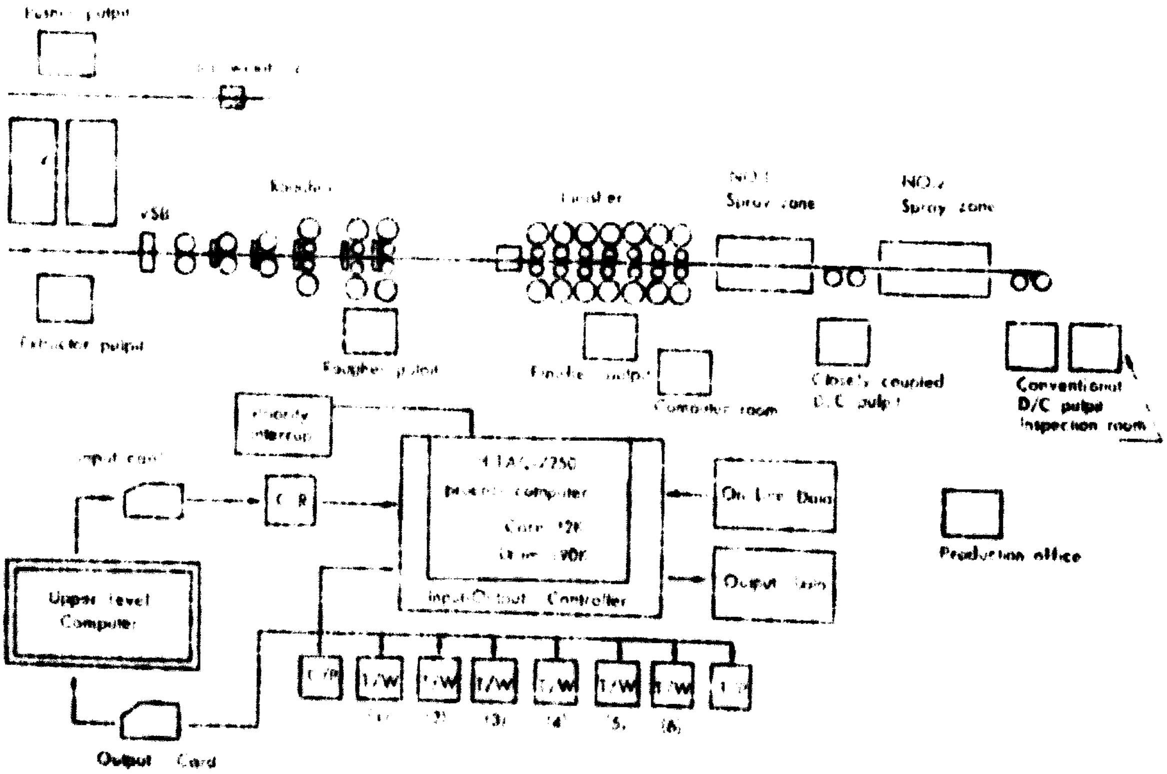


Fig.14 COMPUTER CONTROL SYSTEM

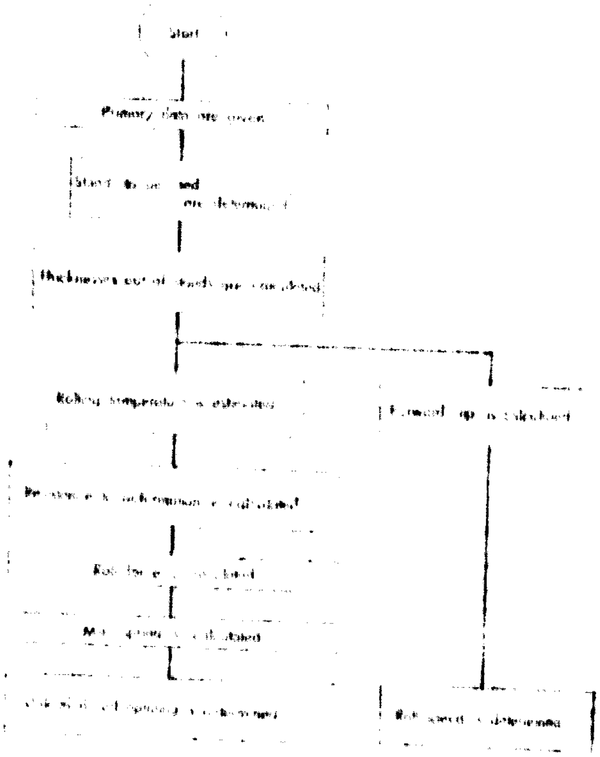


Fig. 15 FLOW CHART OF SETUP CALCULATION FOR FINISHING STANDS

The MLS objective is to deliver software in an almost perfect condition by settling the problems caused by timing in a stage earlier than delivery. The characteristics of MLS are (1) an early grasp of problems caused by timing and their early solution, (2) repeatability of the same timing, and (3) substantial reductions in the field debugging period. The MLS simulates circumstances where several slabs are successively running on a mill line. The spacing between two slabs is initially given as a time interval. Another kind of time interval between two interrupts of a slab moving on a mill line is stored in a timetable as a predetermined time difference. In the table, a program number is also stored which corresponds with each interrupt time interval.

The mathematical model of finisher setup of Wakayama is fundamentally the same with that of Kashima, which is described next.

1-2-2 Computer Control in Kashima.(2)

The computer used is the HITAC-7250. It has a core memory of 32,768 words and a drum memory of 131,808 words. The range of controls of this computer extends from the entrance side of the reheating furnaces to the coil weighing scale. The combustion of the reheating furnace is not yet controlled by the computer (Fig. 14). When a slab stops on the table for the slab weight scale, the pusher operator has to check to see if the slab number painted on the slab coincides with the number displayed by the computer. Then the computer determines the furnace number into which the slab should be charged and gives the pushing stroke.

The extractor control function is similar to the pusher control function. The extractor stroke and the furnace from which the slab should be discharged are determined. The extraction signal is given by mill pacing function, which controls the spacing on a time scale between the tail end of one slab and the head of the next at the entry to the finishing mill, this interval being selected by the operator.

The roughing mill set-up function determines the horizontal roll opening and edging roll opening, as well as the table speeds between the stands. In the No. 5 stand which is closely coupled, a D.C. motor is used, and the computer is used here also to set the mill speed. Of course, it also sets the width gauge and the thickness gauge at the delivery side of the No. 6 stand.

The chief purpose of finishing mill setup function is to set the roll gaps, the roll speeds, the side guides, the width and thickness gauges. In addition to these settings, the computer is also used to select the descaler and to perform settings such as the table speed at the entry to the finisher, the acceleration rate, the deceleration rate, the maximum speed, the looper pressure, and the looper height. As a rule, the calculations for these settings are carried out twice for each strip. The first calculation is made when the strip reaches the pyrometer on the delivery side of the roughing mill using the temperature measured. When the strip reaches the finishing entrance, the roll gap alone is again calculated in order to compensate for the difference between actual and estimated traveling time of the strip. This is the second calculation. If the operator must change the finishing thickness or the rolling speed when the strip has reached the entrance of the finishing mill, he can demand recalculations by keying in the changed conditions on the computer console. In

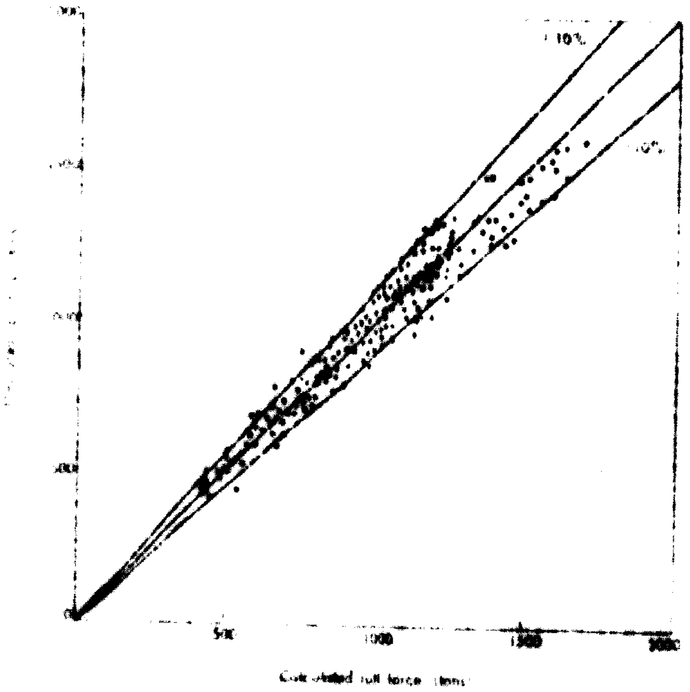


Fig.16 COMPARISON BETWEEN ROLL FORCE MEASURED AND CALCULATED

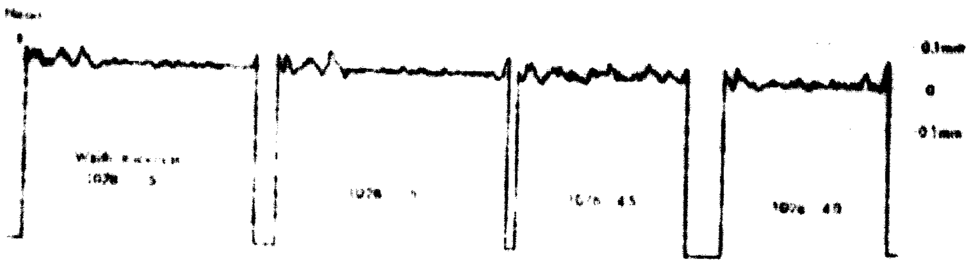


Fig.17 X-RAY CHART OF ORDER CHANGE FROM 1.8 TO 4.8 mm

these setup calculations, the standard load distribution patterns are used, but the operator can use the potentiometer on the operator console to change the load distribution if the shape is poor. The setup calculation is performed according to the flow chart in Fig. 15.

The coiler setup function is for setting the coiler side guide, the wrapper roll gap, and the pinch roll gap when there has been a size change.

There are two kinds of temperature control. The first controls the finishing temperature. The computer selects the finishing roll speed and the spray between the stands. The speed and spray selection are excuted every five seconds from the strip head to the tail. The other type controls the coiling temperature.

In the mathematical model of finisher setup, the estimation of roll force is of prime importance. In order to calculate roll force, theoretical method has been adopted. Roll force is predicted by the following formula, making use of resistance to deformation of steel,

$$P = 1.15K_{fm} \cdot b \cdot \sqrt{R'(H - h)} \cdot Q_p$$

where P is the roll force, K_{fm} is the mean yield stress, b is the strip width, and R' is the deformed roll radius. H and h are the entry and exit thickness of each stand, respectively, Q_p is the roll force function. A study of resistance to deformation has been conducted for a long time by various investigators and it is accepted that resistance to deformation of steel at an elevated temperature is a function of the temperature, reduction and strain rate. An experiment has been carried out in our laboratory to measure resistance to deformation of steels of various carbon content with a drop hammer tester and cam-plastometer. An experimental formula was compiled by regression analysis. Fig. 16 shows the comparison between the measured and calculated rolling force.

Fig. 17 is the X-ray chart of order change from 1.5 to 4.5 mm in finishing gage.

2 Automation of Cold Strip Mill

The equipments of two cold tandem mills in Sumitomo are compared with regard to automatic operation (Table 3). Compared with the mill of Wakayama, that of Kashima has been fully automated, introducing various automatic systems recently developed, which are described in detail below.6)

Recently, NKK in Japan has developed the fully continuous tandem cold mill, which had been the dream of cold rolling.7)

2-1 Coil Handling

In Fig. 18 is shown the main equipment from entry to delivery of the cold tandem mill at Kashima.

2-1-1 Automation of entry equipment

When a coil arrives at the nearest position on the conveyer to the mill, tongs of transfer crane are lowered to catch the coil. During this displacement of tongs, outer diameter of this coil is measured as is shown

Table 3 Specifications of Sumitomo's Two Cold Tandem Mills

( ) shows extension already accomplished.

ITEM		Wakayama	Kashima
	TYPE	56" 5-stand 4-high mill	68" 5-stand 4-high mill
Entry equipment	coil measuring device	—	measurement of coil width and outer dia.
	coil transfer device	(transfer)	transfer crane
	tie-band cutter and remover	—	equipped
	edge position controller	—	equipped
Mill proper	screwdown system	electric motor screwdown	hydraulic screwdown
	main drive motor	No 1 stand 2250 kw, No 2 - No 5 stand 3750 kw	No 1 stand 4500 kw, No 2 - No 5 stand 5000 kw
	maximum rolling speed	1800 m/min	1812 m/min
	AGC	No 1 stand screwdown No 5 stand roll speed	No 1 - No 4 stand screwdown No 5 stand roll speed
	shape control	—	No 1 - No 5 stand work roll bending
	steering sensor	—	No 1 and 2 stand exit
	X-ray gage	No 1 and 5 stand exit	No 2, 4 and 5 stand exit
Delivery equipment	coil-banding machine	—	equipped
Computer Control	type	—	TOSBAC 7000/20
	function	—	1. set-up 2. automatic screwdown control at strip head end 3. production log and engineering log

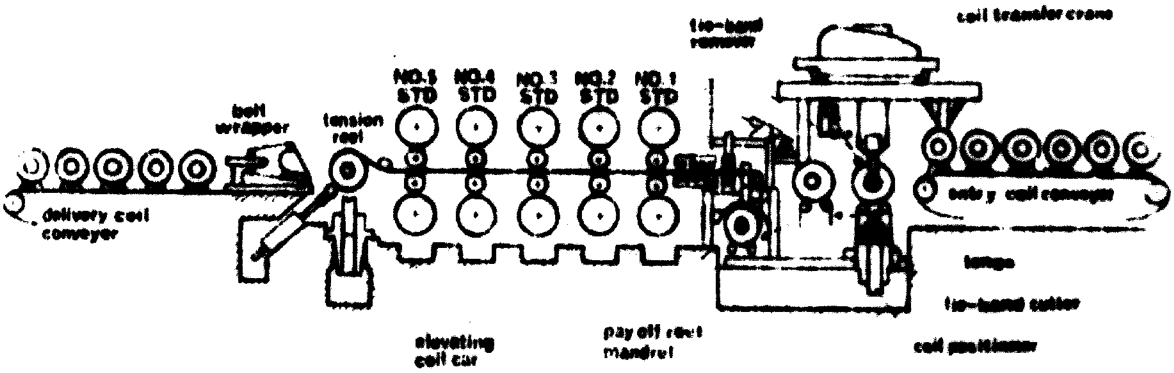
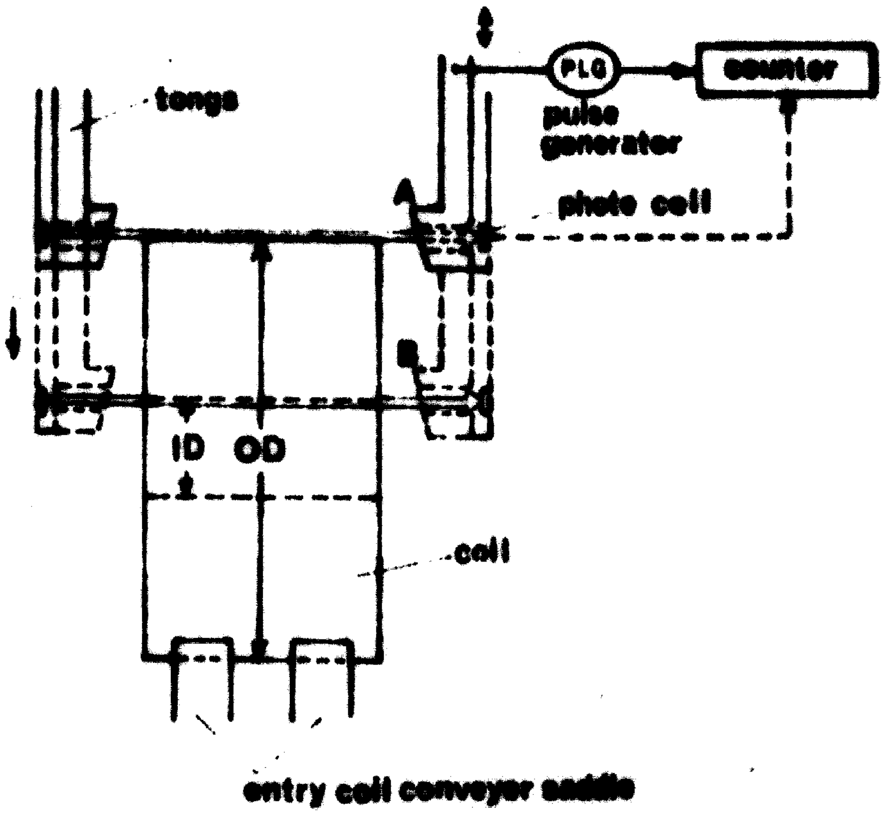


Fig 18 SCHEMATIC LAYOUT OF 5-STAND TANDEM COLD MILL AT KASHIMA



(1) Tongs are lowered.

(2) Position "A" is detected by photo cell.

(3) Position "B" is detected by photo cell.

(OD of coil is measured by tongs'
displacement from A to B)

Fig. 19 MEASUREMENT OF OUTER DIAMETER OF COIL

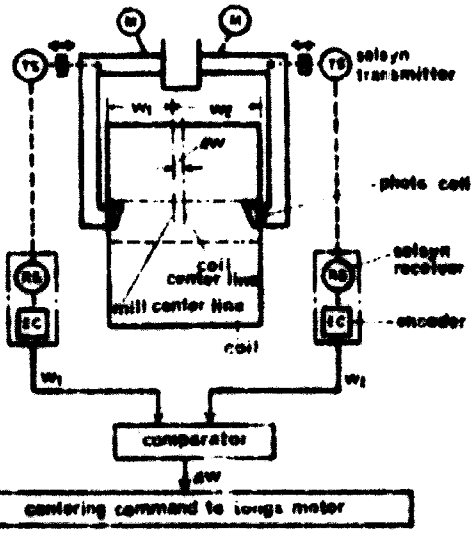
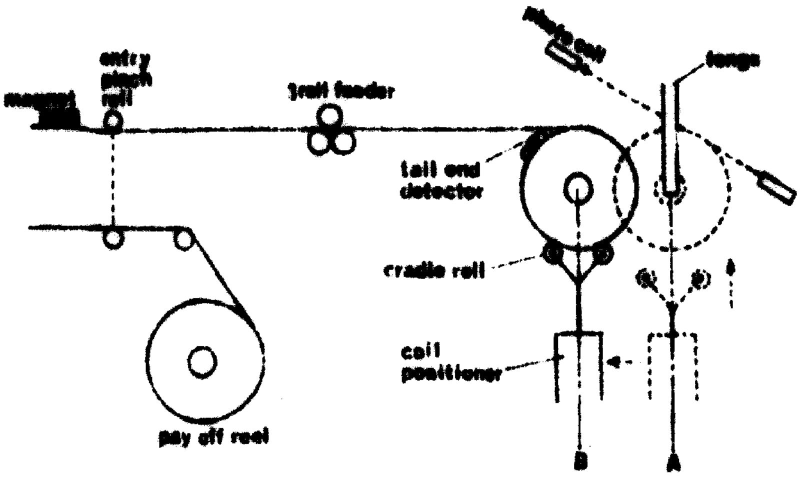


Fig. 20 CENTERING OF COIL ON MILL CENTER LINE



(1) Cradle roll of coil positioner begins to be elevated by photo cell signal and coil is supported on it. (position A)

(2) Coil is transferred from A to B by coil positioner.

(3) Tail end of coil is detected by anti-clockwise rotation of coil. (position B)

(4) Coil is rotated clockwise to feed the tail to magnet.

Fig. 21 ENTRY EQUIPMENT FOR RECEIVING AND OPENING OF COIL in Fig. 19. This value is used to determine the height of coil positioner. Then the coil is lifted by transfer crane and centrally positioned on the center line of the mill by means of a pulse generator attached to tongs (Fig. 20). The coil is transferred and lowered on the cradle roll of the coil positioner. After the tie-band of the coil is cut and removed, the coil is transferred to the opening position. From this action to holding the strip head end by a magnet is explained in Fig. 21. After the preceding coil trailed out of mill, the strip head end is dropped to the normal pass line, then the coil rotation by cradle roll and the coil movement for the pay off reel are begun at the same time, until the strip head end enters into No. 1 stand roll bite, and the coil is supported by the pay off reel mandrel.

2-1-2 Automation of delivery equipment

The principle of the automatic stopping of the coil tail end at a certain position is the same as that of the hot strip mill mentioned previously in this paper (Fig. 9). Just before the tension reel stops, the elevating coil car is pushed up and touches the coil in order to prevent the tail from flapping. Then the tension reel mandrel is collapsed and the coil is transferred onto the delivery coil conveyer by the coil car. The delivery conveyer, together with the coil, is then carried forward, and the coil weight is measured automatically by the coil weighing scale which is located under the delivery conveyer line. After that, the coil is banded by the full automatic banding machine.

2-2 Hydraulic Mill

The position controlled hydraulic mill is highly appreciated and the six cold tandem mills, which have been constructed within the recent several years in Japan, are all of hydraulic type. The one of Kashima, which was manufactured by Mitsubishi Heavy Ind., Ltd., is shown in Fig. 22. For measuring the cylinder movement, load cells are mounted in the tension bar system which connects the cylinder to the housing top beam. The cylinder is 900 mm in diameter, and a stroke of 55 mm is allowed. Load of 1,330 tons per cylinder can be applied. Initial roll gaps are set by tension bar, while roll gap correction during rolling is done giving the signal directly to servo amplifier. Roll gap correction range is ± 3 mm. (The range of extension of bar is from 2.75 mm to 8.75 mm). Fig. 23 shows response to a step change in screwdown position of this mill under the condition of kissing work rolls. The time to reach the first crossover is about 50 msec. for 50 μm change in cylinder position. These hydraulic screwdown responses are compared with the conventional mill with electric motor screwdown system in Fig. 24.[8] In Fig. 24, the hydraulic screwdown mills are classified into two types according to its feedback system, that is, the one is hydraulic screwdown with electrical feedback such as Loewy Robertson type[9], IHI type, which is manufactured by Ishikawajima-Harima Heavy Ind. Co., Ltd., and MHI type, which is adopted at Kashima as is mentioned above. The other is hydraulic screwdown with mechanical feedback such as HYROP, which is manufactured by Hitachi, Ltd.[10]

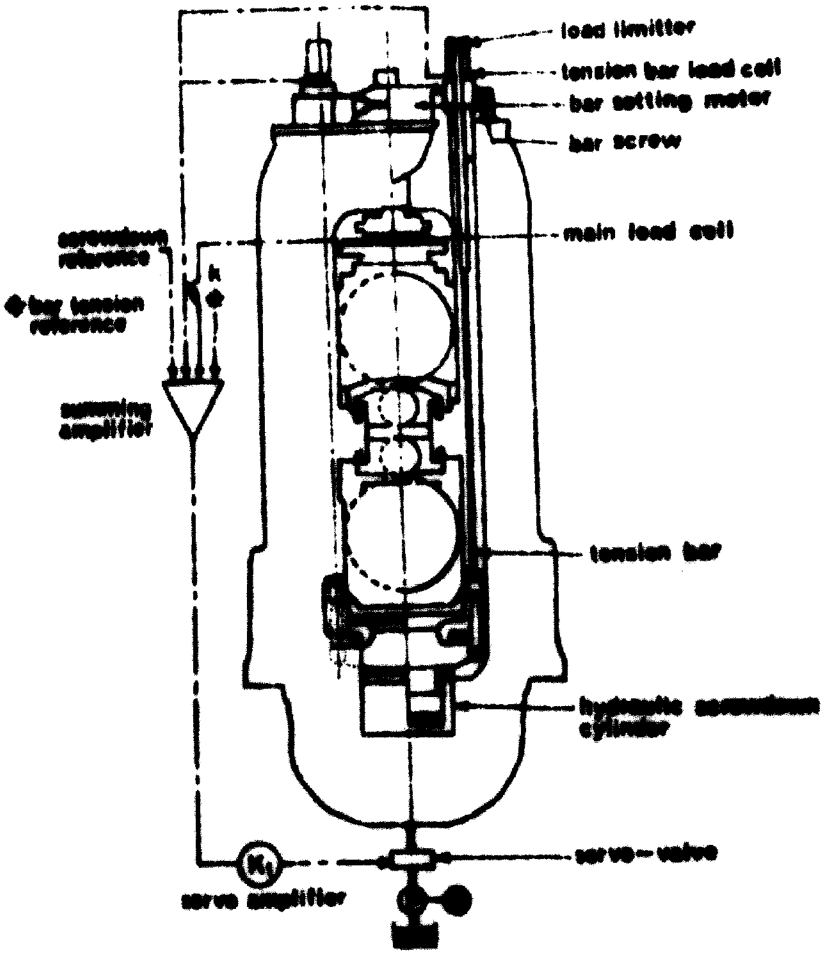


Fig. 22 SCHEMATIC DIAGRAM OF HYDRAULIC SCREWDOWN MILL

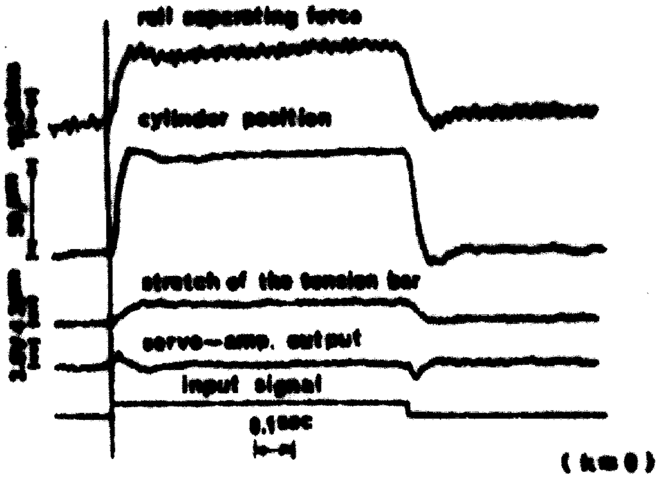


Fig. 23 RESPONSE TO STEP CHANGE IN SCREWDOWN POSITION

2-3 Automation of Tandem Mill

2-3-1 Automatic threading

One of the function of automatic threading is the automatic operation of guides and sprays during the strip head passes through the mill, and while the strip tail goes out of the mill. The other is the automatic steering of the strip head, for which the steering sensors are located at the exit of No. 1 and No. 2 stand. When the sensors recognize the deviation of strip head from mill center line, levelling signal of screwdown is actuated in order to insert the strip head into the entry guide of the next stand.

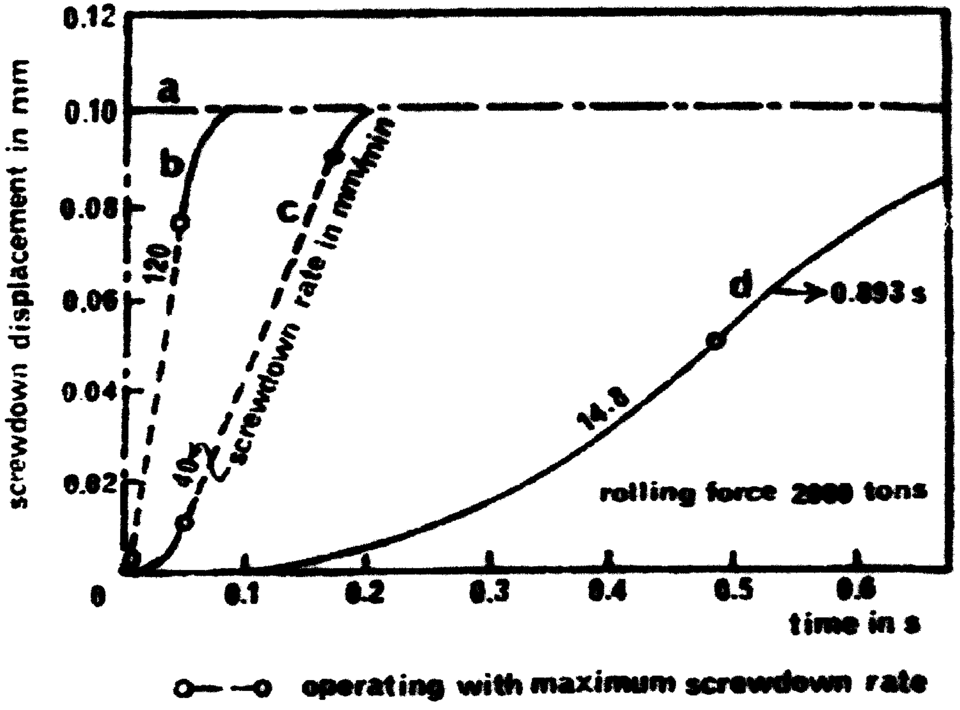
2-3-2 Interstand tension control

On the conventional tandem cold mill such as the mill at Wakayama, the interstand tension control means the tension limit control, namely maintaining the interstand tensions within a desired limit. However for the advanced mill at Kashima, the above mentioned control system is set aside, and a new interstand tension control system, which maintains the interstand tensions at target values, is adopted. That is, this tandem mill is unique in that it is tension-regulated rather than speed-regulated. By this new system, troubles such as strip breakages or pinches caused by abnormal tension have been decreased, and it also has relieved operators of a part of their strained work.

Two methods are possible in order to maintain the interstand tensions at target values. One method is feeding the tensiometer signal back to the screw position controller and the other is to the roll speed controller. Since it is feared that controlling both gage and tension by screw position movement is very complicated especially during strip threading, the tension control has been made independent of gage control, that is, interstand tensions are maintained at target values by controlling stand speeds. The control of interstand tension between No. 1 and No. 2 stand is designed to begin as soon as the strip head end enters into No. 3 stand roll bite. The interstand tension control between No. 4 stand and No. 5 stand begins soon after the tension between No. 5 stand tension reel is established. Actual step response of the constant interstand tension control has been measured, and the time to reach the input tension reference value has been found to be about 0.5 sec. Fig. 25 shows the typical traces for the interstand tension control. In this figure it is evident that the each interstand tension is constant throughout the rolling.

As it is supposed that the behaviour of the tandem mill under the constant tension control greatly differs from the behaviour of the conventional mill without constant tension control, it is necessary to make clear the fundamental differences between the two. The transfer coefficients, denoting the relationship between an input signal and its response of the tandem mill without constant tension control, have already been discussed in detail.[11] On this paper, by means of calculating the transfer coefficients under the constant tension control, the influences on the delivery gage change by screwdown movements are discussed. The following equation shows the influence on the delivery gage change caused by input screwdown signal $(\Delta S)_j$

$$\left(\frac{\Delta h}{h}\right)_i = \sum_{j=1}^{5} A_{ij}\cdot(\Delta S)_j$$



(a) Input Screwdown Signal

(b) Hydraulic screwdown with electrical feedback
ex. Loewy Robertson type, IHI type,
MHI (Kashima tandem mill) type

(c) Hydraulic screwdown with mechanical feedback
ex. Hitachi HYROP

(d) Conventional worm gear screwdown

Fig. 24 TIMES AND SCREWDOWN RATES WITH MECHANICAL AND HYDRAULIC SCREWDOWN DEVICES

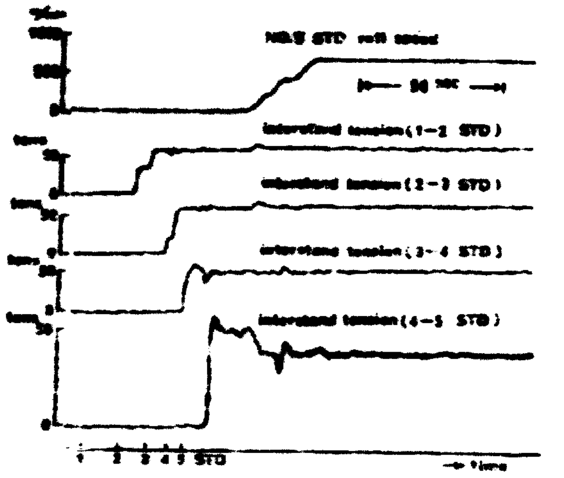


Fig.25 TYPICAL TENSION TRACES FOR INTERSTAND TENSION CONTROL

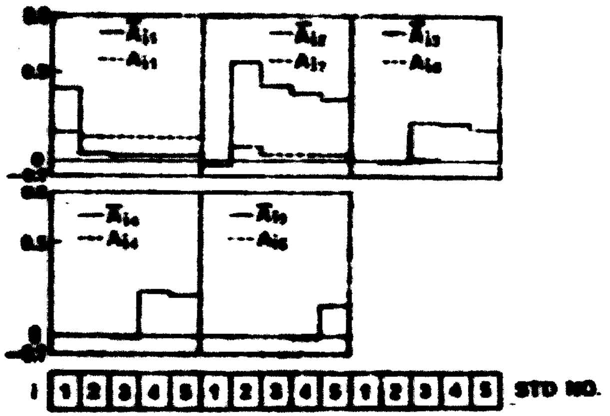


Fig.26 TRANSFER COEFFICIENTS FOR THE MILL WITH AND WITHOUT CONSTANT TENSION CONTROL

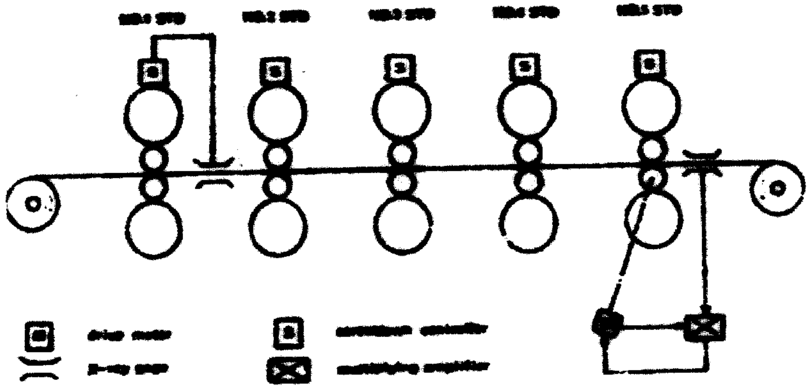


Fig.27 AUTOMATIC GAGE CONTROL SYSTEM (CONVENTIONAL TYPE)

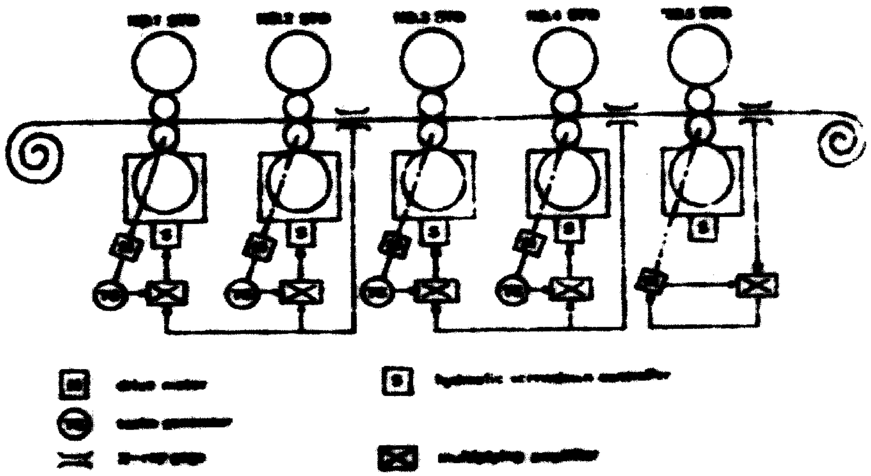
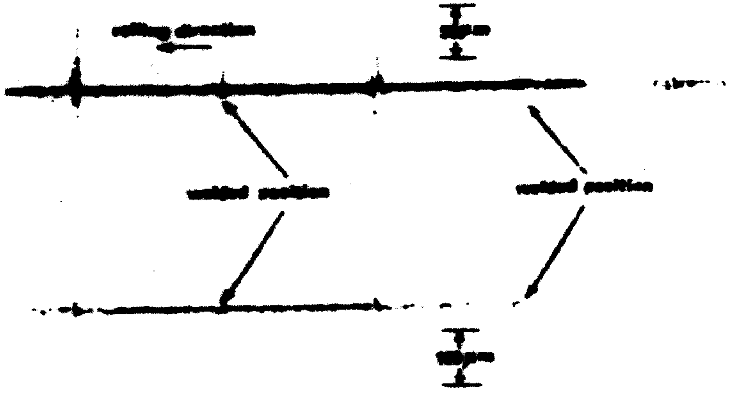
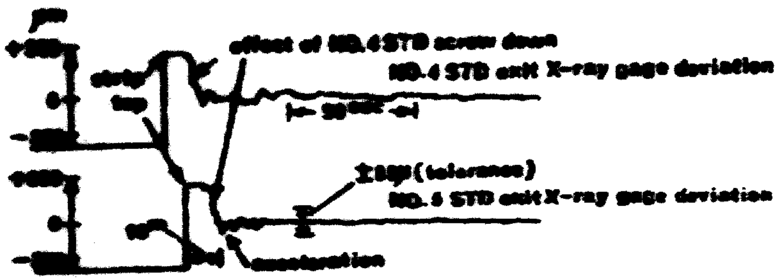


Fig.28 AUTOMATIC GAGE CONTROL SYSTEM



(size 2.7→[illegible] x [illegible])

Fig.29 PULPIT X-RAY CHART OF FINAL GAGE



(size 4.5→[illegible] x [illegible])

Fig.30 AUTOMATIC SCREWDOWN CONTROL AT STRIP HEAD END where A_{ij} is a transfer coefficient for the case of mill modulus of each stand being 170 tons/mm and without the constant tension control. In the other hand $\bar{A}_{ij}$ is a transfer coefficient for the case of equivalent mill modulus of No. 1 and No. 2 stand being 7,000 tons/mm and under the constant tension control. Fig. 26 shows calculated results of A_{ij} and $\bar{A}_{ij}$. The rolling condition used in this calculation is hot strip gage 2.6 mm, final product gage 0.8 mm, strip width 930 mm. The result of calculation is as follows. On the conventional mill without constant tension control, screw movement of only No. 1 stand causes the following stands delivery gage change, and screw movements of other stands bring about interstand tension change, scarcely affecting delivery gagos (See A_{ij}). Under the constant tension control on the other hand No. 2 - No. 5 stand screw movement causes the following stands delivery gage change including finishing gage change (See $\bar{A}_{i2}$-$\bar{A}_{i5}$).

2-3-3 Automatic gage control by X-ray gage feed back

No. 1 stand screwdown control (coarse control) and No. 4, 5 stand roll speed control (vernier control) are in general for the conventional tandem cold mill AGC by X-ray gage feed back (Fig. 27). This is natural because of the fact that screw position corrections except No. 1 stand scarcely affect the finishing gage, discussed in this paper. However, on this tandem mill under the constant tension control, No. 2-No. 4 stand screw position corrections affect greatly the succeeding interstand gage. So it is possible to maintain the desired interstand gage from strip head end to trailing end by interstand screw correction. The advanced and new AGC system of this tandem mill consists of the three feed back loops as is shown in Fig. 28. Fig. 29 is the gage traces of this AGC system showing that strip gage variation is controlled within the limit of ± 5 μm (± 0.6%) from strip head to trailing end.

2-3-4 Automatic screwdown control at strip head end

Usually, off-gage length at strip head end is 30 ~ 40 m or more, because of absence of interstand tensions and screw position setting errors. The advanced gage control system is developed to reduce the above mentioned off-gage at strip head end. The strip position at No. 4 stand roll bite when the strip top enters into No. 5 stand roll bite, is tracked by the computer, and when this position reaches the X-ray gage located at No. 4 stand exit side, No. 4 stand screw position is corrected according to No. 4 stand X-ray gage deviation. The strip position where No. 4 stand screw position correction was carried out, is also tracked by the computer and when this position reaches the X-ray gage located at No. 5 stand exit, No. 5 stand screw position is corrected according to No. 5 stand X-ray gage deviation. This automatic screwdown control at strip threading stage is one of the functions of the process control computer introduced to this mill. Fig. 30 shows the practical traces for this gage control. For this example, off-gage length at strip head end is less than 10 m. It is extraordinary short compared with the mill without this control system. For this control, X-ray gage has to be always located at normal position, though it is usually backed until the threading of the strip has been finished.

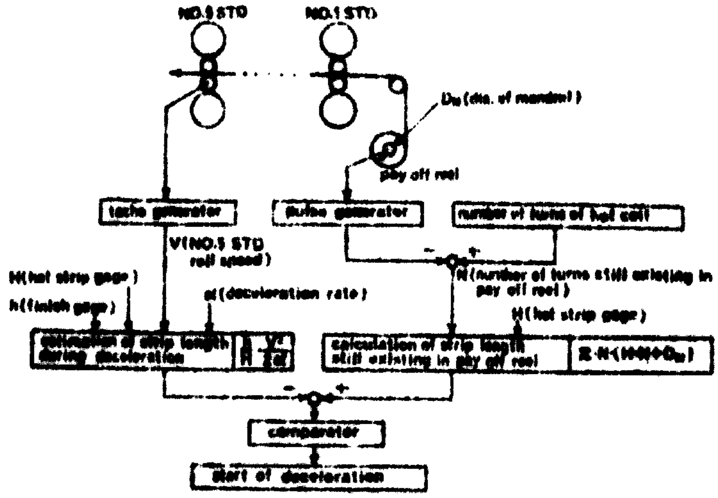


Fig.31 AUTOMATIC DECELERATION SYSTEM AT KASHIMA

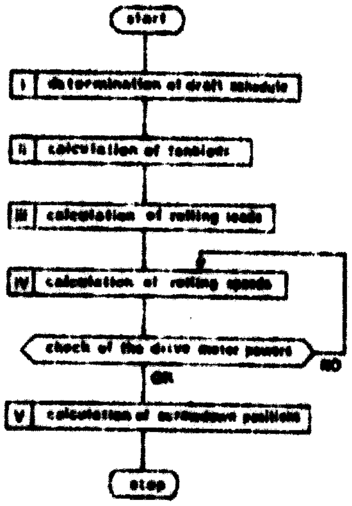
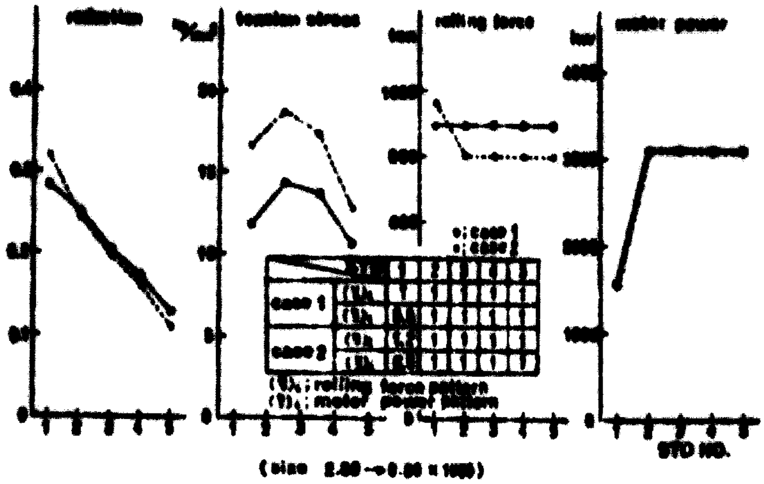


Fig.32 FLOW CHART OF SET-UP CALCULATION



(size 2.80→0.80 × 1000)

Fig.33 NEW METHOD OF PASS SCHEDULE CALCULATION

2-3-5 Oil film compensation at acceleration and deceleration

The oil film thickness of backup roll bearings changes according to roll speed change during mill acceleration and deceleration. Correction of screw position as the function of roll speed is necessary for maintaining the strip gage within the tolerance. Since the oil film thickness change is also affected by the rolling force, the screwdown signal for oil film compensation is fed every 0.1 second from the computer as a function of roll speed and rolling force during mill acceleration and deceleration. The function has been decided by actual measurement of oil film thickness. By this oil film compensation, strip off gage during acceleration and deceleration has been completely prevented.

2-3-6 Automatic deceleration

The automatic deceleration of the tandem cold mill at Kashima is illustrated in Fig. 31. Number of turns of hot coil is initially set. And analog calculations of strip length still existing in pay off reel and necessary strip length for deceleration are continuously carried out during rolling. When the difference of the two reaches a certain value, the deceleration command is issued.

2-3-7 Shape control

Shape control is extremely important for cold rolling. In recent years various types of shape sensors have been developed, such as BISRA type, J & L type, ASEA type, IHI type and Hitachi type.12),13) Though shape control systems making use of these shape sensors have been investigated, it is still not yet sufficient for practical cold rolling.12)

2-4 Computer Set-up

At Kashima, items of the mill set-up calculation are screwdown positions, tension and roll speed references and gage settings. Due to this initial set-up and automatic screwdown control at strip head end, which was mentioned previously in this paper, off-gage length at strip head end has been considerably reduced. Fig. 32 shows the flow chart of the set-up calculation, which is described in detail below.

2-4-1 Determination of draft schedule

The draft schedule of tandem cold mill is usually determined by experience to ensure the rolling under proper force and load condition considering strip shape and other factors. But the authors have made a theoretical approach and developed a method, by which the draft schedule can be calculated completely theoretically. By this unique mathematical model, interstand gages and interstand tensions are theoretically determined if patterns of rolling force and drive motor power of 5 stand are given. Since it is unnecessary to calculate the draft schedule on-line this calculation is done off-line and the result is stored in the online computer. Fig. 33 shows two cases of draft schedules for the same hot strip gage and finishing gage : one is computed on the condition that the rolling forces of 5 stands are the same, and the other is for the condition that rolling forces of No. 1 - No. 5 stand are in the ratio of 1.2 : 1 : 1 : 1 : 1, the drive motor powers of No. 1 - No. 5 stand being restricted in the ratio of 0.5 : 1 : 1 : 1 . 1. The draft schedules for the combination of typical hot strip gage and final product gage, which have been computed by the off-line computer as mentioned above, are stored in the on-line computer. If a set-up is required for a hot strip gage or for a final product gage which is not one of those selected, then this draft schedule is accomplished by simple linear interpolation according to % overall reduction.

2-4-2 Mathematical model of the rolling force calculation

Flow stress has been measured experimentally by tensile test, which was carried out at room temperature on many strips rolled to various reductions. This measured flow stress is modified by strain rate and temperature at actual rolling state, and experimental formula for flow stress is shown as follows.

$$k_m = l\cdot(\bar{r} + m)^n\cdot K_s\cdot K_t$$

where k_m is flow stress, l, m, and n are constants, K_s is a modification factor of strain rate and K_t is a modification factor of temperature, $\bar{r}$ is overall reduction. It is said conventionally that the coefficient of friction between the work roll and the strip varies according to the rolling speed. After various tests were carried out on the practical mill, it has been made clear that the coefficient of friction scarcely depends on the rolling speed, and it is almost constant for each stand. The experimental formula for the coefficient of friction has been compiled according to the above mentioned facts. Then the rolling force can be theoretically calculated. Bland & Ford equation is selected as the calculating method of the rolling force.14) However, it is not suitable for the on-line computer, it has been simplified as below, based on Bland & Ford equation taking account of elastic recovery of strip.15)

$$P = b\cdot\left(k_m-\frac{2t_b+t_f}{3}\right)\cdot\sqrt{R'}\left\{\sqrt{\Delta h}\cdot f_3+\frac{2}{3}\sqrt{\frac{1-\nu^2}{E}\cdot k_m\cdot h}\right\}$$

$$f_3(a,r) = A_0+A_1 r^{\frac{3}{2}} + A_2\cdot\sqrt{\bar{r}}\cdot a + A_3\cdot r\cdot a^2$$

$$a = \mu\sqrt{\frac{R'}{h}}$$

where b is strip width, t_b and t_f is back and front tension stress respectively, R' is the deformed work roll radius, h is draft, E is Young's modulus, A_0 - A_3 are constants, r is reduction, μ is the coefficient of friction, ν is Poisson's ratio, h is stand delivery gage.

References

1) T. Isahaya, H. Mitsuya, T. Okamoto, Y. Misaka and M. Ohnari
Computer Control of 80 - In. Hot Strip Mill
Internationale Eisenhuttentagung 1970 "Automatisierung in Huttenwerken".

2) T. Okamoto and K. Nishizawa
Computer Control of a Hot Strip Mill at Kashima Steel Works
The Sumitomo Search No. 6, Nov., 1971

3) Mitsubishi Heavy Industries Vol. 7 No. 5 p.156

4) K. Sakaguchi, T. Matsuda and S. Kawano
Hitachi Review Vol. 20, No. 11, p.450

5) M. Ohnari, Y. Morooka and Y. Yamamoto
Experience in Installing a Computer Control System in a Hot Strip Mill
Proc. IEEE Vol. 58, No. 1, 1970, p.30

6) K. Murakami, H. Takeuchi, M. Onodera, K. Oshima, A. Yamashita and K. Watanabe
Outline of New Cold Strip Mill at Kashima Steel Works
The Sumitomo Search No. 8, Nov., 1972

7) T. Okamoto, Y. Kawasano, S. Fujii and T. Arimura
Fukuyama's Fully Continuous Tandem Cold Mill
Iron and Steel Engineer, May, 1972, p.79

8) P. Meyer, H. Pfeffer and H. Reihlen
New Developments in the Roll Screwdown Devices for Strip Mills
Stahl und Eisen Vol. 90, No. 6, 1970, p.263

9) R. Jackman, R. W. Gronbech and G. A. Forster
The Position-controlled Hydraulic Mill
Journal of The Iron and Steel Institute, April, 1972, p.235

10) K. Toda, B. Kawasaki, T. Saiki and M. Kurihara
Operational Experience of Hydraulic Screw-down System
Proceedings ICSTIS, Suppl. Trans. ISIJ, Vol. 11, 1971, p.787

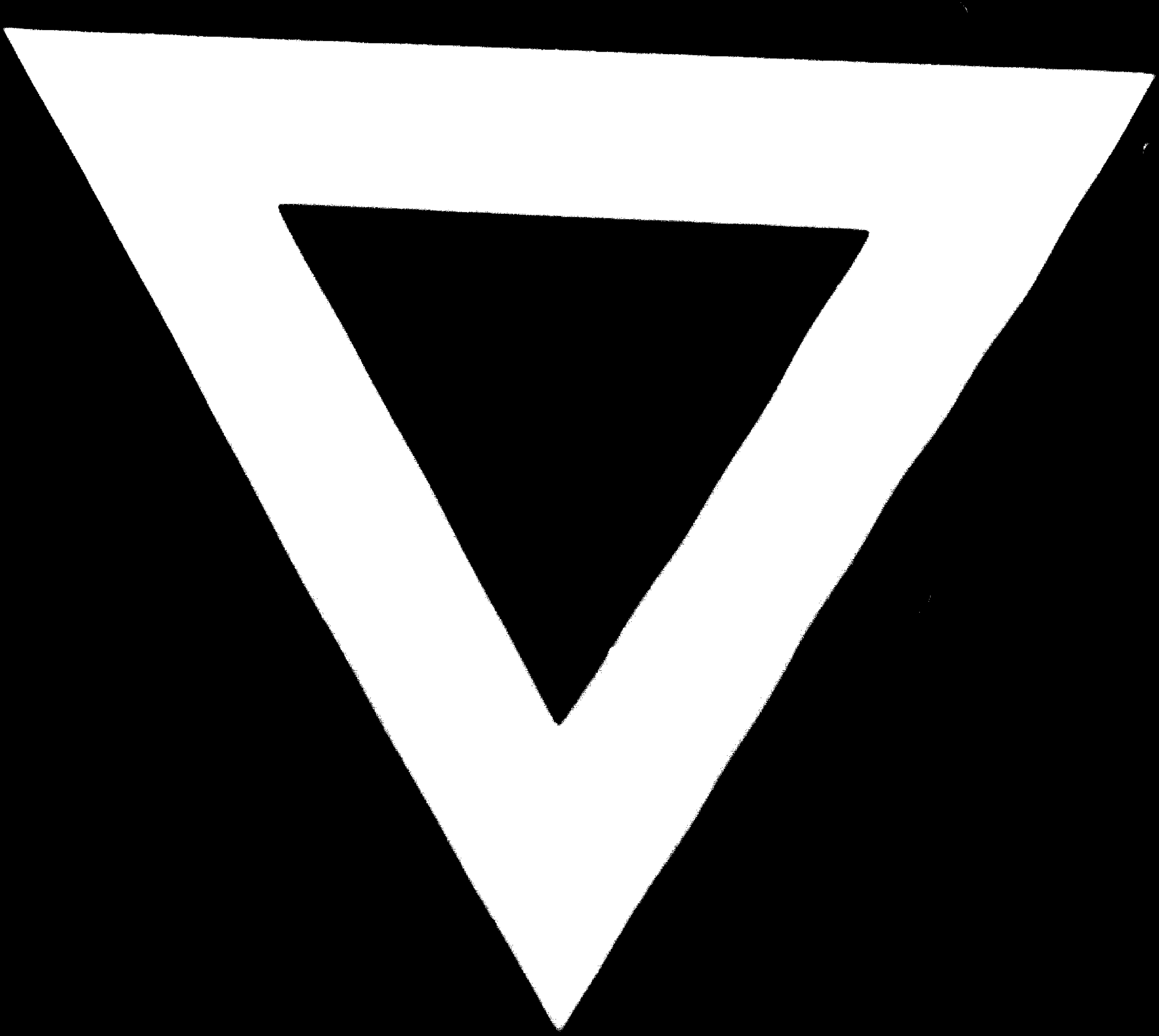
11) Y. Misaka
Control Equations for Cold Tandem Mills
Research Article Trans. ISIJ, Vol. 8, 1968, p.86

12) B. Sabatini and N. A. Townsend
Control of Gauge and Flatness in Cold Strip Rolling
Preprint for International Meeting on Iron and Steel Making Dusseldorf, April, 1970

13) J. R. Dahm
Measurement of Shape on Double-Reduced Tin Plate
Preprint for 20th ISA Conference on Instrumentation in the Iron & Steel Industry, Pittsburgh, Pennsylvania, March, 1970

14) D. R. Bland and H. Ford
Proc. Instn. Mech. Engrs., Vol. 159, 1948, p.144

15) D. R. Bland and H. Ford
Journal of Iron & Steel Inst., Vol. 171, July, 1952, p.245



8. 4. 74