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COMPUTER CONTROL FOR MILL AND PROCESSING LINE

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I. FOREWORD

Application of computer control to mills and processing lines in large iron and steel plants has become common practice, although the art itself is relatively new. Operation of such plants is now very complex, the outcome of expansion, higher operating speeds, and continuonus processing. Too, it is necessary to utilize existing facilities in the most efficient manner.

With the passing of time, steel product specifications have become more stringent. Manpower shortages raise another problem, forcing management to consider and incorporate effective means of reducing labor requirements. To solve the many problems involved, the computer proves an indispensable tool. In this article, we would like to cover accomplishments at Fuji Electric in this field and to discuss actual examples of application.

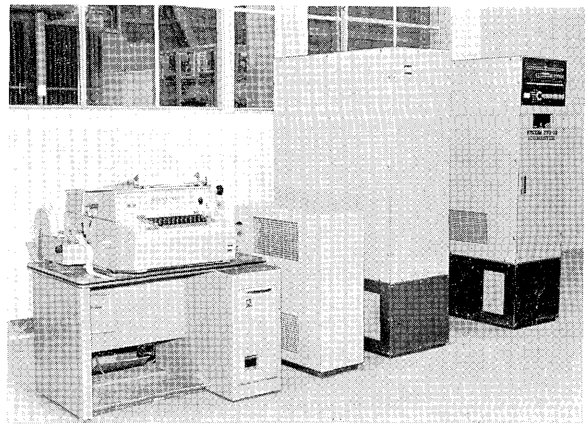

Fig. 1 Computer control system

II. COMPUTER CONTROL OF SLABBING MILL PROCESSES

In the actual application of computer control to slabbing mill processes, the following three areas prove most important in obtaining effective results.

(1) Preparation of operation in the soaking pit, prediction of ingot heating and logging of actual data.
(2) Mill scheduling, automation of operation, and equipment supervision.
(3) Automation of repair line and slab tracking.

Item (1) leads to soaking pit operation at high efficiency, accomplished by scheduling soaking pit operation and predicting slabbing mill operation from data taken from the steel making process, mill conditions, and the soaking pits themselves. At the same time, a mathematical model is revised in accordance with pit conditions, the type of ingot, and ingot temperature.

Item (2) leads to reasons for going to computer control, that is, reduction of mill operators, curtailment of the number of required passes and the time required per pass, and uniformity in product output (conformity to specified dimensions). Here, equipment operation can be held within established ratings and stable, continuous operation can be maintained over long periods of time.

Item (3) leads to higher repair line operating efficiency, automation of slab transport and line operation, providing a means of tracking slabs on the repair line and recording slab history.

We have seen how the computer may used for control at various points. To construct a system giving desired results, means must be provided for smooth and positive acquisition of pertinent data. One of the more recent system improvements is on-line data acquisition between the process level computer and the computer used for top echelon quality control. For example: during mill operation, data concerning ingot size, final slab size, slabbing, weight, slab orientation, etc., may be passed from the top echelon computer to the process level computer to establish ingot scheduling. After slabbing has been completed, the same path in reverse may be used to send ingot slabbing data from the bottom to the top. With such a system, the time lag between origination of slabbing instructions and return of final slabbing data would be very small. Duplication of information would not occur and accurate exchange would be achieved.

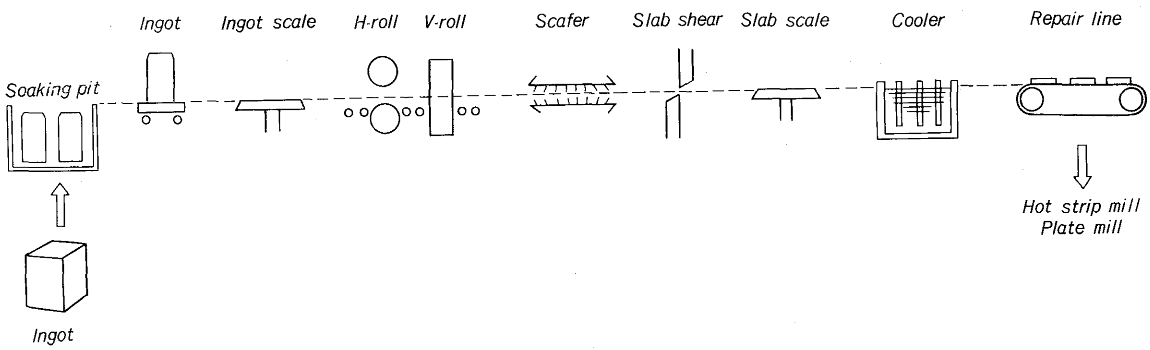

Fig. 2 Outline of slabbing mill process

1. Operation Under Automatic Program Control (APC)

There are three approaches to automatic operation of slabbing mills at the present, card program control (CPC), stored program control (SPC), and automatic program control (APC).

With APC, a mathematical model and required tables are stored beforehand in the magnetic drum of the computer. In accordance with data derived from the ingots themselves, a slabbing schedule is prepared just prior to execution of the actual slabbing operation. All items for the individual passes have been prepared. A vital aspect is development of a mathematical model offering a high probability of achievement.

CPC has been used in the past but card revisions, storage, and preparation prove troublesome. Too, this approach is unsuitable when the number of types of ingots and slabs is large and when size specifications are stringent.

In the case of SPC, schedule revisions, registrations, and cancellations may be made with comparative ease but no provision is included for minor ingot differences, a serious problem.

Here, we have listed functions which the computer in an APC can handle.

(1) Tabulation of slabbing schedule.
(2) Prediction of speed at inpact, rolling and run-out stages.
(3) Setting of roll openings.
(4) Organization of mill tables.
(5) Timing control at inpact stage.
(6) Control of manipulators and fingers.
(7) Tabulation of rolling results.

In addition, the computer handles ingot drag at the start of the rolling schedule as well as tandem separation between passes. The following models are widely used for rolling schedule calculation.

(1) Mathematical model obtained by stressing material, property, and temperature conditions.
(2) Mathematical model obtained by stressing roll pressure (based on motor capability) and material spread.

In either case, the probability of achievement is excellent. With on-line computer control, processing must take place in a very short time span. Major factors affecting these models are roll strength, maximum permissible motor torque, effect on the material under pressure, and the method of rolling (single or tandem, finishing method of products). Determining factors other than roll opening are processing speeds and draft between the rolls, as well as control of manipulators and fingers.

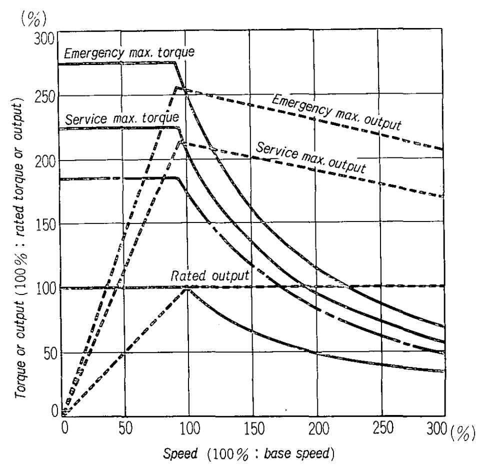

Fig. 3 Characteristic curves of DC motors for reversible mill

Impact and run-out speeds are determined by material thickness, but rolling speed is established by calculating motor torque in the following sequence. In practice, speed is taken from the torque-speed curves. (Refer to *Fig. 3*).

Elongation→roll force→roll torque→motor torque→predication of rolling speed

When a difference arises between speed set for the previous pass and the measured speed, provision must be made for correction of speed between passes, so that the measured difference in speed is added to or subtracted from the speed during the next pass.

Fig. 4 depicts data required during APC operation, types of line signals, and output of the computer.

2. System Features and Problems

As far as the computer is concerned, the slabbing mill processes:

(1) Consist of batch processing system elements for the most part.
(2) Have many interrupted points, necessitate high-speed processing.
(3) Exhibit complex functions in the working state.
(4) Require that ample consideration be given to manual operations when the system is operated automatically.

Ingot and slab sizes are given as initial and final conditiohs. As tracking from start to finish and repeating steps for execution of control are necessary, the configuration is a type of batch processing. During execution of the rolling schedule, interrupted signals from HMD (10–15 points), load cells, and the operating console arrive at random over the line. As the material movement is rapid and safety must be maintained, the interrupted signals must be processed signals without delay, that is, at high speed. As a result, the individual programs are relatively short and in many cases must be permanently stored in the computer core memory.

Due to dfferences in the method of rolling (single or tandem) and fact that most slabbing mills are of the reversible type, system analysis becomes very complex. It may be assumed that manual operations such as correction of material attitude, correction of parts not conforming to the established calculation, and switching in the event of emergency will be necessary.

In constructing an APC operating system, mature thought must be directed to two or three points concerning sensors and software. Points of concern are tandem separation, processing following manual operations, and prediction of impact. Due to difficulty in maintaining proper spacing between two slabs in tandem and ascertaining the shape of slab ends, means must be employed to separate slabs. Even though the time and manner of manual operations is not set, there will be times when it is necessary to consider a number of alternatives and the point in time to which return is to be made when automatic operation is to be restarted. There will be times when manual operations will always have priority, that is, problem free control in which instructions from the computer can be disregarded in favor of the next step. One of the major factors affecting efficiency of slabbing operations is the time between passes. Processing which minimizes the difference between the time interval from shut-off of the load cell to resetting of roll opening and the time interval between passes must be used.

III. COMPUTER CONTROL OF SLAB FURNACE CHARGING

The drive system for walking beam slab furnaces normally consists of vertical and horizontal drives for the beam itself, the charger, and the extractor. The walking beam configuration advances slabs in the furnace by means of repeated operations. That is, the walking beam beigns to more upward from its lower limit, intercepting and accepting the slab on the fixed beam. At the upper limit, the walking beam stops, moves ahead by a fixed stroke, again stops, drops to its lower limit (there by depositing the slab on the fixed beam), and returns to its original position. This sequence completes one cycle. In this manner, all slabs in the furnace are moved ahead by a fixed stroke. The usual stroke is 300–500 mm, adjustable in increments of tens of millimeters.

At the outlet of the slabbing furnace, the arrangement must be such that the trailing end of the slab

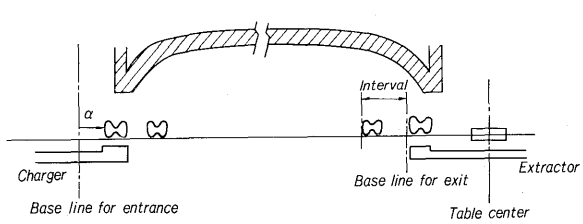

Fig. 5 Walking beam type slab furnace

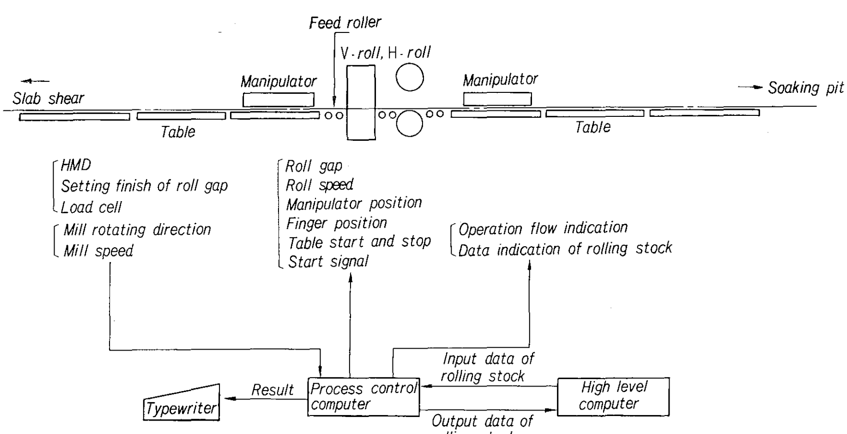

Fig. 4 APC system

at the front of the train always matches the reference line when the slab comes to a stop. If, for instance, the trailing end of a slab were to come to a stop 1,500 mm ahead of the reference line when slab spacing is 1500 mm, three 500 mm strokes would be required to bring the slab to the reference line. In practice, so that furnace efficiency can be held to a high value, slab spacing is made a function of slab width. The stroke length and rate are then determined accordingly.

At the inlet of the slabbing furnace, insertion (α) must be adjusted so that slab spacing can be held to a fixed value. Usually, insertion is continuously variable between zero and 500 mm.

Attempting to conduct the operations just described manually is next to impossible. Use of a computer allows operations to be automated, as described below.

Computer functions

1) Tracking

Slab spacing may be indicated manually or automatically, and slabs tracked within the furnace.

2) Stroke length and rate of walking beam

Through tracking, spacing of slabs to be extracted can be determined and stroke length of rate of the walking beam established.

3) Specifying insertion (α)

Through tracking, insertion can be specified to obtain required slab spacing.

4) Operation of walking beam, charger, and extractor

The walking beam is automatically started by stroke length and rate information derived from (2). It is stopped automatically when the slab reaches the outlet reference line, at which time an EXTRACT OK indication is made. Automatic stopping takes place upon completion of one cycle if ample space for loading a new slab at the inlet develops prior to the slab at the outlet reaching the reference line, at which time an INSERT OK indication is made. Slabs are shifted over set intervals α (in the case of the charger) by separate charger and extractor digital control devices. Problems pertaining to furnace doors are encountered in starting operation, but timing is made manually.

In the event that two furnaces are used (♯1 and ♯2), automatic selection of the furnaces according to a fixed rule, staggering within a single furnace according to slab length, or automatic selection of inlet positioning (alternate insertion on one side) is possible, by utilizing a computer.

IV. COMPUTER CONTROL OF BILLET SHEAR

One process between the slabbing mill and the rod mill is the billet mill. Here, a flying shear is used to cut the billet to required length so that a suitable amount of material can be supplied to the rod furnace. The length of material remaining after the final cut must be made as short as possible, to reduce scrap.

In the billet rolling process, material divided into a number of pieces during earlier processes is rolled by a ♯1 and ♯2 continuous rolling mill and cut into optimum lengths. To determine the proper length of cuts, it is necessary to measure the length of billets as they come from the last rolling mill. The flying shear is located immediately following the ♯2 continuous rolling mill. At this point, measurement of the entire length is not possible. Therefore, measurement is made following the ♯1 rolling mill. Determination of the length of individual billet cuts must be made from a final length (culculated value) which takes into consideration extension in the ♯2 continuous rolling mill.

To satisfy the above objectives, computer control equipment having the following functions may be introduced.

1) Measurement of billet length
   a. Measurement of billet length following the ♯1 continuous rolling mill.
   b. Calculation of billet length following the ♯2 continuous rolling mill.
2) Computation of length of cuts
3) Instruction to flying shear

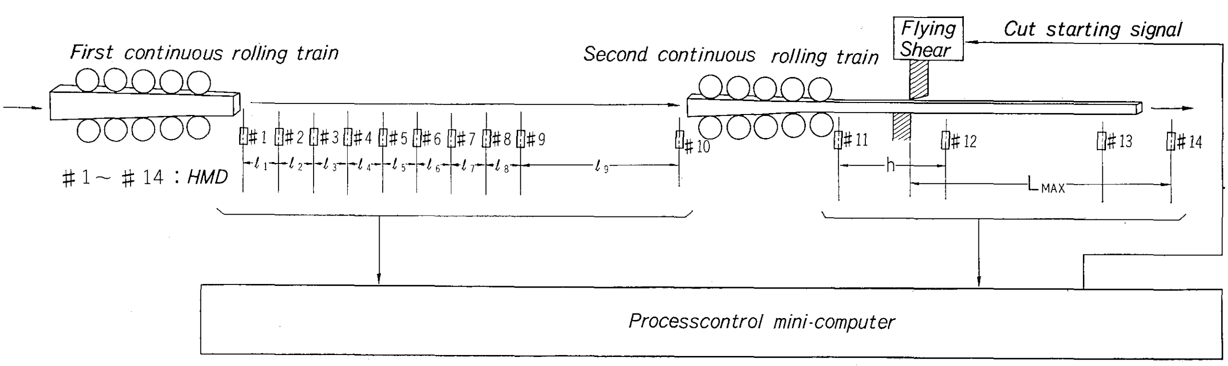

Fig. 6 Block diagram of automatic billet measure

The following paragraphs are devoted to describing the functions.

1. Measurement of Billet Length

1) Measurement of billet length at outlet of ♯1 continuous rolling mill

As shown in *Fig. 6*, m ($m=10$ in this case) HMD units are installed between the ♯1 and ♯2 continuous rolling mills. At the instant in which the leading end of the billet passes ♯10, billet length L_1 can be found from the following equation, as long as the trailing end of the billet lies between ♯n and ♯$n+1$ HMD units.

$$L_1 = \sum_{n=m}^{9} l_n - l_{n-1} \frac{M'_n}{M_{n-1}}$$

With: M_{n-1}: Number of reference pulses counted by counter M in computer as trailing end of material passes from ♯$n-1$ to ♯n.

M'_n : Number of reference pulses counted by counter M in computer between trailing end of material passing ♯n and leading end of material passing ♯10.

2) Calculation of billet length following the ♯2 continuous rolling mill

Total length (L_2) of the billet at the outlet of the ♯2 continuous rolling mill can be found from the following equation, after elongation (γ) caused by rolling pressure has been preset to a fixed value at the operating console.

$$L_2 = \gamma L_1$$

Arrangement is made so that elongation (γ) can be set to different values, depending on billet dimensions.

2. Computation of Length of Cuts

With upper and lower limits for the final length of cuts designated by l_{max} and l_{min} and total length L_2 already described, optimum length of cut (l) and the number of cuts (n) can be calculated with the flow chart (*Fig. 7*).

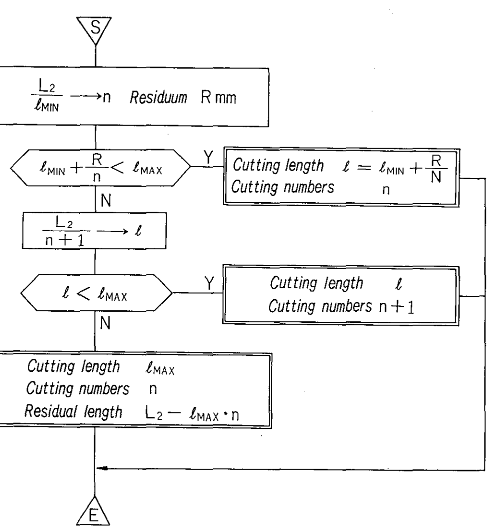

Fig. 7 Flow chart of optimizing shear calculation

3. Instruction to Flying Shear

Reference pulses are counted from the instant the leading end of the billet passes ♯11 HMD until the instant it passes ♯12. This count is designated S, and can be used to determine the number of pulses per meter (K). So that the cutting length can be preset, HMD ♯13 and ♯14 are used. These HMD's:

Located at $l_{min} - \alpha$ from shear: ♯13
Located at l_{max} from shear: ♯14

Using l(mm) obtained previously from the computer:

$$(l_{mm} - l_{min} + \alpha) \times \frac{K}{1000} = C$$

Then, counting reference pulses C from the instant that the leading end of the billet passes ♯13 brings the leading end exactly l mm from the shear. Therefore, value C is inserted at the preset counter for the length of cut. When the number of counter pulses coincides with the preset value, the shear command is issued. Subsequent cutting lengths are set in same manner, so that suitable shear commands may be issued.

At the final cut, the trailing end of the billet separates from the continuous rolling mill and the billet forward speed rises. So that a maximum cut can be made at this time, HMD ♯14 has been installed.

V. COMPUTER CONTROL ON PROCESSING LINE

Coils produced by the hot strip mill pass through a number of processing lines ahead of and after cold rolling mill, becoming end products. Processing lines include the pickling line, annealing line, galvaniging line, shear line, and recoiling ilne. Each has its own characteristics. At the present, these processes are by and large automated. In comparison to rolling mills, however, introduction of the computer is somewhat lagging. The reason for the lag lies in the fact that manual operations are required at each process from coil insertion to the start of operation. Manual operations include joining of coil ends (by welding), inspection, and coil handling after winding. Even though manual operations are unavoidable, still the computer can be used to improve product quality, smooth line operation, and save manpower. On processing lines, the computer may be used to handle the following tasks.

1) Data logging
2) Operating instruction and display in high-level sequence control

3) Computation including unit conversion, efficiency calculation, and sorting

Data logging is usually accomplished with punched cards or tapes. More recently, however, on-line systems with a centrally located computer are being used for production supervision. In this case data is forwarded to the central computer via a suitable means.

In the case of 2) above, shear commands (for flying shear), automatic decelerate commands, conditions pertaining to the state of operations, etc., are displayed to the operator as they occur or appear.

Category 3) includes unit conversion involving weight and length, calculation of efficiency based on time and production achievements, and scheduled shearing to reduce scrap levels. Computer systems of this type can have a variety of functions. If a computer is to be used, selecting one of the following basic configurations is necessary.

1) Independent installation of computer at each system.
2) Central installation for a number of system.

In the first case, Fuji Electric makes use of smaller computers designated FACOM 270–10 and FACOM R. Avoiding duplication of installation, that is, wasted investment, is very important. With inlimits set by operating efficiency of the computer, the installation should offer common functions in respect to censing devices and automatic operating devices.

In the second case, medium size computers (FACOM 270–20, FACOM 270–25, FACOM 270–30) are used. As the computer is given a number of duties, the installation includes measuring and control devices which are independent of the computer, so that a single failure will not affect the remainder of devices. Because of differences in completion times and maintenance, an on-line debugging function must be made available to the computer.

In view of these considerations, the following paragraphs give examples of computer application to a recoiling line and a hot skinpass mill.

1. Recoiling Line

The recoiling line is the final process of processing for thin sheets. The cold-rolled coil is inserted to pay-off-reel inspected, oiled, and cut into fixed lengths. These lengths are recoiled and weighed, to form end products. Processes are more involved than in other operations.

Fig. 8 illustrates the layout of recoiling line. System devices provide output to the computer, positive-negative pulses from the measuring roll, digital signals representing actual values from the γ ray thickness gauge and weighing scale, and inspection data from the input control panel. Data from the original coil (pay-off reel) consisting of the coil number, weight, material, etc., and from the end product coil consisting of date, sheet width, sheet thickness, etc., is read out from a card reader. Length of the coil is measured by pulses from the measuring roll. These pulses are used to obtain a command signal for the automatic decelerating device (for line speed control) and for the shear (to cut the sheet).

The γ ray thickness gauge monitors sheet thickness over the entire length of the run so that the computer may maintain comparison to the specified thickness. Samples are taken at fixed intervals, to give thickness data. This data may be converted to give product weight.

Inspection result, flow information, and other data are set up at the input control panel and read out to the computer when the recoiling operation has been completed. Digital data indicating the weight of the end product is fed from the weighing scale to the computer, providing a check on product weight and means for determining the difference (if any) between specified weight and actual weight. Results are displayed to the operator.

At the preset panel, card data is revised, the line operating state verified, operating control effected, and data processing system operation handled.

Tabulation in printed form is carried out when all process have been completed according to data and instructions, by item and format specified at the preset panel. Pertinent data is stored in the computer. As soon as data is no longer required, that data is cleared from the computer memory.

— Computation —

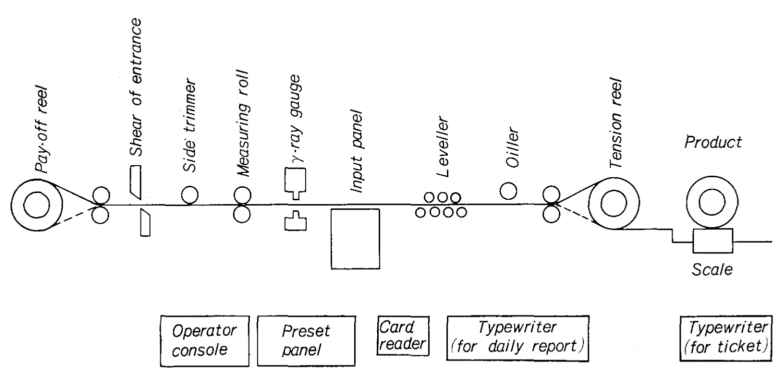

Fig. 8 Layout of recoiling line

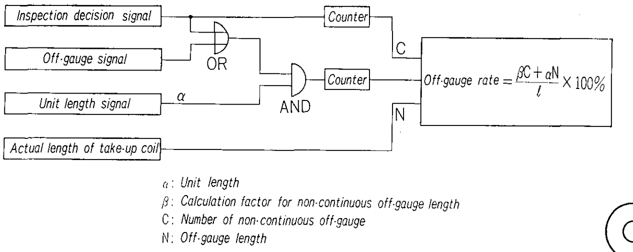

Fig. 9 **Block diagram of off-gauge calculation**

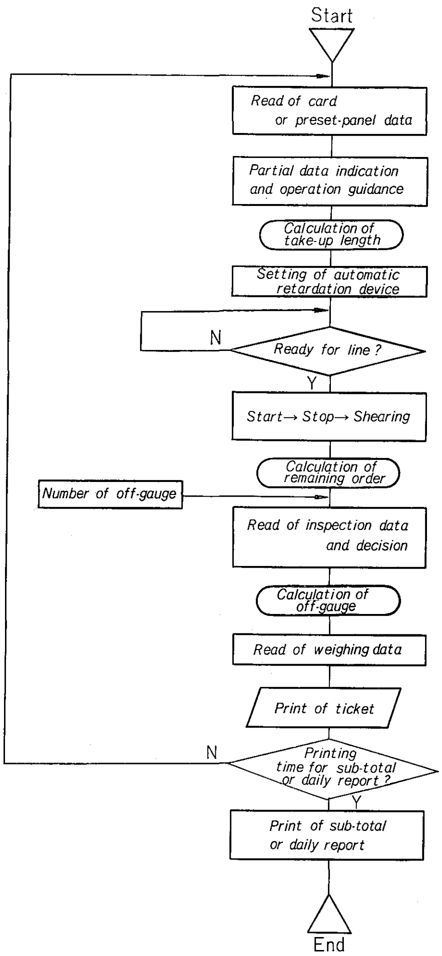

Fig. 10 **Flow chart of operation**

1) Calculation of coil length

Material in the original coil is inserted pay-off reel cut at a specified point, and recoiled on tension reel, to provide an end product. As the customer specifies the weight of product coils, data is given in the form of weight. Using the specified weight, sheet width, and sheet thickness, the computer calculates the correct length of the product coil and sends a control signal to the automatic decelerating device. The final coil weight must fall within the specified range. Calculation is effected so that an excess length (weight) is not pulled off the original coil.

2) Calculation of weight

The weight of the product coil is actual measur-

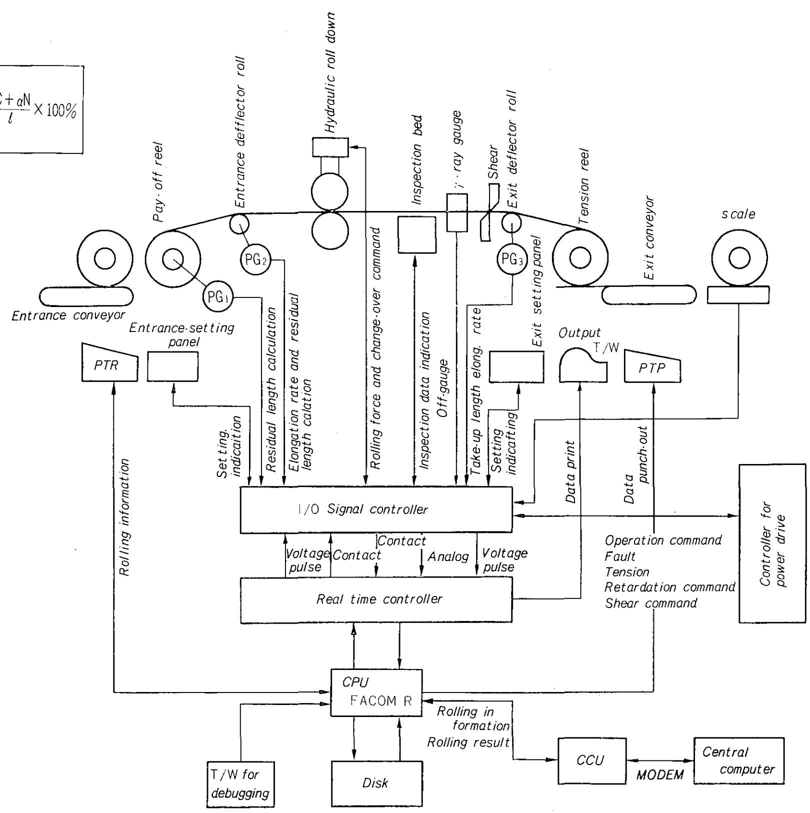

Fig. 11 **Layout and block diagram of hot skinpass mill**

ed by a scale. In the event of scale failure, however, calculation of weight from coil length, width, and material thickness is possible.

3) Calculation of quality

The amount of material (length) exhibiting substandard quality can be calculated and expressed in percentage form. Refer to *Fig. 9* for an example.

4) Others

Provision may be made for collecting and classifying data pertaining to accumulated line down time, formation of daily reports, and classification of end products.

Refer to *Fig. 10* for flow of the above operations and processes.

2. Hot Skinpass Mill Data Logger

The hot skinpass mill is used to be skinning of hot rolled and pickled coils, and to recoil the material. In comparison to other rolling mills, the hot skinpass mill is quite simple. As the operating system is also simple, introduction of a computer presents no particular problem. Here, the computer system is equipped with functions previously handled by a variety of measuring devices, that is, with the exception of sensors. Objectives include reduction of installation costs, curtailment of operating manpower, and partial computer control.

Fig. 11 shows the layout of major components in the installation and system structure. Here, the pay-off reel, the entry deflector roll, and the exit deflector roll are equipped with a pulse generator of the directional valve type, so that the pay-off reel may be stopped when all material has been payed off and the coil length at the tension reel may be controlled. For this automatic decelerating arrangement, provision is made to handle processing with a computer. To stop the pay-off reel, the coil diameter can be calculated over a fixed period. The computer access factor is not so high and at the same time installation costs can be reduced. Entry and exit side pulse generators can also be used to measure extension during skin-pass rolling operations.

Ordinarily, extension (α) in percent is obtained from the following equation, that is, if entry and exit deflector roll diameters are the same.

$$(\%)=\left(\frac{\text{number of exit side pulses over fixed interval}}{\text{number of entry side pulses over fixed interval}}-1\right)\times 100$$

In practice, the number of entry pulses (P_1) is specified. As soon as this number of pulses has appeared, a break-in instruc ion is issued to the computer. Exit side pulses (P_2) at that point in time are checked and the above calculation carried out. Therefore, an external extension measuring device is not needed. So that extension may be held to a fixed value, the computer sends operating instructions to the mill hydraulic system. In this manner, roll pressure is varied as required. Three instructions are required : Increase pressure, maintain pressure. A γ ray thickness gauge is used at the exit side of the mill to monitor strip thickness and calculate the percentage of sub-standard material. With this instrument, γ rays are used to determine material thickness. Output is an on-line signal which shows whether or not thickness is acceptable. This signal is fed directly to the computer, at which point it combines with pulse generator output to indicate the percentage of sub-standard material in individual coils. Inspection of coil surfaces is conducted at the inspection control panel ahead of the shear. Results of inspection are set up and fed to the computer. In the skin-pass mill, the coil is cut into fixed lengths. Here, the computer feeds a signal to the shear, thereby controlling the point at which each cut is made. At the exit side of the mill the product coil is weighed by scale. Weight data is taken in digital form and fed to the computer. Digital signals from mill may be obtained from contacts, pulse generators, or analog voltage at this point. In view of avoiding problems such as noise and time delay, a contact system is perhaps the best. The input-output converter panel in *Fig. 11* is for the most part constructed in using wire spring relays and semiconductor logic element (F–Matic).

The computer system is designed for transmission of mill control data over data channels from the central processing unit. In the event of channel failure, however, the data can be fed from a paper tape reader located at the point to be controlled. In similar manner, mill output data may punched into paper tape at the point of origin.

Here we have described the data logger for skin-pass mill application. Although involved data may vary, the basic data processing system for data logging on a recoiling line is the same. Therefore, description is omitted.

VI. CONCLUSION

Some ten years have passed since the computer was applied to iron and steel making operations. During this period, social demands and progress in both hardware and foftware areas have led to phenomenal development in the computer control system field. The future will see installations on a much larger scale, a greater degree of unification between the data and electrical drive devices, and high-level scheduling by computer. One of the real future requirements is true cooperation between the manufacturer and the user, so that the effect of interfering problems can be minimized. This can be accomplished by forming a tightly knit system of control.

We have touched on Fuji Electric accomplishments in computer control for the iron and steel industry. While the information presented in this article is not extensive, still it should serve to demonstrate our line of endeavor.