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AUTOMATIC CONTROL IN THE IRON AND STEEL INDUSTRY

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Basic iron and steel production processes, starting in the blast furnace and followed by steelmaking and rolling procedures, have not been altered greatly, although there have been modifying developments in each, viz., basic oxygen steelmaking and the continuous casting process. However, while in recent years production equipment has become much larger, and thereby the output increased, the operating cost has been reduced and the productivity has been improved. The achievements, I believe, are due largely to an extensive use of automatic control systems in each process. These have, in turn, decreased labour requirement and resulted in improved working conditions. Approximately ten years ago, the digital computer was introduced in plants for the purpose of controlling processes, and much effort has been expended on studying its use. Improving the aid of this computer is a basic problem in the steel industry even today.

The following are descriptions of the recent development in automatic control techniques and their trend in the various fields of the iron and steel industry.

I. Ironmaking Process

The most representative equipment in iron production is the blast furnace in which iron-ore is reduced to pig iron at high temperatures. There are, in addition, sintering and pelletizing facilities for the preparatory treatment of iron ores, the coke oven, and equipment for the chemical treatment of by-products.

1. Blast Furnace

The blast furnace is a semi-continuous process utilizing several different kinds of iron ores to produce a constant quality of pig iron and yielding 4,000 to 6,000 tons per day in newly-constructed plants.

A chief objective to control the blast furnace has been considered in order to eliminate every perturbation effect, thereby making it possible to keep the internal metallurgical reaction in a steady state. It was primarily for this purpose that the following items were controlled with conventional analogue controllers in the past:

(a) the flow rate, temperature and moisture content of the blast
(b) the furnace top gas pressure
(c) the flow rate of fuel oil injected into the furnace
(d) the combustion and reversal of the hot stoves.

The sequence control of charging and the regulation of furnace conditions have been accomplished only since digital techniques and computer applications have become practically available. The sequence control was first carried out by the use of relay switching circuits nearly ten years ago. More recently, the use of a small computer has made it possible to improve its performance markedly.

The regulation of furnace conditions aims at maintaining metallurgical reactions which could not have been accomplished by the above means of control. This has been considered as one of the most interesting processes to which computer control can effectively be applied.[1, 2, 3, 4, 5]

In order to achieve such control, a mathematical model which expresses the changes of the furnace conditions as a function of a set of other variables is constructed in order to let a computer calculate the appropriate actions to be performed at definite given intervals. There are various approaches to the construction of such models: The first is a statistical one which is derived from the analysis of operational or experimental data; the second, a theoretical one which can be constructed on the basis of the heat and the material balances; and the third is a combination of the two. Of these, the models which have been deemed as practically feasible are formulated on the basis of the heat balance existing at the lower part of the furnace in combination with the material balance, and whose values of coefficients are statistically determined from actual data.

For instance, a model which was developed by IRSID,[6] (France) is:

$$W_u = \frac{1\,000}{P_i}\left(1.375B - 0.145C + 0.44\,\frac{h}{1\,000} - 0.336\,\frac{\theta}{1\,000} - 0.87j + 0.896\right) - 0.14F + 96$$

where W_u: parameter characterizing the thermal state of the hearth

P_i: index of production (ton pig iron / 1 000 Nm^3 blast)

B : $(CO + CO_2)/N_2$ of the furnace top gas

C : H_2/N_2 of the furnace top gas

h : blast humidity (g/Nm^3)

: blast temperature (°C)

j : rate of fuel injection (g/Nm^3 blast)

F : metal charged (kg raw iron / ton pig iron).

The control maintains the parameter W_u at a constant level W_R by adjusting the blast temperature, the blast humidity and the rate of fuel injection at the tuyeres. When there are changes in operating conditions, a new level W_R is established and the control then maintains W_u at the new level W_R.

It is not easy to assess the economic evaluation of such a computer control. Fig. 1 shows one example of such an evaluation, which was reported by the Inland Steel Co.[7] (U.S.A.). In this case there was an effective reduction in fluctuation of Si content in produced pig iron, as a significant characteristic for the furnace operations.

In order to control the furnace with a mathematical model, the roles of measuring instruments and sensors are not negligible. There are actually many cases in which an entire system does not work effectively owing to the lack of reliability of an instrument. Namely, a gas analyser for the furnace top gas is one of the most important instruments to regulate the furnace conditions, because observation of the gas composition is believed to be the fastest means of obtaining information on the state of reactions occurring in the furnace.

An infra-red gas analyser or gas chromatograph has been useful for this purpose. Its questionable stability and precision which were not negligible in the past have been much improved for practical application.

Fig. 2 shows a modern control room of the blast furnace, including a graphic display of automatic charging and ITV's to monitor conditions at the furnace top.

2. Sintering Process

The sintering process which is indispensable as a preparatory process for the blast furnace consists of mixing fine ore and coke, agglomerating by heating and producing a material ore in suitable grain size. A typical continuous sintering process, the Dwight Lloyd process, is shown in Fig. 3.

To maintain a continuous state of operations, the following measurement and control systems have been employed:

(a) The mixing process of materials is controlled for the purpose of keeping the physical and chemical properties of products uniform. This is achieved by blending them in a steady ratio with constant feed weighers which regulate the amount of materials received from the hoppers. In some cases, the material compositions are analysed by an on-line fluorescent X-ray analyzer to decrease the fluctuation of the basicity and slag ratio of the sintered ore.

(b) The moisture content of the ore and coke is closely related to the resulting property of the sintered ore, because it affects the air permeability of the material mixture as well as the combustibility. As a means of measuring this content, a neutron-type and an electric conductivity-type of moisture meter have been developed; and, as a means of controlling these, there are cases in which a sampled-data control system has effectively been used. To obtain the maximum strength of the sintered ore, optimalizing control of air permeability of the material mixture by adjusting the moisture content has also been tested.

(c) In the sintering process, control of layer thickness and bulk density of the material which is supplied on the pallet, as well as the control of the pallet speed have been carried out. Recently, optimization of the pallet speed by measuring the burn-through point on the pallet, and further sequence control of start-up and shut-down operations of the sintering process have been achieved by Yawata Iron and Steel Co. (Japan), and in several works[9] in the Benelux countries.

All of these controls may be improved by the use of a computer. A system recently developed by Fuji Iron and Steel Co. (Japan) is supported by the following computer functions:

(a) Continuously collecting values of a process variable, such as those of the burn-through point, air permeability of material, temperature and pressure of waste gas, and their tendency to change, etc., all of which are closely related to the resulting quality of sintered ore and to the process productivity. The computer classifies the process state presented by a set of those values as "patterns of production state", by registering the high, low or normal condition of each variable. When the states of variables are distributed on a list, the computer identifies the "present pattern" of production.

(b) According to the identified pattern, the computer determines whether the pallet speed should be increased or decreased.

(c) As to the extent of control action, determination is made by a separately prepared control equation.

II. Steelmaking Process

The steelmaking process consists of refining pig iron with scrap at a high temperature and producing steel ingots. In the past, steelmaking facilities were the open hearth furnace and the electric furnace. Recently, however, the method of basic oxygen steelmaking by an LD converter has been developed.

The method is that of blowing high pressure pure oxygen into the molten bath of pig iron and eliminating existing inpurities, viz., C, Mn, Si and P for example, by oxidation, to convert the pig iron to steel. In order to maintain a steady operation and high productivity, correct control of the reaction process is technically very important. However, since the time required for refining is fairly short, accomplishment of the control is not easy.

1. LD Converter

The chief objective of controlling an LD converter is to control the metallurgical reactions occurring in the bath, and to obtain a final state of molten steel of a desired composition and temperature at the termination of the blowing of oxygen. However, numerous factors which influence the changes in the steel bath and slag conditions are related in a highly complicated manner and the progress of the reaction is so rapid that it is indispensable to rely upon the aid of a computer.

In the early stages, Jones and Laughlin Steel (U.S.A.) developed a mathematical model for the bath temperature control and applied it to actual operations with the aid of an analogue computer to provide a numerical operation guide. Since then, with the development of the digital computer, many steel works have introduced them to accomplish the control of reaction. And the mathematical models have been developed to predict the end point more precisely.

This process of progress in computer control is discussed below in two separate parts: static control and dynamic control.

(1) Static control

Though complicated metallurgical reactions occur in an LD converter, they are regarded as a batch process with relatively high reproducibility. Static control of the converter is a type of predictive control. At the beginning of a heat, the computer determines the amount of materials to charge as well as the volume of oxygen to blow into the converter, by forecasting the results of refining, in order that the state of molten steel finally corresponds to the desired temperature and composition.

The theoretical and statistical models which were studied in an early stage of development, were not satisfactory for practical purposes. However, it was shown by Nippon Kokan[10] (Japan) that the accuracy of prediction was much improved by taking into account in the succeeding heat the relationships existing between the given input conditions and the obtained operational results of the preceding heat. In this mathematical model, each heat was not considered as an independent batch process but as a continuous process, and it was mainly due to this procedure that the influence of the changing inner shape of the lining and the error due to inaccuracy of the measuring means were eliminated. Mathematical equations in this case provided the following eight control items: the end point temperature, carbon content, phosphorus content, manganese content, amount of molten steel produced, ladle carbon, ladle manganese and ladle phosphorus.

Fig. 4 shows the process of refining operations accompanied by functions of the computer.

Besides the above functions, the computer also controls operating sequences from charging to refining, provides operation guides, and carries out abnormal condition monitoring and data logging.

Fig. 5 shows a view of the control room of an LD converter including a display of the computer output.

(2) Dynamic control

Static control has been effectively employed in many plants, yet its limitations have become apparent. To realize far more precise control, it is necessary to develop a modification by tracing the process of refining (though this is not easy to achieve because it should be done under the conditions of high temperature and oxygen blowing). The reaction process is presumed and the results of refining predicted in order to correct control actions.[11, 12] Such systems are being studied in many firms to attain a practically useful state.

The development of a quick means of measuring bath composition (particularly of carbon content) and temperature at a given time during oxygen blowing is an essential key to achieving dynamic control.

As to the measurement of the temperature of molten steel, continuous recording using a radiation pyrometer or a two-color pyrometer has been studied. At present, however, a thermocouple is superior to either of the above as far as precision is concerned, since this can be evaluated more practicably. A sinker thermocouple of Pt-PtRh, connected with a long cable, with a heavy weight made of cast iron at the formost edge, and thrown into the bath is useful for this purpose. In the case where the converter provides an auxiliary lance in addition to a lance of oxygen, an immersion thermocouple is sometimes attached to the foremost edge of the auxiliary lance. Since the temperature of molten steel is extremely high, it is impossible to utilize such a thermocouple for a long time. But recent improvements[13] in protecting tubes made of special refractory material, which is mounted in the auxiliary lance, have made it possible to measure the temperature continuously during several heats. Furthermore, a study is being made on installing special thermocouples in the wall of the furnace.

Concerning the measurement of the carbon content of molten steel, it is useful to base estimates on the composition of waste gas, and not directly on the molten steel at a high temperature. The method which has been developed consists of estimating the percentage from the amount of decarburization in the steel bath, which, in turn, is calculated from the waste gas flow rate and its CO and CO_2 contents accurately measured. Based upon this method, a dynamic control system has been studied practically.

In order to improve the precision of this means of measurement, much research on particular instruments and sensors still continues. Spectrometer analysis or special high speed composition analysis of a molten steel sample taken either by a method using the auxiliary lance or by throwing a sampler, have been studied. At present, a method is being considered to find the carbon content from the freezing point of steel, estimated from a cooling curve which is recorded on a chart by the use of a thermocouple mounted in a sampler. The proportional relation between the carbon content and the freezing point is being utilized.

Moreover, a sensor which is able to measure simultaneously the carbon content and the temperature are also being investigated.[14] These studies should provide practically powerful tools in the future.

By making use of such sensors, various dynamic control systems have been proposed and experimented with. The following example which was reported by Jones and Laughlin Steel (U.S.A.)[15] most closely approaches a degree of practicability at this stage of research.

(a) The specific decarburization rate which is defined as the rate of carbon removal divided by the oxygen blowing rate, namely,

$$\varphi = -\frac{dC}{dO} = -\frac{dC}{dt}\Big/\frac{dO}{dt}$$

is calculated with a computer at approximately the middle of the oxygen blowing period, as a function of the carbon content in percentage C, expressed by an exponential function,

$$\varphi = \alpha + \beta e^{\gamma C}.$$

During the succeeding period, φ is repeatedly computed from the measurements until 3 minutes prior to the end point, to obtain values of parameter α, β and γ fitting best for the data. See Fig. 6.

(b) Let an instant during the final blowing period make correspondence with a point on the determined φ - C curve. Calculate the amount of oxygen required to obtain the desired final carbon content of steel in the bath, and denote it as O_c.

(c) Measure the bath temperature by a thermocouple simultaneously thrown into the bath and calculate the amount of oxygen O_t, required to obtain a state of the desired state of bath temperature at the end point according to a model of temperature rise.

(d) On the basis of the observed values of O_c and O_t, control both the carbon content and the temperature so as to obtain their desired values at the end point by adjusting the amount of cooling materials thrown or the lance height.

2. Open Hearth and Electric Furnaces

In the open hearth furnace method, automatic combustion control and the automatic reversal system using analogue controlling means have also been in use for approximately twenty years. However, the advent of an LD converter has decreased the demand for the open hearth furnaces. This tendency seems to result in neglecting capital investment to replace facilities, and less attention has been paid to the control.

The electric furnace presents several advantages over the open hearth furnace and the LD converter. One of the most important variables in control of the electric furnace is the electric power consumption in the furnace. Furthermore, in firms with several electric furnaces, distribution of electric power to each of the furnaces is an important item of control. Computers have recently been installed to monitor the power distribution and the blending of materials and to provide an operation guide for the operator in these firms.[16]

III. Rolling Process

Steel ingots produced in the steelmaking process are uniformly heated in a soaking pit and rolled into slab, bloom, and billet. They are reheated in the reheating furnaces and then rolled into plate, strip, bar, wire and pipe form through the corresponding mills. Subsequently, by cold-rolling, galvanizing, tinning, shearing for example, they become finished products.

Automatic control systems on the rolling process include some familiar controls such as Automatic Combustion Control (A.C.C.) of the reheating furnace, Card Program Control (C.P.C.) of the reversing mill, and Automatic Gage Control (A.G.C.) of strip and plate rolling mills. Though it cannot be assumed that these systems are technically faultless, they are commonly installed in modern facilities, requiring continuous improvement however.

The control of present-day rolling mills is conventionally carried out by computers, particularly in hot strip mills, cold strip mills, slabbing mills and plate mills. The use of computers for these processes has been extensively investigated and reported in the many papers presented at IFAC congresses and symposia, so that, at present, most emphasis is placed on the practical problems involved with that use.

The functions of control computers applied to these processes are described below:

1. Pass Scheduling

Steel ingots are shaped into their final size by repeatedly passing them through rolls. A computer identifies the process at the termination of each pass and computes the amount of screw down required for the next pass. The requirements for pass scheduling are to prevent the overloading of rolling equipments, to keep the deviation of the rolling-force within an allowable limit from its predicted value, and to complete the computation in a time as short as possible.

There are several types of pass scheduling, some aiming at exactness in size and others aiming at optimization to make the time required for rolling as short as possible.

Two examples of such pass schedulings, are described in the following:

In the case of a plate mill in Nippon Kokan (Japan)[17], a mathematical model was constructed for computing the following items;

(a) Determination of the optimum finished thickness by taking account of the nominal thickness of the plate, the allowance of the thickness by specification, the variation in thickness within and between plates, the width and length of plate, the plate crown, etc.

(b) Determination of the roll gaps for the successive passes to obtain the optimum finished thickness by taking into consideration the property and temperature of material, abrasion and temperature rise of the rolls, etc.

Immediately after the first pass, calculation is made, on the basis of the obtained result, for final adjustment of roll gaps for the last several passes.

In the case of a roughing mill of the hot strip plant of A.T.H. Duisburg Beckerwerke (Germany),[18] an optimum pass schedule according to the thickness of the slab is calculated, so as to give maximum deformation to the slab in a time as short as possible, and to prevent a temperature drop which should be otherwise compensated by excess heating in the reheating furnace.

As a parallel to pass scheduling, the optimization of timing for decreasing roll speed and preventing the over-running of material is important to increase productivity. Studies have been conducted in this field in a blooming mill in A.M.S. (Belgium) by C.N.R.M.[19]

Models for these systems are formulated by theoretical as well as statistical considerations, as in the cases of the blast furnace and LD converter. They have a self-adaptive nature to fit on-line controls, besides being in a form for efficient calculation.

2. Mill Set-up

At every alteration of the type and size of steel to be rolled, in the rolling facilities, viz., rolls, shears and coilers etc., the roll gaps, speeds and set points of all the controllers should be changed. These changes are executed rapidly and correctly by a mill set-up made with the aid a, control computer.

In this case, the computer not only sets up the mill to a given value predetermined by calculation, but it also examines the results obtained constantly during the progress of the rolling process, making repeated calculations and adjusting the values and controls accordingly. The model in this case is self-correcting or in other words, is updated according to the rolling results. The setting operations of the mill on the basis of pass scheduling may be considered to be a part of the mill set-up.

Today the computer control of the hot strip mill has become a matter of common practice. Its mill set-up calculation is one of the most important problems and many studies are being carried on to improve it for practical purposes.

As examples of the analysis of mill set-up of the finishing train of hot strip mill, studies are cited on optimal load distribution and on roll force prediction in the 7-stand hot strip finishing mill in DOFASCO (Canada)[20] as well as in the 6-stand hot finishing mill in Japan[21]. The mill set-up in cold strip mill has also been studied in various firms.[23,24]

Screw down control operations of rolling mill have been done electrically, but hydraulic means are being substituted for that means to improve the control performance.

3. Slab Tracking

The function of slab tracking consists of tracing slabs which move along the line, and storing each movement in the memory of a computer to maintain the correspondence between the computer record and the real process. The position and the movement of a slab are picked up by Hot Metal Detecters (H.M.D.) with photo-cell, load cell, or ultrasonic detectors being arranged at many points along the rolling process line, and each movement of the slabs thus detected is transmitted to a computer which in turn, issues various directing signals.

4. Mill Pacing

The productivity in the rolling process is limited by that of the lowest efficient process in the line from reheating furnace to coiler. Mill pacing aims at determining the optimum rolling pitch, and is usually carried out by controlling the discharge timing of slabs from the reheating furnace so that the distance from the tail end of a slab being rolled in finishing mill to the nose of the next slab coming from the reheating furnace is minimal.

5. Temperature Control

The temperature of steel strip at the exit of the last roll stand and that in front of the coiler in the hot finishing mill markedly infuluence the quality of rolled products.

The former temperature is determined by the roll speed of the mill set-up and is set so that the temperature of the tail is kept within a prescribed temperature allowance. It is so difficult to maintain a uniform temperature of a long coil from the nose to the tail that the rear part of the slab is heated to a higher temperature in the furnace and the roll speed is increased during the latter part to make the temperature compensated by heat generated during rolling.

The latter temperature is controlled by spray cooling between the finishing mill and the coiler. It is very difficult for a conventional analogue controller to control it precisely, because a transportation lag predominates and because the controlled system is of a distributed-parameter type. A precise feedforward control with the aid of a hybrid computer has been carried out in Wakayama Works, the Sumitomo Metal Ind. (Japan), by introducing a dynamic model which simulates the system to control in real time. The basic equation for the model is given by

$$\frac{dT}{dt} = -\frac{1}{h}\left\{\frac{dK}{dL}T + \frac{K'}{3}(T + 273)^4\right\}$$

where by T denotes the temperature at a point of the strip, K, spray cooling power, K', coefficient for radiation cooling, and L, distance to the point from a pyrometer installed at the discharge point of the finishing mill.

Fig. 7 shows a schematic diagram of computer control system of a hot strip mill.

6. Other Computer Applications

Computers are now being introduced to other applications in the rolling process, such as :

(1) Optimization of cutting schedules,[25,26]
(2) Automatic threading in a cold tandem mill,[27]
(3) D.D.C. applied to soaking pits[28] and to annealing furnaces,[29]
(4) Automatic inspecting and classification of products.

Automatic control of rolling plate and sheet seems to have been highly developed, whereas further improvements are deemed necessary in other processes, such as in those of bar, wire, and pipe.

IV. Production Control

With the size and scale of production facilities becoming greater and the production rate higher, the amount of information generated inside and coming from the outside of a plant is increasing so rapidly that it almost exceeds the human capacity for processing it.

In order to overcome this difficulty, efforts have been made to devise an information processing system including computers for a plant or a firm, by introduction of the information processing techniques which have been developed recently.

It is not easy to complete such an information system, because it requires a large data processing machine and also complicated design considerations.

Since it is not easy to build an entire system at a single time, it seems more efficient to divide the whole system into parts; first developing the local systems, and then organizing them into a type of hierarchy system as a whole.

Actually, in rolling plant, a rush of orders which come from the customers should be dealt with by arranging them in appropriate order to put into production. Preparation of the best production schedule for the arrangement requires so much labor that the computerization has been regarded as one of the most profitable subjects among others.

Spencer Works[30] and Park Gate[31](U.K.) installed such computers in an early stage.

A production control computer receives fundamental production schedules from an off-line computer for the production planning of an entire plant. Rolling schedules are recorded in detail in the computer every hour of every day and transmitted to the operators in the rolling process line through visible displays. By the computer, the progresses of the rolling operations are monitored and the operational information is fedback to succeeding rolling schedules.

In the blooming or slabbing mill, the use of a computer in soaking pits has prompted increased interest. The computer in this case minimizes the waiting time of ingots to charge to or to discharge from the soaking pits, on the basis of estimation of the heating up time of ingots in the pits.

There are examples of installation of such computers at ELWRO Works (Poland)[32] and Chiba Works of Kawasaki Steel Corp. (Japan)[33].

At the hot strip mill of Hoesch A.G. (Germany),[34] control of production has been carried out by the use of two computers covering all the lines from slabbing mill to hot finishing mill.

At Thyssen Röhrenwerke (Germany), two computers have also been controlling the tube mill.

Such a production control system not only makes a single process the object of control, but possibly grows to be an integrated production control system of an entire plant or of an entire firm.

Computerized production control system at Kimitsu Works of Yawata Iron Steel Co. (Japan) is one of the working examples of this trend. Framework of the system is illustrated in Fig. 8. The production planning computer makes an overall production planning for each order. Then the scheduling computer makes a detailed schedule and sequence of a given mill with the reference to the report of the preceding operation through the production control on-line computer, which sends the production order to the operators and receives the operational results. The heavy plate mill portion has been used satisfactorily since summer of 1968, and the rest from the end of the year, when the blast furnace and the subsequent facilities started operation. Fig. 9 shows a view of that computer room.

There are not many completed examples of such an integrated production control system. Many studies are being made,[35, 36] however, in expectation of establishing a larger well-organized system.

V. Conclusion

The development of control systems in iron and steel plants has been surveyed. This industry has a positive attitude toward the use of automatic control systems, and is not less enthusiastic than others.

The first stage in the development was the utilization of conventional analogue controllers for single loop feedback control. More complex analogue control systems, A.C.C. and A.G.C. for example, followed. The last and most recent stage is the utilization of computers for higher level control.

In the present stage, computers are being extensively and effectively used for accomplishment of various functions in controlling production processes. There seems, however, to be much room for improvement on the systems, such as obtained by their optimization and integration to make productivity higher. There is much to be relied upon control theory. The computer techniques also offer problems. For instance, they are presently not enough flexible at the modification or alteration of systems, and no proper countermeasure can be found for the troubles due to the input mistakes by the operators yet. The input and output devices are short of high reliability. All of those problems have to be solved.

Studies on computer control of processes have affected an increase of demands for specific measuring means suitable for specific purposes. The demands for those methods of checking qualities and classifying patterns are also presented. For such purposes, researches for means on new principles are being done by making use of radioisotopes, ultrasonic waves, microwaves, lasers and so on.

At the beginning of this paper, we mentioned that basic iron and steel production processes have not been altered greatly. However, it is necessary to point out here that much effort is being done to make the processes continuous. Direct reduction steelmaking processes have been studied. Continuous casting is already in a stage of practical use, and continuous rolling is in a stage of trial. With these basic process modifications accompanied by computerization of their controls, it seems that the industry is gradually making her way toward the end of achieving a full automated production plant.

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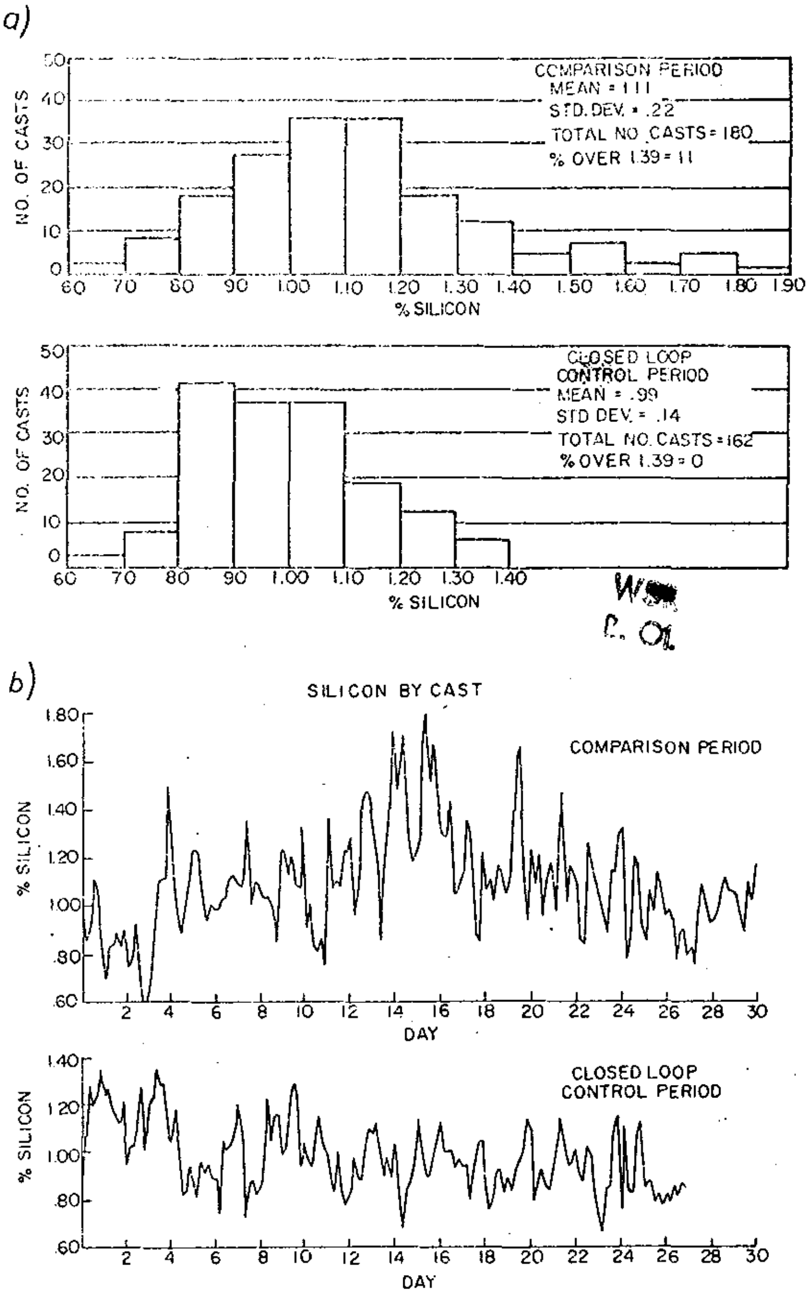

Fig. 1 Reduction in fluctuation of Si content in produced pig iron due to control of furnace conditions. (Inland Steel Co.)

(a) Si frequency plots, (b) Si by cast.

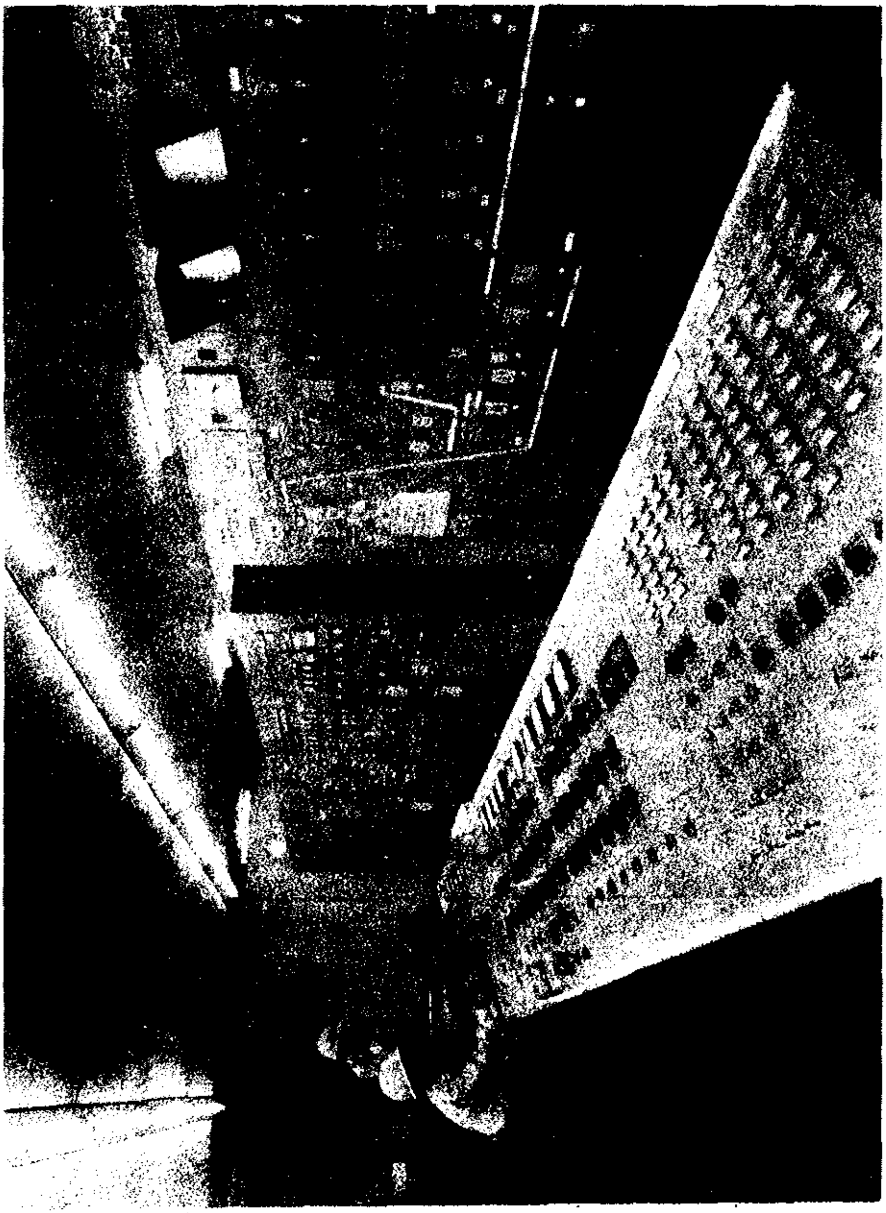

Fig. 2 View of control room of blast furnace at Nippon Kokan, Fukuyama Works.

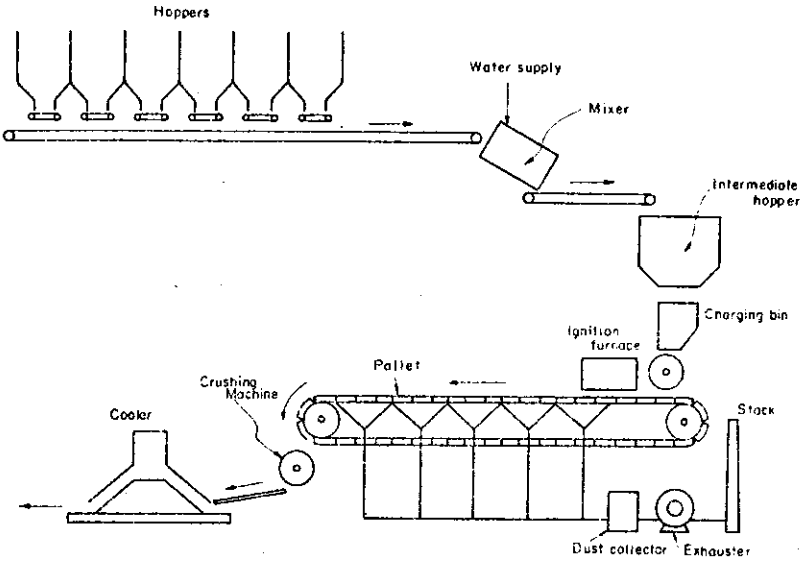

Fig. 3 Schematic diagram of a continuous sintering.

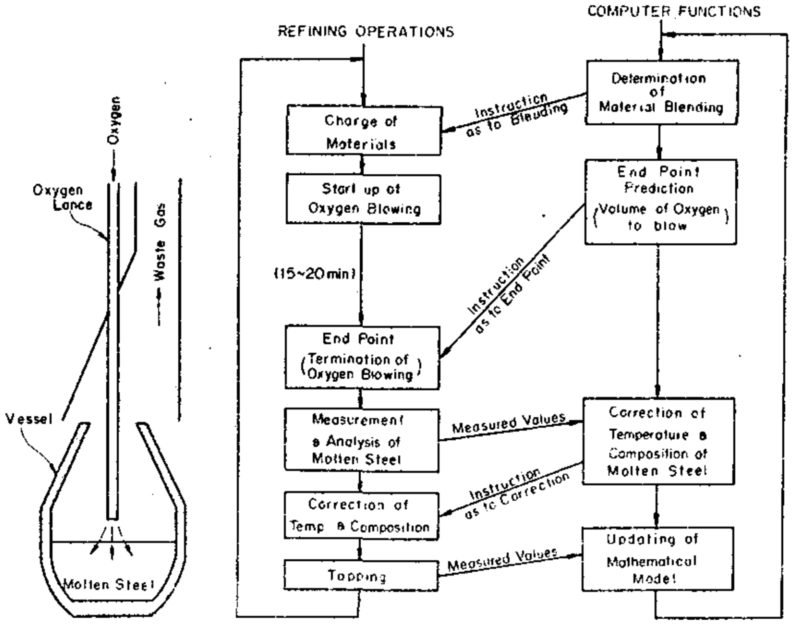

Fig. 4 Refining operation of LD converter accompanied by functions of computer.

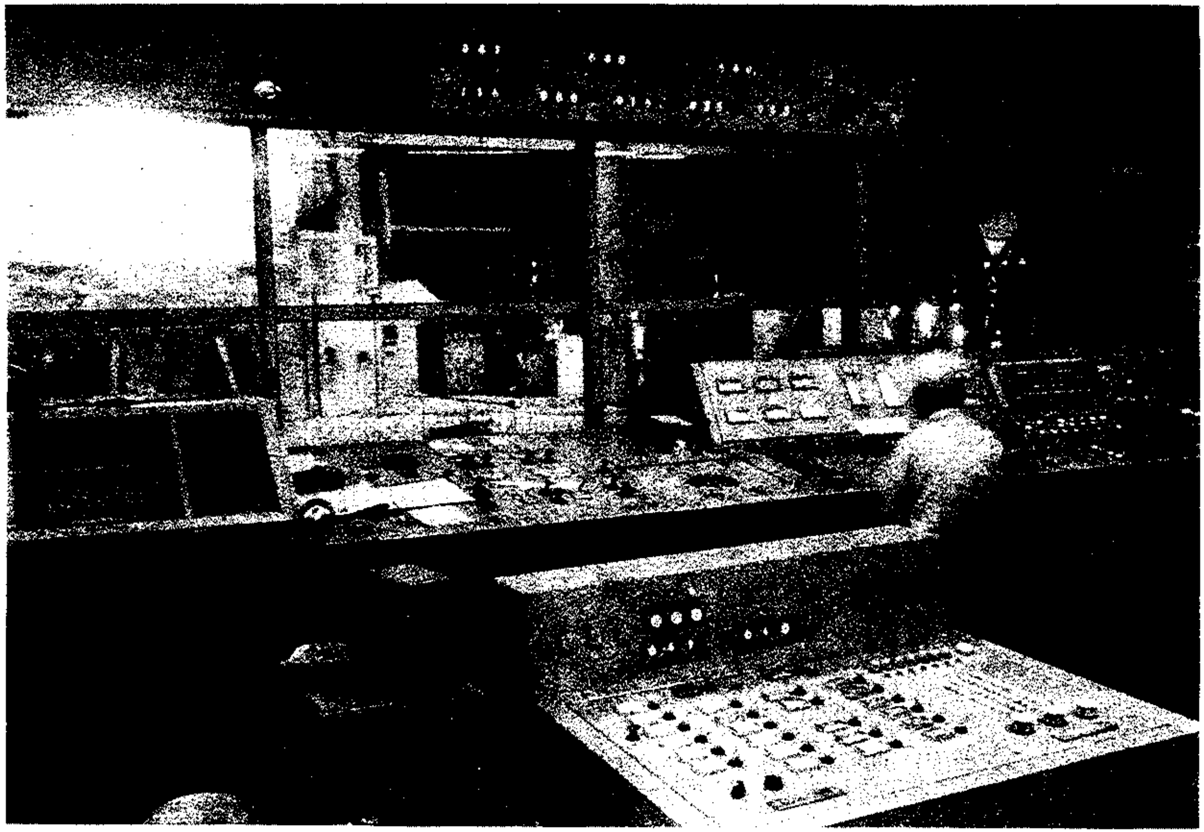

Fig. 5   View of control room of LD converters at Yawata Iron and Steel Co.

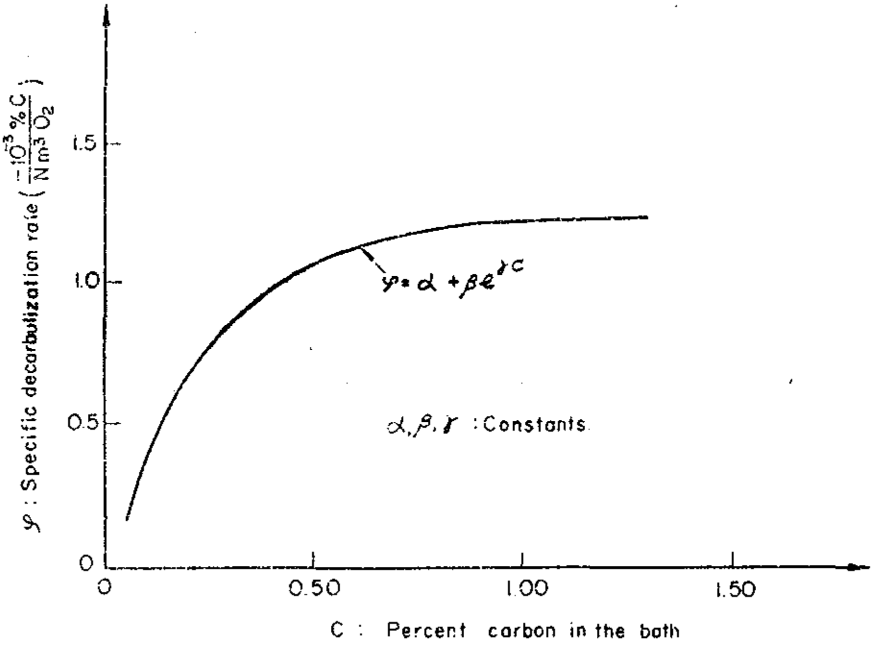

Fig. 6 Specific decarburization rate vs. percent carbon curve for dynamic control (Jones and Laughlin Steel Corp.)

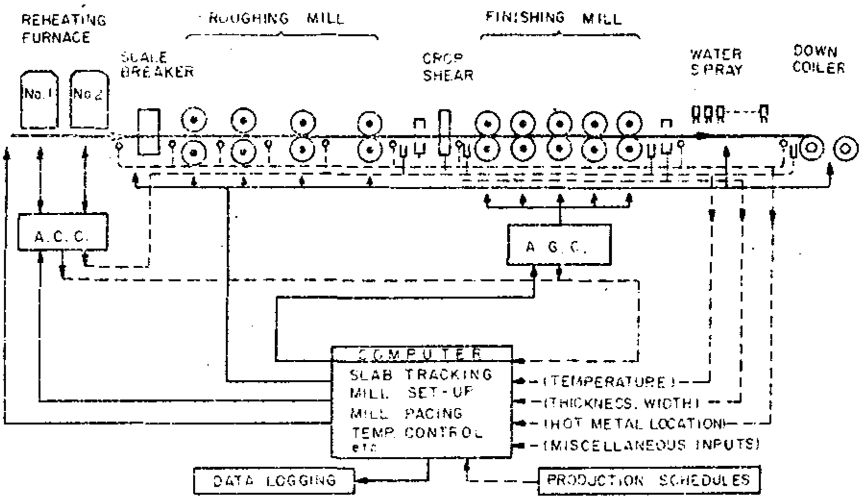

Fig. 7 Computer system arrangement of hot strip mill.

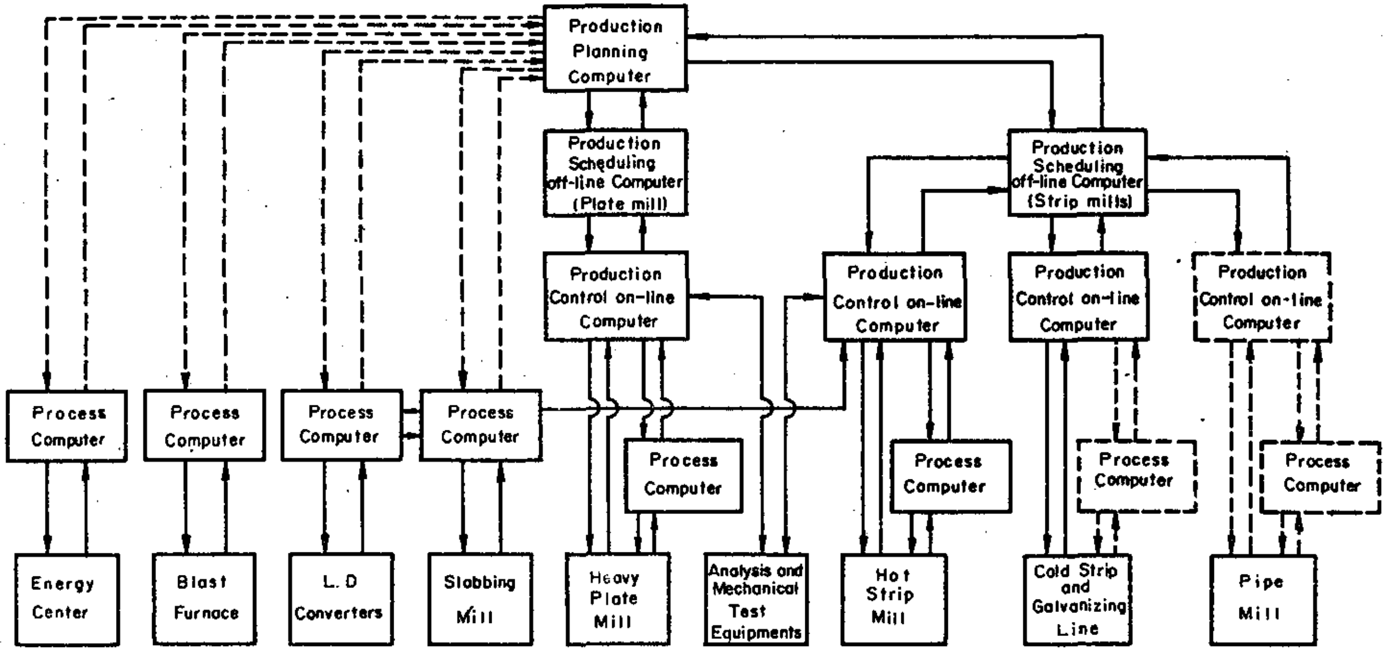

Fig. 8 Schematic diagram of an integrated production control system at Yawata Iron and Steel Co., Kimitsu Works.

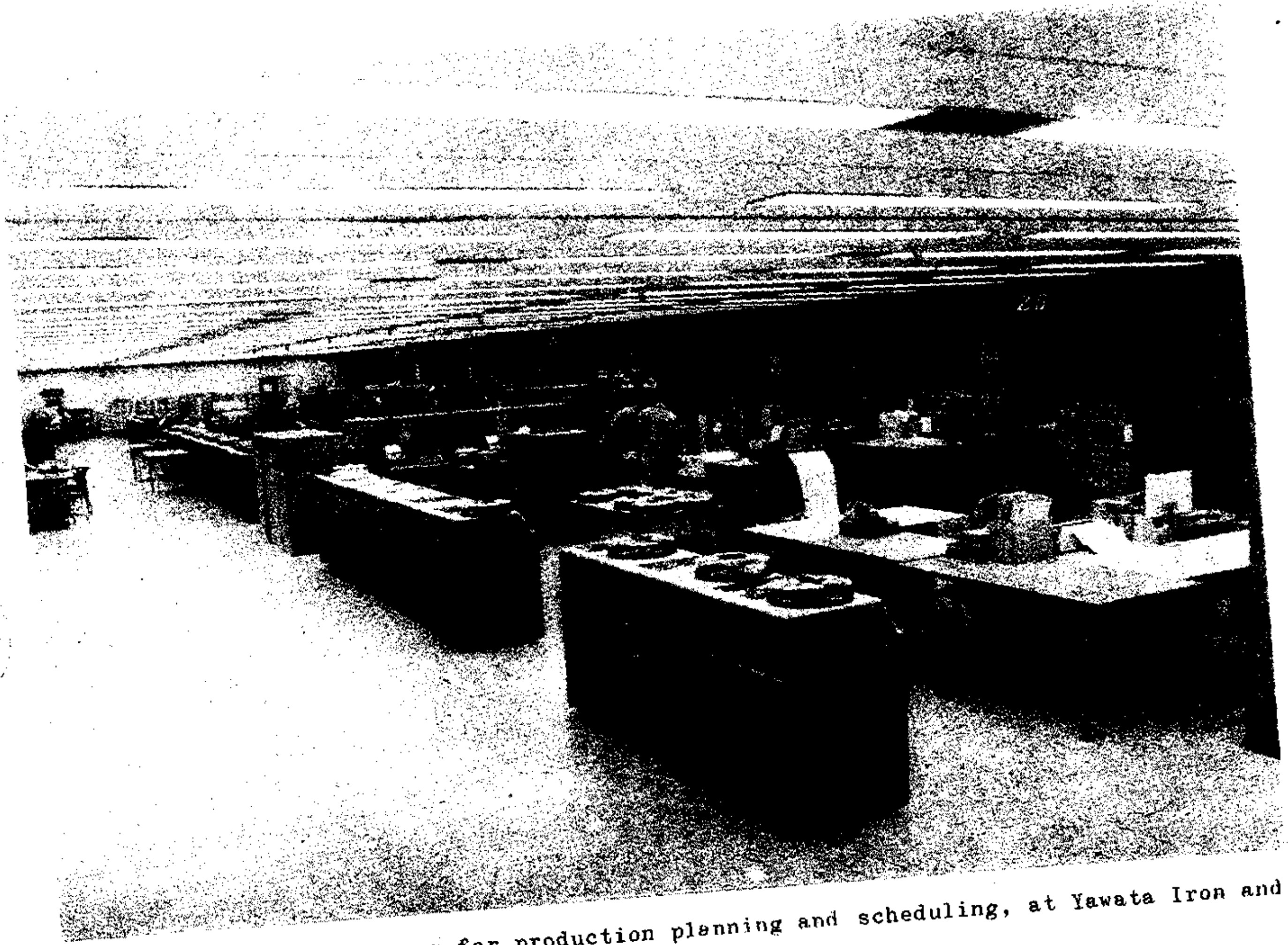

Fig. 9 View of computer room for production planning and scheduling, at Yawata Iron and Steel Co., Kimitsu Works.

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