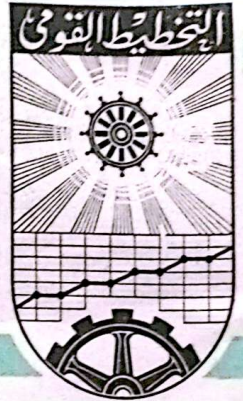


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PROCESS CONTROL SERIES

PROCESS CONTROL IN
THE IRON & STEEL INDUSTRY

by

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INTRODUCTION:

The field of digital computers application is very large, but this is exactly the reason why we want to learn to answer where, when and under what conditions they would be introduced so that each recommendation is based on sufficiently strict quantitative indices. A priority of theory progress over industrial application of computers is a necessity. But the introduction should in no way be hindered. The only solution is to maximally develop the whole range of theoretical research. A reasonable proportion of "tactical" and "strategical" research should be ensured.

Recently more interest has been displayed in strategic investigations. But the pressure of time makes us somewhat impatient. That is why it is believed that it is important to separate and speed up research of tactical problems which are possible and must be solved with methods already available to engineers. These are, with constraints already stated, the problems of separate units control, of primary data retrieval and processing which is to characterise on-line the operation of production stages, shops and factories. Especially urgent seems the problem of reliability. I mention these problems to emphasize their importance as well as the fact that it is on their solution that the technological basis necessary for optimal, adaptive and self organizing system depends. As far as synthesis of optimal control structures goes it should be noted that the high cost of digital computer systems lays the emphasis on development of regular methods for such a synthesis.

On the other hand, use of computers should proceed very fast so as to allow for practical experience and to feed research people with extensive material and creates discipline for various studies.

One of the most important fields of computer usage is control. This involves various divisions branching from on-line & off-line techniques. This article presents some computer control techniques used in

the Iron and Steel Industry. Process Control and Automatic Control techniques are explained in a more detailed approach.

There is no doubt that the trend toward more and higher forms of automatic control is increasing in the iron and steel industry. The reasons for this trend are many. Process and product specifications are continually being tightened because of customer demands and the need for more economies in production. Along with these demands for tighter controls has come the search for new knowledge of the basic chemical and metallurgical aspects of the iron and steel making processes. These facts not only direct the industry toward more intensive control means; they, in themselves, make more control means possible. In addition, iron and steel making technology is tending toward a higher speed, more closely coupled operations. Continuous casting is an example of such operations. Here, instead of making ingots of the steel from the steelmaking furnace, the steel is poured directly into an openended mold, and the slab itself is cast. The ingot, ingot stripping and rough rolling operations are eliminated. Needless to say, close regulation is required of this process to make it a feasible high tonnage operation.

Computers as control means, or as overall directing means, are being installed in very nearly all the finishing departments, of steel industry, under construction in U.S.A. at the present time. Computers are becoming fairly common in the installation of new basic oxygen steelmaking processes. This does not necessarily mean that higher levels of control are being achieved, but it does point out the efforts being made to obtain them. Perhaps a stimulus is the decreasing cost of computer equipment. These present systems are mainly directed at actual process control; physical control over the particular product being formed or manufactured in the process.

The most difficult disciplines of control is that it needs the knowledge of many other disciplines as well. To design a control system; the control systems engineer, the process engineer, the electronics engineer

and the mechanical engineer must work together to establish control technology, process technology, electronics and electrical and mechanical equipment requirements. Only when all these experiences get together and accomplish required functions in a practical sense can control systems be made workable and usable.

With the advent of the modern industrial computer, equipment became available which make the extension of automatic process control feasible. Recognition of this is evidenced by the fact that many process control computers have already been applied in the steel industry, and others are being planned. These applications include installations in sintering plants, blast furnaces, basic oxygen steelmaking plants, rolling mills, continuous annealing lines and electrolytic tinning lines.

PROCESS OF STEEL PRODUCTION:

Steeling in principle, appears to involve only a relatively few, simple steps. The principal iron ores used, consist of iron oxide mixed with varying percentages of useless earthly materials. To remove the oxygen and useless materials, the iron ore is mixed with coke and limestone and charged into a blast furnace. Hot air blown into the blast furnace burns the coke to generate heat. The hot carbon of the coke and the carbon-bearing gases generated by its burning combine with the oxygen of the iron oxide, leaving the iron in metallic form. The iron collects in a molten state in the hearth at the bottom of the blast furnace. The limestone combines with the useless part of the ore to form molten slag that floats on top of the pool of molten iron.

In the ironmaking process, the iron becomes saturated with some of the carbon from the coke. The product of the blast furnace, pig iron, may contain somewhat over 4% carbon. To make steel from pig iron, some of the carbon must be removed. (Most steels contain considerably less than 1% carbon). The unwanted carbon is removed during steelmaking, now principally accomplished in the open-hearth furnace and the basic oxygen is blown directly into the molten iron bath to burn out the excess carbon. The final product, steel, is poured into molds to form ingots, which are then formed into useful shapes by rolling or other forming processes.

A modern, integrated steel plant is made up of a group of massive, complex, interrelated, individual processes. The chemical, metallurgical, and thermal aspects of the steelmaking processes seem to be fairly obvious and simple. In practice, this is not quite so. Measurements are difficult to make and process theory is complex; consequently, precise knowledge of the state of the process is not always available. Much of the present-day process control actually consists of control of the processing machinery.

Raw materials, many times, are put through complex beneficiation or preparation processes before they are useful for iron or steelmaking. Many low-grade ores are now being mined which must be concentrated and

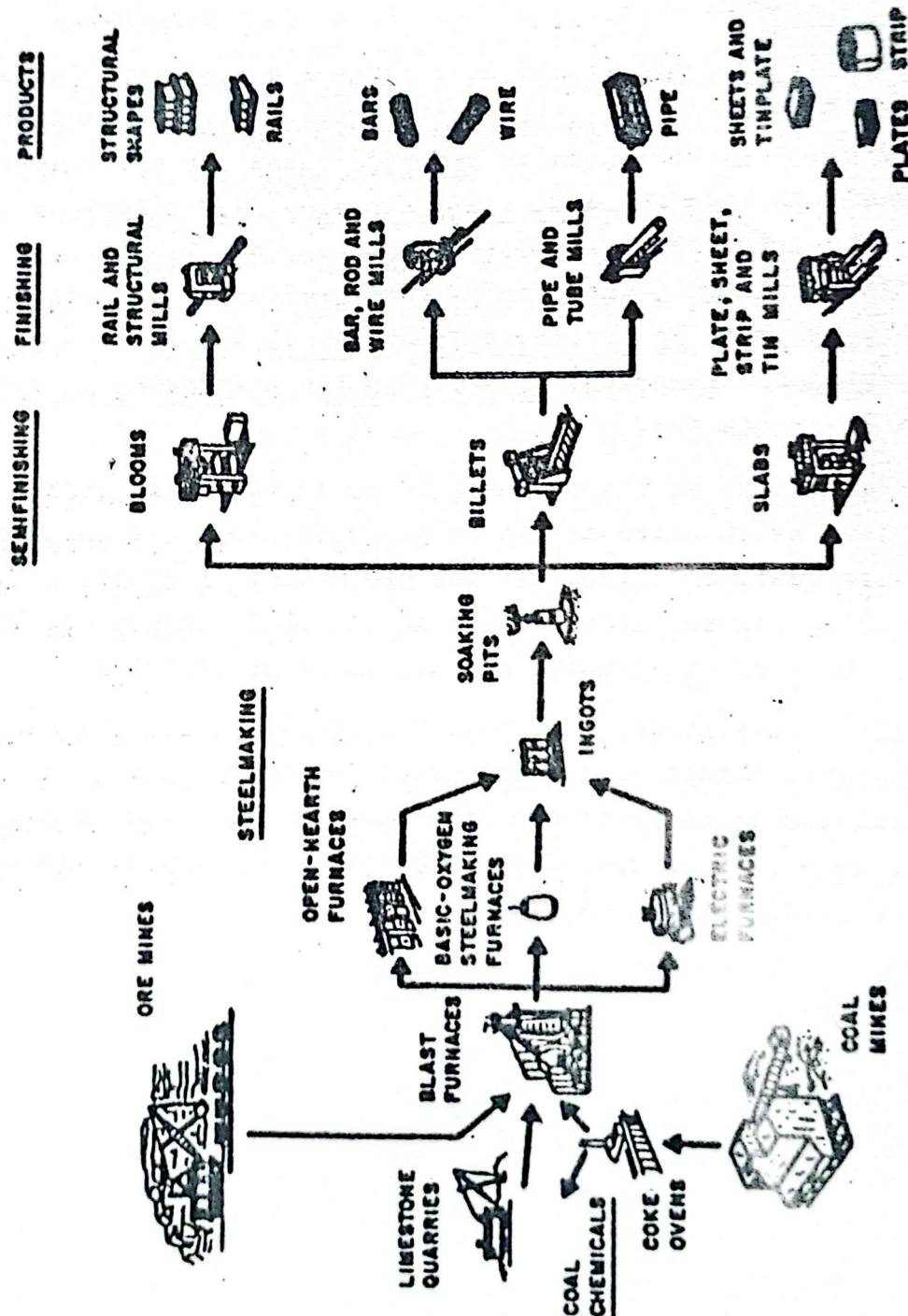


FIG I : PROCESS OF STEEL PRODUCTION

then further prepared before they are available for blast-furnace burden. The preparation of coal as the metallurgical coke required for the blast furnace has, in present-day steelmaking, become a veritable chemical complex. By product coal-chemical processes have led to large processing plants for anhydrous ammonia, phenols, and other chemicals.

The blast furnace itself is a large and expensive industrial complex. Modern furnaces are well over a hundred feet in height, and the regenerators, or stoves, used to heat the blast air are equally large. Three stoves are used for each blast furnace. Raw materials are charged into the top of the blast furnace in batches, and liquid iron is periodically discharged from the hearth. The production of iron ores inside the furnace takes place continuously, however, and it is a major task to start and stop the furnaces. Modern-day blast furnaces produce well over 2500 tons of iron a day.

Steelmaking, in the open-hearth or in the basic oxygen steelmaking furnace, is a batch process. These processes turn out hundreds of tons of steel per heat, or batch. In the open-hearth furnace, a heat of steel may be made in six to eight hours. In the basic oxygen steelmaking furnace, a heat of steel would be made in under one hour.

After steelmaking, the molten steel is poured into ingots, many tons in weight. These ingots are permitted to solidify; the mold is then removed and the ingot is placed in a soaking pit. The soaking pit brings the ingot to a uniform specified temperature in preparation for the rough-rolling or semifinishing operations.

Direct digital control

There presently appears to be a general trend toward the use of digital techniques in process control. The most common form of these trends is called direct digital control. Here general-purpose types of digital control computers are being used to replace individual analog controllers now in common use on process equipment. Considerable success has apparently been obtained in various industries with this approach. Success is judged on the basis of performance and overall economics. Although the iron and steel industry has had very little experience to date with direct digital control, we expect to see more efforts made. In the beginning, these efforts will be experimental to establish reliability factors, economics and in some cases, quality of control.

JUSTIFICATION OF COMPUTER CONTROL IN STRIP MILLS :

The requirements of a hot strip mill are that it shall roll as big a coil in terms of pounds per inch of width as is possible, with as close a tolerance in thickness from end to end of the coil as can be achieved while maintaining good shape, freedom from scale, and completely consistent width. Finishing temperature and coiling temperature are also invariably specified in the standard practice laid down for any hot strip mill product.

Today customers for hot rolled products expect uniform coil or sheet dimensions that are better than BSS1449. The inability of a hot strip mill to perform in accordance with those requirements certainly results in proportionally greater loss for width and gauge variations which are impossible to avoid on a manually controlled mill. Furthermore, there is a comparable loss in quantity since manual attention to quality requires a sacrifice in production rate. The total value of the anticipated improvements in production efficiency and product quality can be easily converted into currency expressions once anticipated performance values were compared to non-automated operation standards, this has proved to be very satisfactory in most of the cases.

However, there is one particular aspect of the on-line computer that cannot be equalled by manual operation, and that is the achievement of more accurate changes from gauge to gauge without rolling out of gauge coils in the meantime.

The full computerisation of the hot mill is expected to achieve more consistent operation in pushing the slab furnaces, a more consistent width due to better control over the speed between the stands and the looper operation, and an improved yield of on-gauge material due to elimination of off-gauge pieces when changing from one thickness to another.

On the other hand, the cost of automation project is considerable, in addition to the equipment itself, it includes:

- Lost production during installation

- Installation labour and engineering
- Cabling and materials
- New system spares
- Scrap value of replaced existing equipment
- Training, operating and maintenance costs for new systems

The nature of process influences decision for computer control. Any process is suitable economically for computer control if any of the following criteria is present. Several examples, from the hot strip mill processes, justifying this criteria will be mentioned.

1) PROCESS COMPLEXITY:

If the process is complex, having many variables requiring frequent, rapid and accurate adjustment for most economic operation, then computer control is justified.

For example: on the hot strip mill:

- a) The incoming metallurgy, temperature, width and thickness can all be varying as the bar goes through the mill.
- b) There are internal disturbances, or noise, such as:
 - Improper adjustments
 - Thermal variations in the mill and electric sub-systems
- c) There are system element interactions or coupling, such as:
 - A change in strip tension changes rolling pressure and strip thickness, while at the same time width-profile and flatness can also be affected
- d) There are changing biases, such as:
 - Mechanical wear
 - Thermal level changes
 - Electrical drifts
 - Crew operation capabilities

Definitely, the effectiveness of the computer system is well proved in this process.

2) UNSTABLE PROCESSES:

If the process is inherently unstable, subject to rapid drifts requiring continued manual attention, then computer control works as a perfect substitution to manual efforts.

For example: again in case of hot strip mill, unstability arises due to:

- a) As slabs are heated inductively:
 - The coil inductance changes non-linearly
 - Capacitors must be switched to compensate for the change
 - The power supply is tuned to the load
 - The power factor is corrected
- b) Each slab heater consists of a number of coils which are wholly or partly used according to the size of the slab being heated:
 - For large slabs, all coils are used
 - For small slabs, part of the coils is used, depending on the slab size.

After the slab has been heated, desired temperature has to be regulated by switching the heater off and on intermittently (this is achieved using THYRISTOR POWER SWITCHES)

3) QUALITY EFFECTS UPON SUBSEQUENT PROCESSES:

If quality of the product produced has a decisive effect upon following process efficiency, then a computer would rather be used to guarantee best operation. The computer control can (in case of the hot strip mill):

- a) Reduce end-to-end hardness variations
- b) Reduce strip-body-to-strip-body thickness variations
(further facilitating cold mill operation)

4) EFFECTS ON END PRODUCT QUALITY:

If the process, in itself, determines the end product quality, then the variables would rather be controlled using a computer

Again, in case of the hot strip mill, the computer control offers:

- a) Width control (to minimize shearing scrap losses)
- b) Gage control for the plate mill
- c) Crown control

5) THROUGHPUT VALUE

If the product throughput value is high enough to justify the added cost of the computer system, then computer control should be introduced.

Finally, we have to notice that once the computer control is justified, just as the application of on-line computer techniques requires the most detailed study of the jobs which are to be performed, and the correction of the plant before the on-line computer can function reasonably. Again referring to hot strip mills, the application of production-control from hot coil to finished product by the use of electronic data processing requires the most careful study of:

- 1- Slab stocking, scarfing and scheduling methods
- 2- The stocking of hot coils
- 3- Space between different units
- 4- The ability to locate any slab, coil or sheet unfailingly at any moment. Also, methods of controlling intermediate stocks centrally have to be introduced. It is quite clear that if electronic data processing of production is to be adopted on a large scale, the flat product industry must simplify its method of identification, stocking and handling to the point that it is unthinkable that any coil or pack of sheets could be displaced or mixed.

REQUIREMENTS OF AN AUTOMATED SYSTEM:

To achieve the maximum degree of automation within present-day technical knowledge, several basic features are to be established.

A) ACCURATE RECORD-KEEPING SYSTEM:

The exact data, as taken from factory-floor facts, has to be precisely recorded and compared with planned figures. Extensive use of data logging throughput, and the analysis of the data so received, should quickly bring to light errors in different sensing devices (such as weighing machines, temperature recorders and volume recorders), for until these are put right it will be extremely difficult to improve the standard of practice.

Data logging is usually looked upon as a preliminary to the installation of an on-line computer; in many cases, however, the installation of a data logger may be all that is necessary to prove that the practice can be so greatly improved by attention to the sensing devices and providing satisfactory management control figures, that any on-line computer installation will be unnecessary and waste money.

B) INTERNATIONAL STANDARDS:

Every single part of the plant and every single operation should be greatly committed in writing to a standard practice book which is adhered to by all managers concerned, departure from which would be understood to be a serious offense. This is because, only if the standard practice is adhered to, it is possible to compile sufficient records to decide by planned experiment in what degree it can be varied with advantage.

STRUCTURE OF THE PROCESS CONTROL SYSTEM:

The first stage of control to be introduced at agglomeration plants will combine the function of a Foreman's advisor and centralized monitoring and logging; the second stage incorporates in the introduction of a digital computer system to help maintaining the accuracy of different processes and keeping a certain level of product quality.

Today, practically all digital computers applied to steel works processes are structured into the total drive and control system. Several early computer installations were attempted on the basis of experimentation and regression analysis. However, experience proved that controlled experimentation on a large key production facility was a mere fond hope; the steel plant processes were too complex, with non-linear inter-relationships. The chance of discovering these relationships and the necessary systems structure was concluded to be practically nil. The only sure thing turned out to be expense.

Systems design involves creativity, innovation and analysis. Analysis of complex systems is best handled through a multi-level approach. This approach involves:

- 1) Decomposition of the complex system into a set of sub-systems, each of which can be easily handled in terms of satisfying a local or subsystem objective. In such cases partial problems which comprise the general problem of plant control are solved via installing separate zone control computers integrated into a system with a central controlling computer. Local interacting sub-processes, which make up the whole process, are each controlled by a special computer. Pre-processing of primary data is done synchronously. Local control computers and pre-processing devices are linked with the central computer which controls the process by basic criteria. Though this structure may seem questionable in a number of cases of single units control, at the level of shops and factories it receives first

priority. Along with the chief control problem the system will be engaged in recording of raw, prefabricated and auxiliary material stock as well as main characteristic of the plant operation for a specified period.

- 2) Coordination of the solutions of sub-system problems via computer simulation, so that the objectives associated with the overall system are satisfied.

The approach is iterative in that one works from the total system to the many sub-systems and back and forth, until a model is developed that satisfies the real world of required performance, time and value.

Thus a centralized control is an integrated system of local process control and primary information reception and processing devices linked to the central computer which finds the most profitable operating conditions for the plan as a whole while maintaining the quality requirements for the final product.

The choice of a computer and the structure of the system are mainly dependent on the control algorithms to be put into operation. Development of general control algorithms is a most complex and essential problem in the field of digital computers use for processes control. The notion of a general control algorithm is wider than that of an algorithm of a mathematical problem in process optimization because it includes, besides the latter algorithm, the following:

- a) Algorithms of information read-in
- b) Algorithms of information pre-processing
- c) Algorithms of control
- d) Algorithms of read-out action

As to the CONTROL ALGORITHM design: there is an important difference between control of separate installations and that of integrated plants

Control of separate installations:

- Much knowledge has been accumulated on topics such as :
 - . Mathematical process description
 - . Control technique

Control of integrated plants:

Beside the separate features, the difficulty arises on constructing a new control algorithm for matching all parts together.

Digital computers help to develop and use those methods more profoundly, but call for special data read-in and read-out algorithms. The complexity and labor consumption for this work should not be underestimated.

Finally, a comprehensive system design program will produce data and knowledge permitting development of sound and realistic planning for the system installation and start-up. Task times and costs become definable and finite and can be scheduled with critical path network techniques.

As an example of the control of separate installations, in open hearth furnaces the first stage of automation is to provide for centralized monitoring, data retrieval and pre-processing on the process, and later the computer will assume the functions of the integrated control.

In steel production the computers are used for dispatch control blast furnaces as well as for control of process itself. Interesting experiments have been conducted on remote control of Bessemer converters. A system for integrated control of a converter shop can be developed.

In metal rolling besides cutting control, a comprehensive control of rolling shop includes as subsystems, all-purpose computers which provide a dispatch control of metal feeding to steel melting shops, departments in soaking pits of blooming-mill control rolling on blooming mills and control on-line the ingot store. These local systems are coordinated by a central control system which maintains optimal production variables of the process as a whole as well as comprehensive record of the process characteristics. Computer systems of rolling conditions control (screw-down, rate of feeding and rolling) of heating sections, of the rolling shops, are perfectly working in various installations.

SOFTWARE NECESSARY FOR COMPUTER CONTROL OF IRON & STEEL INDUSTRY:

A special article in this series, which will follow, is devoted specially for the analysis of software necessary for process control situations. Here we will briefly refer to the situation in the iron & steel industry.

The system engineer must create a system design or plan to suit the project or problem requirements. He is also involved in determining the capabilities of proposed sub-systems and may work with other engineers to create new sub-systems required for the total system design.

Beside doing the necessary on-line control job, the computer should be prepared to do some off-line control jobs. During process free-time, special time-shared executive system takes over and allows for using the computer for off-line tasks under the control of the off-line monitor.

Extensive representation of various control algorithms, analysis routines & control of functions is worthwhile a separate series of articles, and hence it is beyond the scope of this article. Instead, I will mention names of algorithms and routines in the appropriate situation. The software necessary for the Hot-Strip Mill will also be presented in a slight more detail.

CONTROL OF BLAST FURNACES:

Flat product plants employ blast furnaces. An automated blast furnace plant would use pellets and sinter, the sinter being produced from flue dust, broken pellets, and fine ore available in unpelletised form. Unquestionably, the whole burden, including fuel and flux, would be prepared in such a way as to ensure that the charge for the blast furnaces was of the utmost consistency. Within the rest of the plant, most of the progress in automation would be in the form of on-line computer for governing the operation of the furnace. The stoves, blower, blast temperature and moisture addition, the input of fuel oil and oxygen, would all be controlled by one on-line computer connected to iron analysis to give the constant silicon and sulphur desired.

The effect of full utilisation of all modern techniques on a blast furnace plant would not materially reduce the work around one furnace, but since the output of the one furnace would be so great, the man-hours per ton will very much decrease, as will the capital employed. The high cost of some blast furnaces is because of their poor location remote from harbours or from ore preparation plants. Very high coke consumptions are due, very often, to poor burden preparation, high ash and low blast heats. In the blast furnace plant we are considering, the coke consumption should be of a very low order indeed, reducing the capital cost of the coke ovens to perhaps half of ironworks of the past.

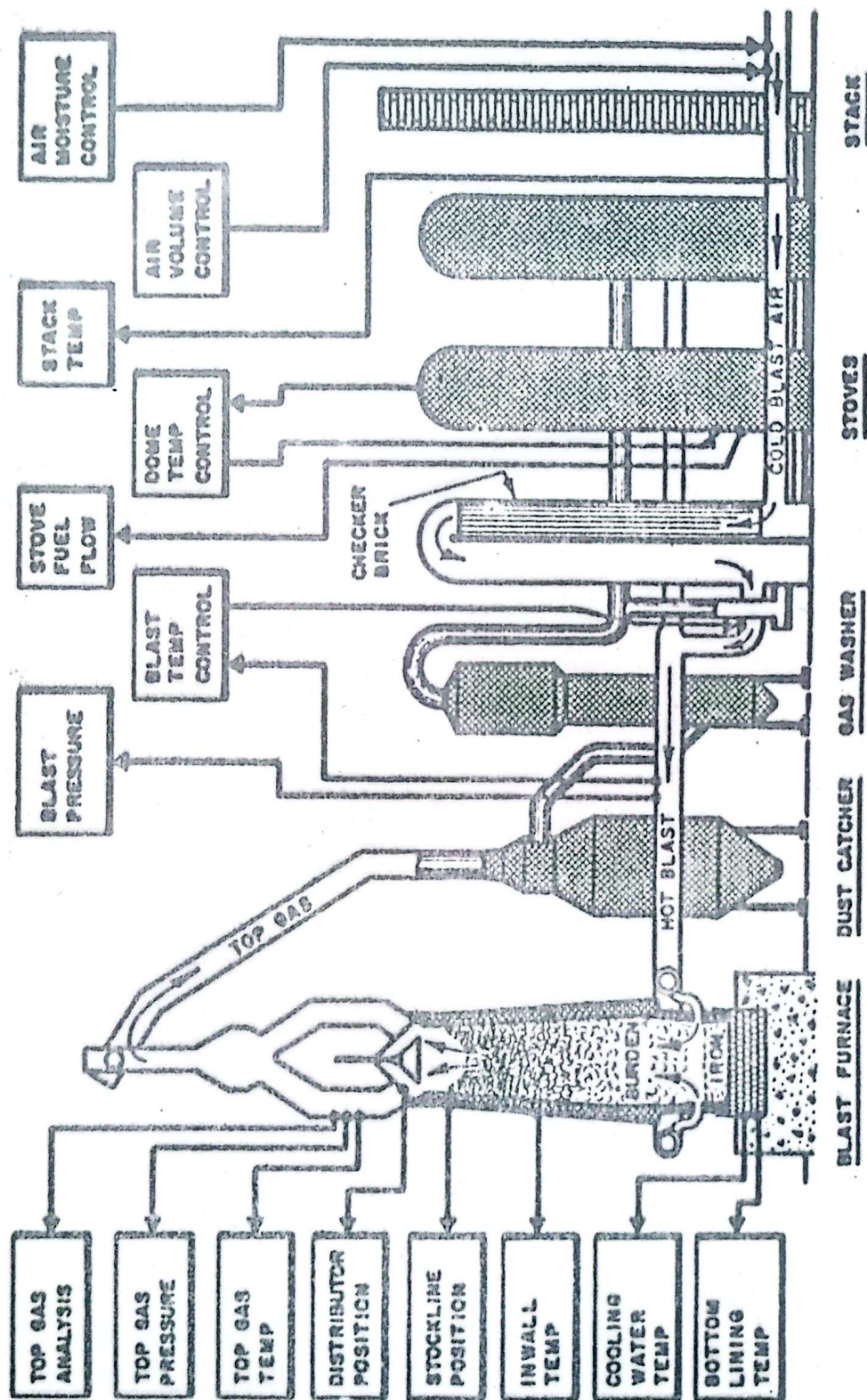


FIG. 10. Blast Furnace and Associated Equipment

CONTROL OF THE SEMIFINISHING OPERATIONS:

In the semifinishing operations an ingot is rolled into blooms (large, essentially square sections), or billets (small, essentially square sections) or slabs (flat sections). Each of these primary sections is intended for a special type of finishing operation. Blooms are sent to rail or structural mills for the rolling of steel rails and steel structural shapes. Billets are intended for bar, rod, wire, pipe, and tube mills. Slabs are sent to plate mills or hot-strip mills. Coils from hot-strip mills move to cold-reduction mills and then perhaps to tinplate mills (refer to FIG I).

All these rolled and finished products have both metallurgical and size specifications. During rolling operations, hot and cold working must be regulated to obtain desired metallurgical properties. The intermediate states of annealing and tempering must also be regulated for metallurgical purposes. In addition, there are size specifications on both semifinished and finished products. Tolerances on the finished products in the finishing mills can be quite strict.

For example, commercial standards for steel sheet thickness permit a $\pm 10\%$ thickness variation. However, the steel industry strives to maintain an even closer tolerance of $\pm 5\%$. This tolerance amounts to ± 0.0005 inch for point to point control of rapidly moving 0.010 inch thick strip.

During all these rolling operations massive problems in material handling are encountered. Tons of steel must be manipulated on roll tables, often at extremely high temperatures. On sheet and strip mills, operating often at several thousand feet per minute, precise control must be maintained over both temperatures and finished dimensions. It is apparent that the control required in the modern iron and steel industry is both broad and intense. All imaginable types of control problems are encountered at one phase or another of the operation. Chemical analysis must be known of raw materials; liquid iron and steel, and solid steel products. Temperatures of liquid and solid metals in various states must be measured. Dimensions of semifinished and finished products must be measured. Environments in the steel industry are hard, and measurement and control equipment must be extremely durable if it is to function properly.

In the past, considerable progress has been made in the development of a wide variety of elementary control systems for such processing variables as temperature, position, and speed. However, the integrated control of these subsystems has been left primarily to the operator because to provide such control by means of equipment was extremely complicated. The required equipment must be capable of handling and manipulating the large amounts of data which are used in properly controlling the process under a wide range of operating conditions.

Control of the Slabmaking Department: I

The flat product world has yet to make up its mind whether continuous casting, making use of all known techniques including that of vacuum degassing, will supplant the slabbing mills due to improved yield and lower capital cost. As yet, most people have conceived continuous casting as the adjunct to a slabbing mill rather than a total replacement, in view of the great problems of controlling temperature and the state of oxidation of the steel in the continuous casting mold, particularly using large casts. If continuous casting is to win the day then there will unquestionably be great scope for the application of on-line computer techniques to control the speed of withdrawal, water addition, cut-off and stopper operation.

However, no major change in the process will be effected by on-line computerisation as seen at the moment. On the other hand, application of computerisation to ingot bogies, stripper bars, soaking pits and the slabbing mills could, indeed, change their form of operation considerably. Already some use of this technique has been made in the consideration of movement of ingot moulds from steel plant to soaking pits. In one Japanese plant, a study of the whole of the planning and operation of slabbing mill and soaking pit practice has been made, using data loggers. Rather, programme-controlled slabbing mills only have been constructed, in which the actions of the normal operator are reproduced by a programme controller.

The normal programme-controlled slabbing mill, of which there are several in existence, can only be expected to equal the rate of rolling of the best driver at all times, while ensuring less damage from faulty operation and closer adherence to dimensional tolerances.

FEEDBACK CONTROL IN THE REVERSING MILLS:

Perhaps a more dramatic example of changes occurring in control technology are those associated with the regulation of hot reversing mills. In this process, a hot ingot or slab is rolled back and forth in a single-stand mill to convert the original slab to a wider and much thinner shape or plate. As many as 25 passes, or reversals, might be required for this operation. In the early control forms, all control decisions and executions were performed by the operator. On each pass the operator would present the roll gap to reduce the thickness of the steel shape. He had to do this in such a way that the plate being rolled would not become too cool but would end up at the proper final width and thickness. In addition, he controlled cooling sprays, the tables the plate moved on, manipulators; side guards, and turnarounds.

Although the operations were manual, this was, in effect, a type of feedback system. The operator observed what was happening during rolling, and when the rolling was finished, measurements of width and thickness would be made and signalled back to the operator. If the plate was undersize it might have to be discarded. If it was oversize and still of suitable temperature, the operator could reduce it further. In this rolling operation, it is clear that the operator has two different functions which, of course are closely coupled. One function is decision making: the operator must decide, on the basis of available information, just what must be done. The other function is the control execution, in which he performs various physical and mechanical operations to implement his decision making. The control step taken in the recent past was to split these two functions.

Controls, called card-program systems, were installed on reversing mills. Here the decisions were still made by the operator, but the execution was performed automatically in accordance with the decisions previously prepared and put on punched cards. These control functions, of course were the manipulation of the mechanical aspects of the rolling operation: the movement of the plate on the roll tables, the movement of the rolls up and down, the

speed of the rolls, and similar functions. This type of control-in which decisions are made by an operator and the execution is automatic- is adequate when variability due to the process is small and changes are at a relatively slow rate.

It was frequently difficult to realize the full advantage of the card program type of system because many cards would be required to include all the various types and sizes of steel that were to be made on the plate mill. Consequently, a more advanced type of control system was proposed that includes not only all the sequencing, or logic, functions provided by the previous card program mills but also the decision making functions for determining the best rolling schedules consistent with existing workpiece, conditions and mill capabilities. In this control system, the only information provided is that of general instructions and limitations for all rolling- that is, the dimensions of the slab, the grade of steel, and the desired dimensions of the finished piece.

The feedback in this system does not include the operator. Instead, a new rolling schedule is calculated automatically for the remaining passes any time a discrepancy exists between measured performance and predicted performance in a particular pass. Computer systems of this type have been installed and are partially operable in the industry.

CONTROL OF THE FINISHING OPERATIONS:

ROLLING DEPARTMENT

A) HOT STRIP ROLLING

The requirements of a hot strip mill are that it shall roll as big a coil in terms of pounds per inch of width as is possible, with as close a tolerance in thickness from end to end of the coil as can be achieved while maintaining good shape, freedom from scale, and completely consistent width. Finishing temperature and coiling temperature are also invariably specified in the standard practice laid down for any hot strip mill product. Recently The Steel Company of Wales undertook a feasibility study with a view to using an on-line computer to achieve the maximum consistency of its product off the hot strip mill. The sum ultimately sanctioned was £2.4 million. Of this sum only £0.85 million was actually devoted to the on-line computer- the remainder was devoted to improving such things as the edging mills, loopers, screwdowns and drive control. Thus, without any on-line computer in operation after this equipment has been added to the mill, it will be possible to produce, by means of manual operation, a more consistent product than was possible before.

This pattern of studying the process and removing obstacles to consistency of operation repeats itself wherever the use of on-line computers is being considered and seems to be a large-scale by-product of the on-line computer; in fact, it may be producing results equal in value to the operation of the computer itself. Once again, the sensing devices have to be reliable, the records must be accurate. To illustrate the point, if the computer is fed with figures regarding dimensions or thickness, they must be correct; there is no room for error. However, there is one particular aspect of the on-line computer that cannot be equalled by manual operation, and that is the achievement of more accurate changes from gauge to gauge without rolling-out-of-gauge coils in the meantime.

Since one of the great desires of purchasers of strip and operators of cold mills is to have the largest possible coil without a weld, the coupling together of the speed of the coiler with

the speed of the mill while controlling the gauge will be of great benefit. It is impossible to run a hot mill with the strip out of the coilers at much more than 2,000 ft. per minute, but once the piece has entered the coilers, provided there is fully automatic gauge control, the whole mill and coiler can be speeded up to, say, 3,500 ft. per minute.

The difficulties which have emerged in all plants attempting to employ an on-line computer in a hot strip mill have been caused by the unreliability of sensing devices, particularly those for temperature, and the difficulty of data logging all the variables which finally affect the issue without first making modifications to the plant.

The full computer control system for the Hot Strip Mill of the previously mentioned company will be discussed in detail in a separate chapter.

B) COLD SHEET ROLLING

As in the cases of the blast furnaces and steel plants, the size limit in mills appears almost to have been reached. Already coilers are in existence that can run the strip mill at over 3,000 ft. /min. by the method described, with coils weighing up to 1,200 lb. per inch of width. Tinplate mills have been designed to run faster than the metallurgy of the metal has ultimately permitted. Marginal increase in outputs of these units can be conceived but nothing material. It is just possible that the fully continuous cold mill, in which the back end of one coil is welded to the front end of the next, may be attempted; this would indeed effect a considerable increase in mill output, but such an idea has been in people's minds for many years and the problems are almost insurmountable, not the least of which being that the scheduling of strip widths must allow for roll wear and continual change in width. A fully automatic

6-stand mill is running in some factories in which threading and other normal operations are automatic. The guide construction of all cold mills is such that the mill must be stopped in order to change the guide width. However, one step in the direction of increasing the percentage of time spent in rolling of both hot and cold rolling mills is the invention of the automatic roll changing gear. Several hot and cold mills are now being built with this gear, which will materially reduce the time spent in roll changing and thus the output of the mill over a long period of time.

Neither is there any immediate output gain visible in the tinning field, exception in so far as gauges are steadily getting thinner, tinplate coatings are getting thinner, and thus an ever greater area of tinplate is available from a given quantity of steel and tin.

CYBERNATION REVOLUTION IN THE STEEL INDUSTRY

The true gains from the "cybernation revolution" do lie more in the mill field than anywhere else. It is unusual for any strip mill or tin-plate plant to produce more than 85 per cent of the product of the hot strip mill against the order for which it is originally intended. The application of on-line computer control for hot and cold mill operation, together with electronic data processing of production control and scheduling, will lead towards a definite improvement in this percentage. At the same time the customer will be receiving material rolled to closer tolerance of gauge, width and shape than before. In addition to better production control and scheduling, one new feature which will result from the better availability of information due to the use of E.D.P. is better information of the actual cost of varying widths, size, steel grades and routing techniques. This will enable the sales department to make better decisions regarding which order mix to accept for maximum profit. The slow progress in this direction is due probably to the causes already mentioned-inaccurate weighing, difficulty of locating items of stock, and, if located, obtaining them; slowness in transmitting information from the various locations of plant or stock to the central data processing organisation; and above all, indiscipline and inaccuracy in the filling-in of records. Nevertheless, the prize is so great that undoubtedly all mills will be pursuing this problem and improving their stocking methods, their recording methods, and, probably ultimately, their methods of transmission of data to the computer. Whether this is to be by punch tape carried through tubes or direct-line transmission, or punch cards carried by hand, remains to be seen.

THE HOT-STRIP MILL

The hot-strip mill is, perhaps, one of the most highly controlled processes in the steel industry. First in a hot strip mill are the reheat furnaces for heating slabs to a specified uniform temperature. These slabs are then delivered to a multistand roughing mill where preliminary reduction and width control is obtained. After the roughing stands, the steel is fed continuously to a multistand, continuous finishing mill. Here the steel is reduced to finished dimensions, cooled to a specified temperature on a runout table, and coiled. The finishing speed in these mills is several thousand feet per minute. During the processing metallurgical requirements demand that temperatures be controlled, and product specifications requires certain finished dimensions. These mills have elaborate electrical controls for driving and positioning the rolls. In addition much equipment is employed in the form of gage, force-and temperature-measuring instrumentations. In the finishing stands, the steel strip is in all the stands at the same time so that reduction of strip thickness is accomplished not only through the position of the rolls in squeezing the steel but also through tension between the stands; therefore, roll position as well as interstand tensions must be carefully regulated. Present-day mills use fairly standard forms of continuous measuring equipment through feedback system to regulate the thickness of the steel strip. The strip enters and moves through the mill at such a high rate of speed, however, that the mill stands must be properly set before the strip enters.

The requirements of a modern hot-strip mill are presently being integrated through computer systems. These requirements include strip tracking, roughing-and finishing-mill setup, temperature control, mill pacing furnace assignment, and data logging. The computers do not usually function as closed loop regulators, but they are used to calculate certain functions, send out references to the regulators

previously mentioned, monitor individual operations, and coordinate the rolling operation and the precision required in the finished product make this an excellent application of computer systems.

The effective control of any process, whether manual or automatic, requires quantitative information on demand relative to the state of the process. Therefore, a prime requisite for control is instrumentation that will adequately translate selected process variables from their physical or chemical units to some usable form. These instruments can usually be considered in two parts: first the conversion of a primary variable to an electrical signal, and second the conversion of the electrical signal to a form that will provide a meaningful output. In many cases, these functions present no particular difficulties, but there are still some measurement needs that have not, as yet, been adequately covered in either or both of these respects.

PRESENT CONSTRUCTION OF A HOT STRIP MILL:

Let us consider an existing hot strip mill, with definite configurations, and then discuss how far can we apply computer control techniques to this installation.

Suppose that we have a Universal Slabbing Mill which rolls slabs from 27 " to 74 " wide and from 5 " to 8 $\frac{3}{4}$ " thick. After automatic scarfing, the slabs are sheared to length, weighed, identified, and most of them sent to a slab yard. After cooling they are passed back into a middle yard where they are inspected (and hand dressed if necessary), then stored till they are scheduled on the hot mill.

A proportion of the slabs (for tinplate and general purpose bars) are directly sent to the 80" Hot Strip Mill, while some of the others being directly loaded into the reheating furnaces. Rimming, balanced, stabilized, silicon and special purpose steel strip is produced, the bulk of the product later being cold rolled for motor car trade, producer goods industry and tinplate.

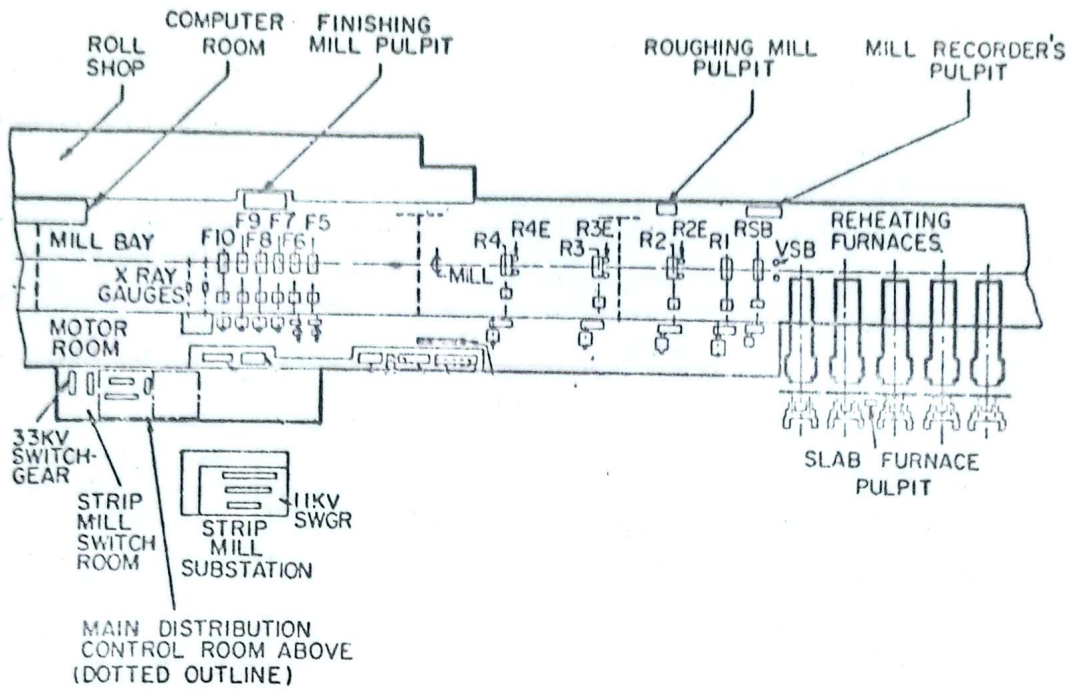
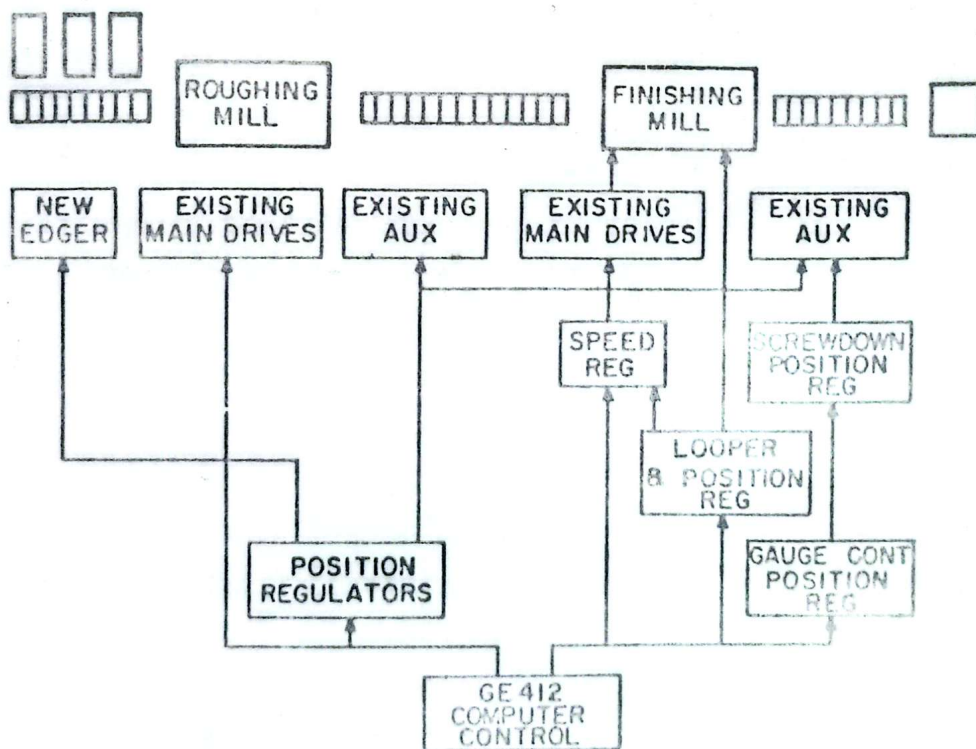


FIG 1



AUTOMATION SYSTEMS ARRANGEMENT

FIG 2

The Features of the hot strip mill are shown in FIGI Following table, beside being a key In different abbreviations, gives distances between consecutive stands:

STAND		DISTANCE FROM PRECEDING STAND
SYMBOL	NAME	FT.IN
VSB	42" VERTICAL EDGER	
RSB	ROUGHING SCALEBREAKER	16'. 9"
R1	NO.1 ROUGHER (FORMERLY BROADSIDE)	30'. 0"
R2E	NO.1 EDGER	43'. 10"
R2	NO.2 ROUGHER	51'. 4"
R3E	NO.2 EDGER	52'. 5"
R3	NO.3 ROUGHER	60'. 0"
R4E	NO.3 EDGER	88'. 11"
R4	NO.4 ROUGHER	96'. 0"
F5	NO.5 FINISHER	186'. 0"
F6	NO.6 FINISHER	19'. 0"
F7	NO.7 FINISHER	19'. 0"
F8	NO.8 FINISHER	19'. 0"
F9	NO.9 FINISHER	19'. 0"
F10	NO.10 FINISHER	19'. 0"

BASIC CHANGES IN THE SYSTEM:

- (1) Installation of a new free-standing edger between the slab furnaces and the roughing scale breaker, edger speed should be controlled to match the speed of the horizontal scale breaker so that slabs would be in both mills simultaneously.
- (2) Installation of pressductor load-sensing units on all the mill stands .
- (3) Modification of the coiler weigh scale to furnish automatic weighing with digital indication and to provide computer input information.

STRUCTURE OF THE OVERALL SYSTEM:

Upon analyzing the proposed Computer & Automatic Gauge Control System, it is better to divide it into a number of independent (but interdependent) subsystems. They include:

- Computer Control System
- Digital position regulators for roughing mill and total mill auxiliary drives
- Finishing mill speed regulators
- Finishing mill looper position regulators
- Finishing mill screwdow position regulators
- Finishing mill automatic gauge control.

FIG. . . 2 shows each of these and illustrates the relation between different subsystems.

COMPUTER CONTROL SYSTEM:

The computer control system should be designed to direct the mill operation from the charging side of the slab Furnaces through the coiler weigh scales.

The physical elements of the computer system and their relationships with the mill and with each other are shown in FIG 3

The proposed computer is an GE 412, CPU of :

- 8000 words of core memory
- 56000 words of bulk drum memory
- 3 levels of priority interrupts (total 12 positions)
- 3 elapsed time counters
- Digital clock
- Programmer's console

The computer does not directly regulate any function. It only acts as a systems director to compute and transmit references to operators and mill regulator elements by performing a number of inter-dependent Functions.

Those functions are:

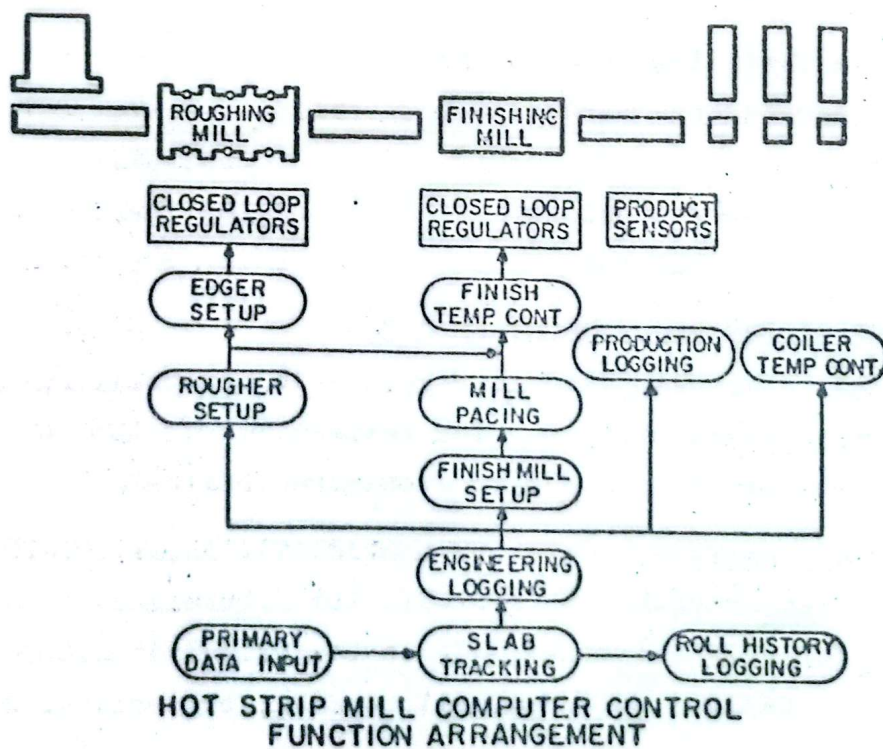
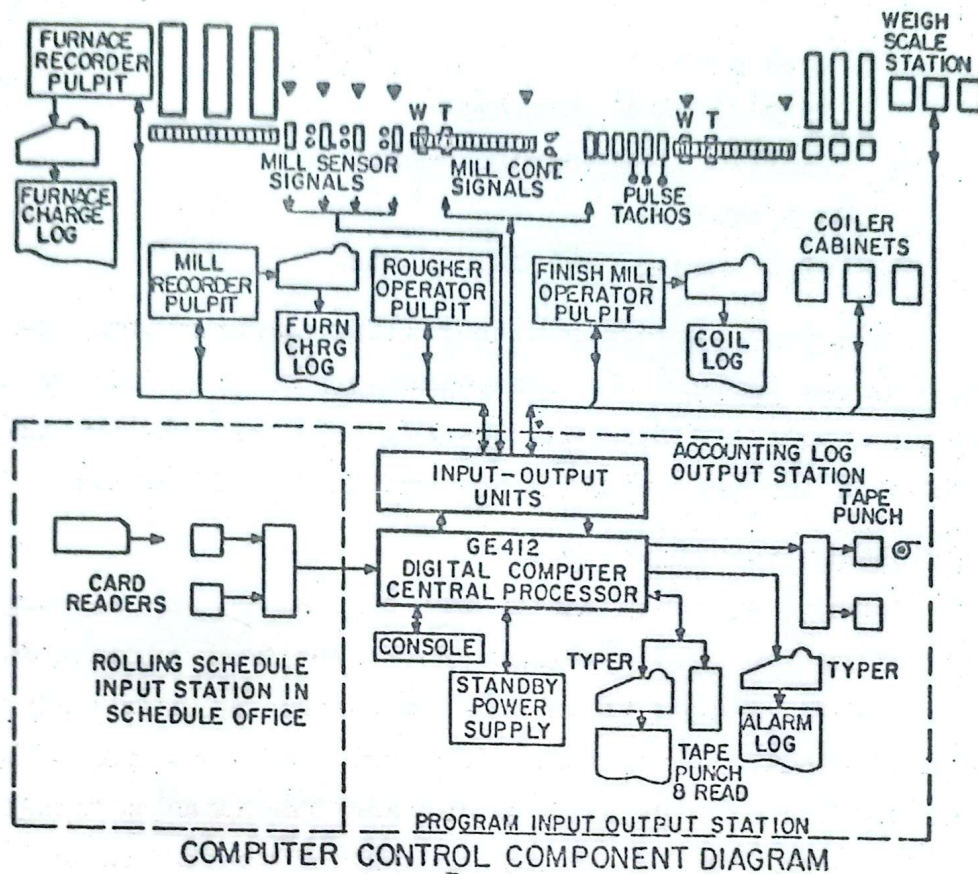
- Primary Data Input
- Slab Tracking Function
- Mill Pacing
- Mill Setup Function
- Temperature Control Function
- Width Control Function
- production Logging Function
- Engineering Log Function
- Roll History Log Function

FIG 4 shows the interrelationship between those Function. Detailed explanation of each of those functions is beyond the scope of this presentation. As an example, let us consider two functions:

(A) PRIMARY DATA INPUT:

The following information must be fed into the Computer before the slab enters the rolling process, such as:

- Identity
- Slab thickness, length & width



- Steel grade
- Strip width & thickness
- Specified temperature ranges
- Cast number
- Ingot number, weight,... etc.

This data, together with rolling instructions are provided using punched cards. The acceptance of instructions by the computer is simple and straightforward. The methods for instruction, preparation and presentation are critical and complex

(B) WIDTH CONTROL FUNCTION (FIG 5)

Control of strip width will be achieved in the roughing mill by adjusting the roll openings of the vertical edgers. Feedback from the width gauges after the last roughing stand and the last finishing stand will correct width calculation errors. Position references for all the side guides and the speed settings of the edger rolls will be determined as part of the width control Function.

MILL SPEED REGULATORS: (FIG 6)

For this installation we need:

- Voltage reference & regulator circuit: to drive rectifier firing control.
- Thyristor power supplies : for the stand motor fields
- Closed loop regulators : for the stand speeds

LOOPER POSITION REGULATORS: (FIG 7)

Regulators are supplied to regulate looper position and to maintain constant strip tension between stands and to avoid necking the strip down due to excessive tension.

MILL SCREW POSITION REGULATORS & AUTOMATIC GAUGE CONTROL

The system is shown in (FIG 8). The figure shows the simplified circuit for only one stand, all to be fitted with identical circuits. Desired unloaded roll opening for each stand will be

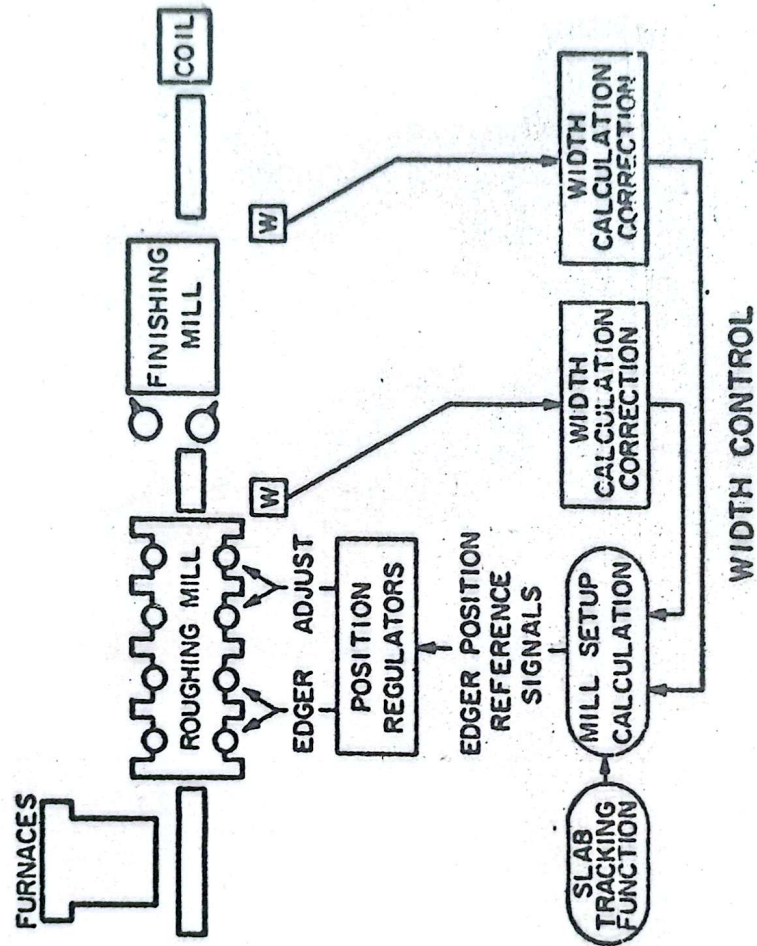
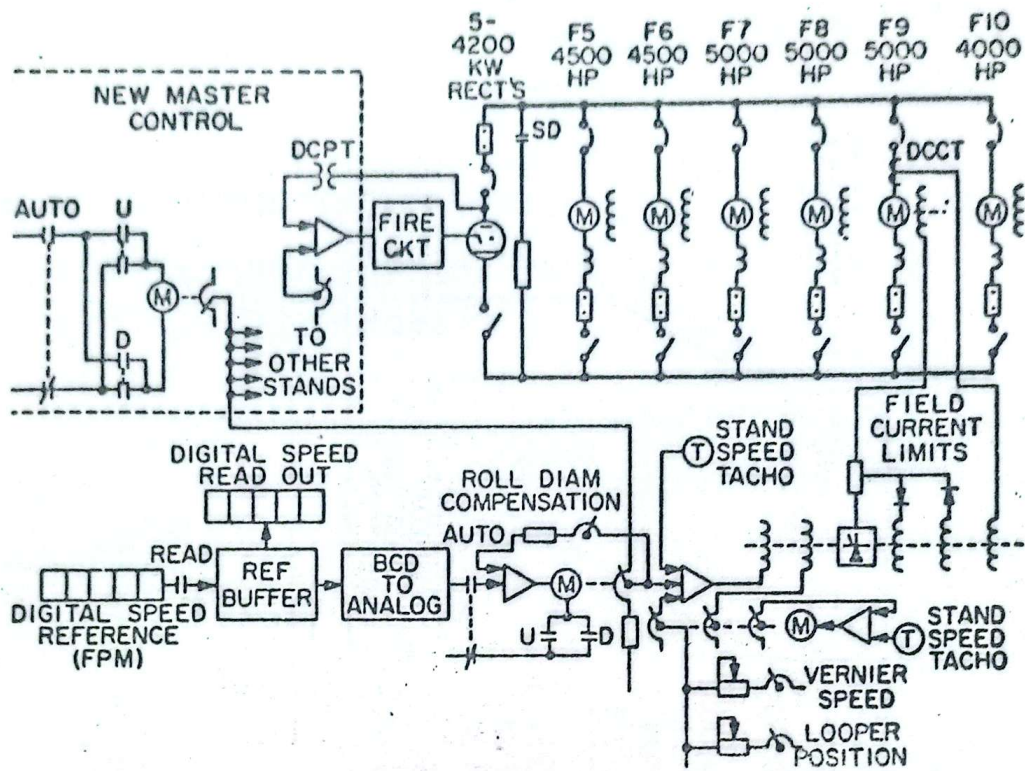
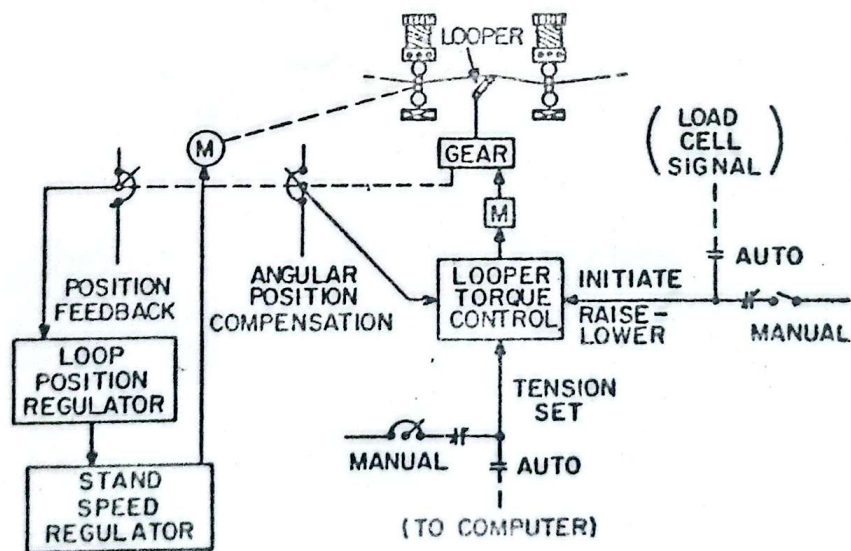


FIG 5



DIGITALLY SET MAIN DRIVE SPEED REGULATOR CIRCUIT

FIG 6



LOOPER REGULATORS

FIG 7

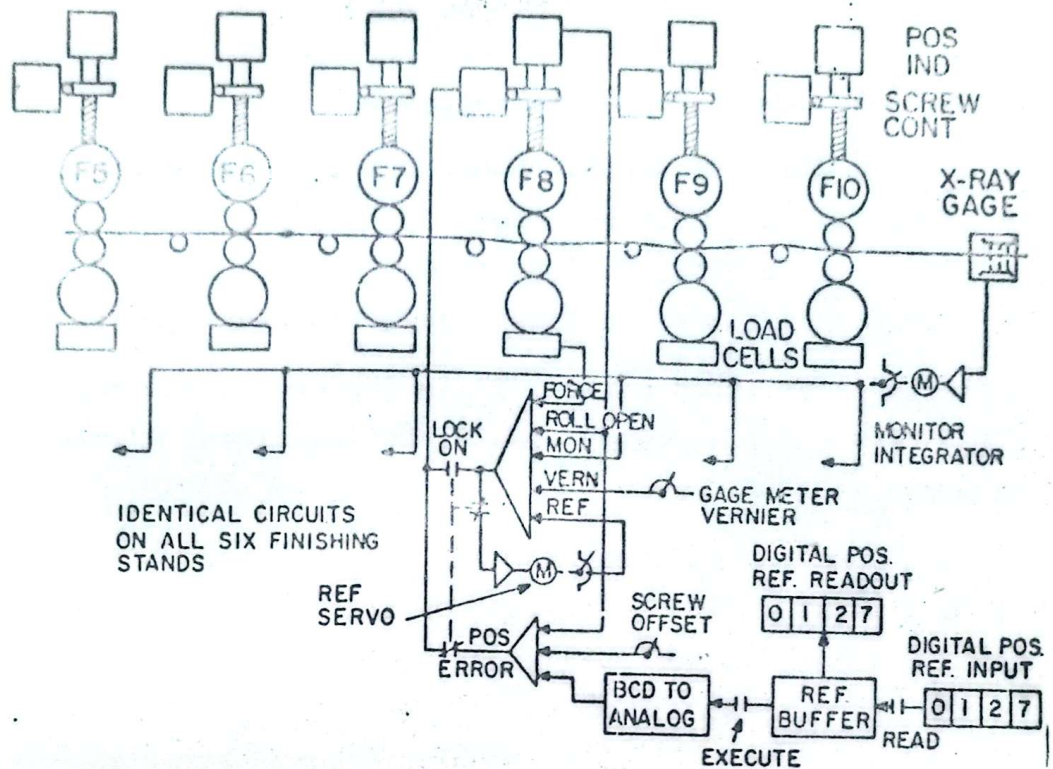
Roughing & Auxiliary Position Regulators

Following features are to be set using the computer:

- Roughing mill roll openings
- Edging mill width settings
- Openings of the various sideguards (throughout the mill)

This is established using a TIME- SHARED DIGITAL POSITION REGULATOR SYSTEM. FIG 9 illustrates used circuits. Total drives handled by this regulator are:

- 5 Roughing mill screws
- 4 Edger roll adjustments
- 3 Coiler pinch roll gaps
- 14 Sideguards



AUTOMATIC GAGE CONTROL 8 FINISHING MILL SCREW POSITION REGULATORS

FIG 8

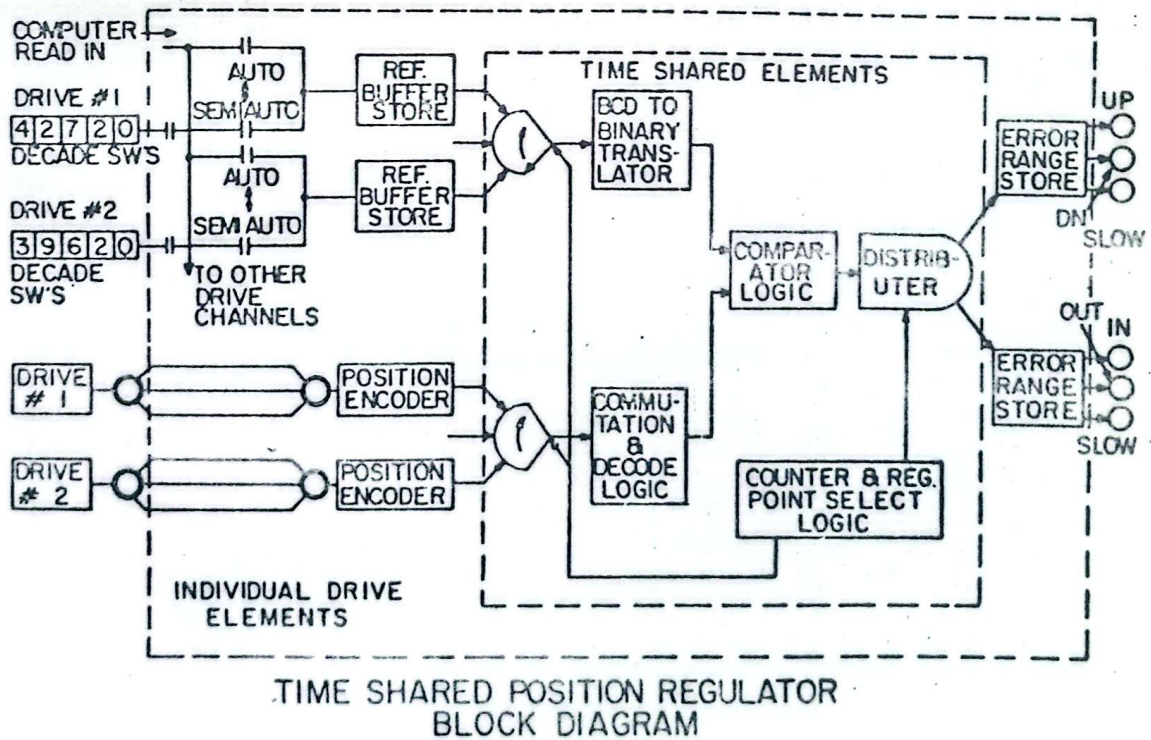


FIG 9

SOFTWARE FOR THE CONTROL OF THE ROLLING MILL:

The success of a computer controlled rolling mill installation is completely dependent upon the team of engineers and analysts spending many man years into creating, defining, flow charting and coding the design and also every possible course of action that might logically be encountered in operating the rolling mill. These engineers and analysts must be intimately familiar with the details of the operation, they must also be familiar with the physical and metallurgical properties as well, such as:

- (1) Mathematics of the plastic flow of metal in the roll bite
- (2) Roll bending characteristics
- (3) Roll flattening characteristics
- (4) Possibility of mill stretch

The following table illustrates the type of study needed for plate mills. There is also an estimation for the time required for such study^{*}

ACTIVITY	Estimated Time
	MAN-WEEKS
Plate Temperature Study	11
Roll Force Prediction	30
Shape Control	31
Pre-installation Testing	20
Scheduling Generation & Feedback Analysis	60
Coordination & Factory Tests	16
On Site Activity	24

Every routine must be logically organized, assigned a priority level and put together into the computer memory.

* The model does not include primary data input, Tracking, logging & sequencing programs.

TOWARDS AN INTEGRATED CONTROL SYSTEM:

It is interesting to note that although the computer control equipment is generally equivalent in all cases, the use of the equivalent ranges from data collecting to highly sophisticated automatic control. Thus, it appears that the industry is presently in a transitional stage of process control in which the control equipment is changing in form, and objectives are leading to a greater extension in the integration of control systems.

An example of this transition can best be seen by looking at some of the facilities. First, consider the blast furnace. The blast furnace might be thought of as two separate component facilities - the regenerators, which preheat blast air, and the furnace, which reduces the ores to iron. Standard controllers of commercial manufacturers are used extensively to regulate the quantity and temperature of the blast air obtained from the regenerators. These regenerators controls are closed-loop feedback controls of the most simple functional types. The furnace itself, however, has essentially no feedback control. The operator calculates a burden, or charge, of raw materials. He has theoretical or empirical formulas available from which to make the calculations. Burden calculation might be thought of as a feed-forward type of control. There is feedback control through the operator by means of chemical analysis of samples of iron taken as the furnace is cast. In the ordinary sense, however, the operator uses the instrumentation on the blast furnace as a guide to the state of the furnace and then he manually controls the furnace operation. Extensive control rooms are found in most blast furnaces, but the majority of the instrumentation tells the operator the state of the various blast furnace auxiliaries.

Recently, computers have been installed on blast furnaces for data logging and alarm monitoring. In a few cases, computers have been used to calculate the burden requirements for the operator, and in even fewer cases, to perform a limited amount of feedback control.

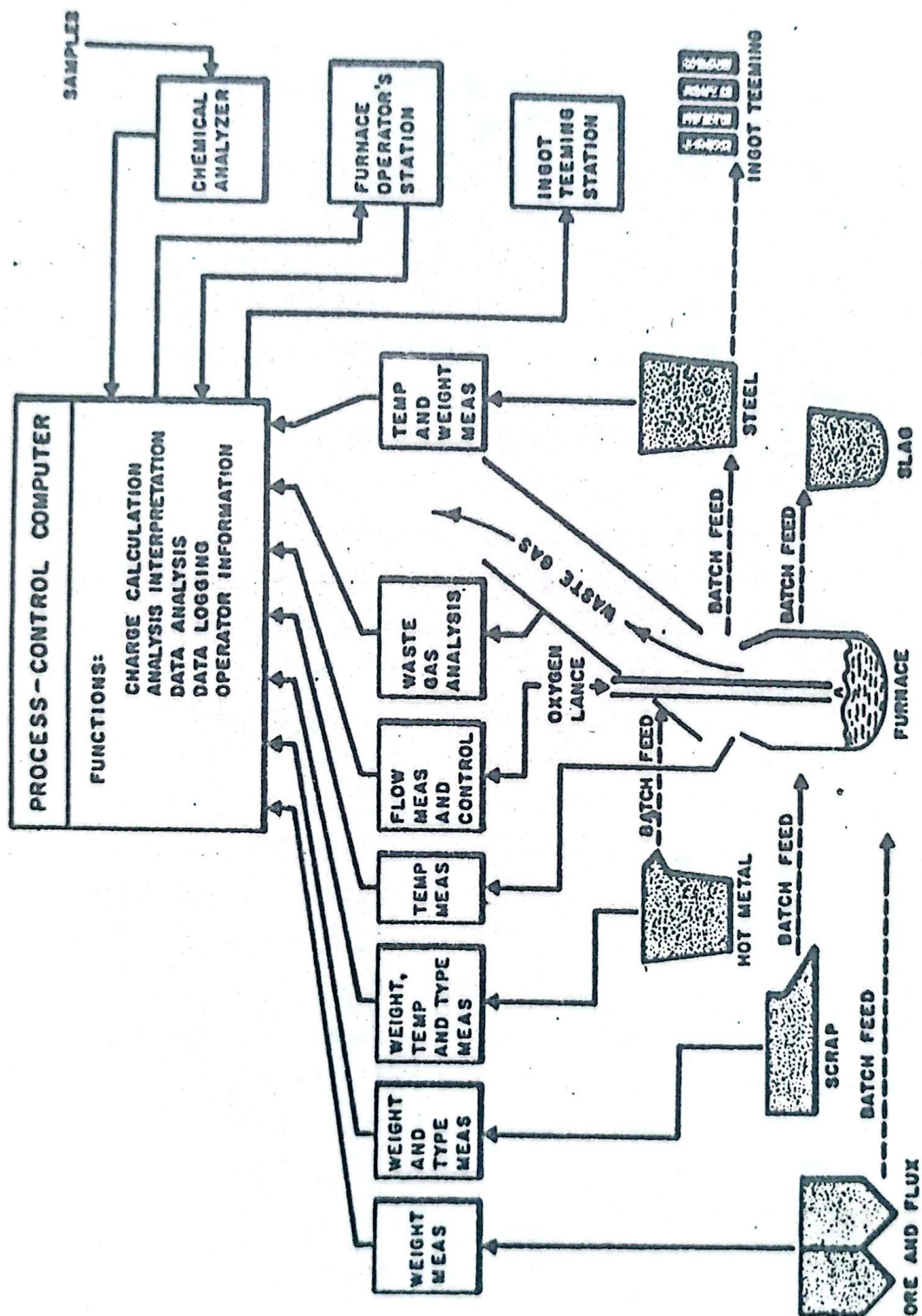


FIG. III: OPEN-LOOP COMPUTER SYSTEM FOR OXYGEN STEELMAKING

As in the blast-furnace process, the function of the basic oxygen steelmaking process is to produce a product of specified chemical composition. However, in addition to composition, the process must also produce steel at a specified temperature. Again, the operator has a great deal of difficulty determining the state of his process while steel is being produced. No method is presently available for continuously making measurements in the furnace ore, for that matter, determining the composition of the steel in the furnace. Both measurements must be made by stopping the furnace, or at least stopping the blowing of oxygen into the furnace, to take a single measurements sample. Again, knowledge of the process provides means for calculating the charge of liquid iron, flux materials, and oxygen required to produce the given temperature and composition. The changing, however, still lacks the desired precision largely because of inaccuracies in the measurement of the composition of input materials and sometimes in the quantities of materials charged. There are at present no generally used automatic feedback systems on the basic oxygen steelmaking process itself. There are, however, some experimental systems in operation. Even though there is room for improvement, the digital process computer has already made a significant contribution to process regulation.

For example, computer control systems for basic oxygen steelmaking include the prediction of charge and blowing requirements for desired end-point steel composition, the automatic interpretation of data from an off-line analyzer of steel samples, and the automatic handling of order information and information for various bookkeeping metallurgical and data logging functions. In these systems, order information(for the heat specifications), chemical analysis of iron from the off-line analyzer, and iron temperature are inputs to the computer which permit calculation of charge and blowing requirements. These requirements are automatically displayed on pulpit consoles for action by the operator. Interpretation of analyzer results is automatic in the computer through a direct wire connection. Process information is handled automatically through wired inputs.

Systems of this type constitute on-line, open loop computer control.

OFF-LINE CONTROL OF IRON & STEEL FACTORY:

The increasing complexity and integration of processes, their intensification, increasing requirements for speed and quality of control, advent of new control problems call for new approaches to formulate and solve control problems for complex, integrated plants. Ideas, methods, techniques and control means used for such purposes constitute a qualitatively new class of system called "large systems". Computer process control at the shops or factories level provides the physical implementation of the control systems of the type. As distinct from the established approach to problems of automatic control theory, in the theory of large systems control the criteria of efficiency cannot, and must not, be considered as given. To set up efficiency criteria for the system discussed or for its parts is a most important and difficult problem which if unsolved would reduce development of control algorithms to point-less exercises.

Digital computer as a multi-purpose device for information handling makes possible to explore different versions of control algorithms as well as the effect of different criteria while simulating the control system mathematical model on an all-purpose digital computer. In this case the environment, the plant controlled and the control system must be simulated.

The model of environment should contain data on perturbations as well as data necessary to establish efficiency criteria.

These can be given as statistic or deterministic laws which describe the perturbations as well as the effect of systems operating characteristics on the final objective for which its functioning has been organized.

The model of the controlled plant can be represented by system of equations, a graph characterizing the priorities and interrelations of operations or tables containing information on properties and characteristics of the process, etc.

Finally, the model of the control system is implemented as program of the integrated control algorithm and identification of the memory zones of the computer, on which simulation is done, for computers which are intended for use in the actual system.

Mathematical simulation considerably reduces the time and costs for development and installation of digital computer process control.

MANPOWER PLANNING FOR THE IRON & STEEL INDUSTRY:

Automation in the Iron & Steel Industry will certainly revolutionize the field of manpower utilization in the various sections of the industry. It is necessary to study every single operation separately in order to evaluate automation and see whether it is justified or not. Once it is justified, an extensive study to see the effect of automation on man-hours per ton follows.

The design of any form of computer merely to substitute the labour of a man is simply not worthwhile. For example, it is not worthwhile to design a fully computerised ore unloader. The gain over a good driver will be small and the cost of the computer and its installation will cost more than any slight gain in output and certainly will save no labour to speak of. Perhaps it might be possible to design a fully computerised teeming crane for an L.D. shop. It would be highly complex, cost a great deal of money and undoubtedly its installation and maintenance cost would far outweigh any labour saving.

But in the field of clerical work there must surely be an outstanding saving. Much of the work, for instance, carried out in the traffic invoicing department of any large iron and steelworks could, with collaboration from road and rail authorities, be computerised with much saving in clerical labour. Undoubtedly the production control office and scheduling departments of future mills will also save much actual clerical labour, but where, in the past, perhaps, a boy will have chosen to train as a clerk to work in one of these departments, in the future he may prefer to train as an operator in one of the highly mechanised or computerised sections of the works.

The balancing of the labour available will probably be automatic, since there will be ceaseless pressure to design equipment to be simple to operate and simple to maintain, as, for example, the car of today which will soon universally have automatic gear-change and no grease points. But the collaboration between the training authorities, the education authorities, the design departments of plant makers and the planners for new

iron and steelworks will need to be a great deal more complete than it has been in the past. There should be a definite attempt to employ the highly qualified man in the job where his abilities will best be used. It seems quite clear that the percentage of Q.S.Es in the iron and steel plants of the future will rise, but this will be, at least in part, due to the availability of education rather than the intelligence level.

In some Japanese works there has been a theory developed that the central department of research, decision-making production and sales planning would be the centre at which most Q.S.Es in a company would be employed, with men of perhaps more practical outlook but lower degrees of qualification carrying out the orders from the centre. While the use of a larger research department, the extension of the principle of standard practice, may in fact bring this about to a certain extent in Great Britain, it seems unlikely that it can ever be a sound method of work, as iron and steel works will always be faced with unexpected problems in the plant as they are a high-temperature industry working on materials of such inherently high strength. However, the rate of change may be such that the older men may find their existing jobs disappear when they are too old to re-train for a new job of equivalent responsibility. This makes it imperative that labour dislocation caused by automation is foreseen the moment any programme of automation is decided upon, whether this be replacement of many open hearths by a few L.D., or the substitution of an on-line computer for slabbing mill drivers. The usual solutions are retraining for the younger man and early retirement for the older man. But the skilled man who has reached the top of his profession and yet is still in early middle age presents a formidable problem as cash alone will not compensate for his loss of satisfaction in doing a highly skilled job. There is also the problem of the managers and engineers of the future. Will the gradual adoption of standard practice, centralised decision-making, and production planning make them feel but cogs in a machine and also feel loss of dignity in the job? This is a definite danger, and one difficult to overcome.

It seems most likely that the overall organisation of a large iron- and steelworks in the future will consist of fewer line jobs and more staff ones.

PROBLEMS OF AUTOMATING STEEL PLANTS:

A) MANPOWER PROBLEMS

1) UNEMPLOYMENT PROBLEMS:

The changeover from the small open-hearth furnaces, the sheet bar mills, and the hand mills of the sheet and tinplate industry in the 1920s to the modern hot and cold wide strip mills resulted in an immense reduction in the man-hours per ton of finished product, but the unemployment problem which was feared, never appeared.

It is quite clear that the man-hours per ton of the most modern flat product plant one can conceive, using present-day knowledge, would be far lower than the average man-hours per ton of the existing industry. The full utilisation of the capabilities of modern blast furnaces, L.D. plants, hot and cold rolling mills, without the intervention of on-line computers or electronic data processing, alone will have a major effect; but customers' demands will almost certainly ensure that those who cannot produce as consistent a product as their competitors will fall by the wayside, and in this direction particularly the application of on-line computers, as well as careful preparation of raw materials, will be essential.

The use of large units, such as the 300-ton L.D. vessels displacing so many open hearths, may well reduce the requirements of managers and engineers more than the requirements of crane drivers and pitside men; if, however, the problem is foreseen of manpower requirements of the future, then training programmes - not only to teach the staff who operate the jobs what they have to do, but also the designers of equipment, to render it free from breakdown and easy to replace - should make the further automation of the iron and steel industry a matter of pride and pleasure to all concerned.

i) NEED OF INTELLIGENT STAFF MEMBERS:

Designers of plant must realise that the plant must employ a cross-section of the intelligence level of the community, rather than picking out the plums and leaving the rest to rot. That this is possible, I am convinced, for two main reasons: in the past, sometimes, brains have been wasted on jobs for which they were not required, and also jobs have been so designed that brains were required to operate them or maintain them when careful planning or design could have avoided the necessity for other than reasonable compliance with instructions. For example, already computers are being designed so that the failure of any part can be remedied by the pulling out of a module, and the pushing back in of a fresh one. Clearly a computer controlled slabbing mill must not be designed with the thought in mind that a slabbing mill driver is going to sit there ready to take over when the automatic device fails. Rather must it be devised so that the failure of any operation of the automatic devices can be simply put right by a trained (but unqualified) man.

ii) NEED OF AN OVERALL REVIEW OF NEEDED CAPABILITIES:

When considering the effect of automation on labour employed in the industry, the following points have to be borne in mind. Although the man-hours per ton may decrease, the probability is that the number of tons will increase due to a cheaper and better product increasing demand. With increasing prosperity more people will be able to buy the end product, a more sophisticated product, which will also require more work to be done on each ton at the finishing end. When the demand for labour for industries to use the increased output of this product is added to this, it can be seen why the automation revolution will not necessarily produce the unemployment which the reduction in man-hours per ton

might imply.

As has been stated before, the main moves in the automation field now to be expected are:

- 1) The better preparation of the raw material ahead of each process.
- 2) For any given output, larger and fewer units operating faster.
- 3) The use of on-line computers for process control and electronic data processing computers for production planning and decision-making and production control.

Roughly, the three grades of employment that are to be considered are:

- 1) Qualified scientists and engineers, accountants and others of relatively high degree of education.
- 2) Those of fair education, having perhaps several 'O' levels or one 'A' level - foremen, technicians and clerical workers with some degree of qualification.
- 3) Workers and clerical workers with no qualification other than training.

The effect of the three degrees of automation on these three grades of employee will vary according to the various sections of the industry. For example, a large fully automated blast furnace will obviously require fewer man-hours per ton, but the percentage of the various grades of employee may not vary much. Only the most detailed examination of each case will reveal the true effects.

B) MEASUREMENTS PROBLEMS:

Consider the continuous measurement of the temperature of molten metal in an open-hearth or basic oxygen or basic oxygen steelmaking furnace. This would be a fairly straightforward measurement with the use of thermo-couples except that, to date, no suitable material is known that will withstand chemical attack under these operating conditions. No other approach is suggested at this time that might provide a continuous temperature measurement in this environment.

On the other hand, some quality measurements such as surface inspection of steel strip are difficult, not because of an inherent difficulty in obtaining a variety of electrical responses from the surface being inspected, but because the quantitative interpretation of these signals in term of established standards would require extensive complex equipment that makes such instruments impractical and uneconomical.

One approach to these measurement problems is the use of an indirect measure that utilizes existing types of practical instrumentation. In the indirect method, the variable to be measured is calculated in accordance with the functional relationship that exists between it and other measurable variables.

The indirect measurement approach can be used most effectively when the digital control computer is available. For example it is impractical at present to measure the thickness of steel in excess of two inches with radiation-type measurements gages. However the thickness can be measured during a rolling operation if the opening between the rolls and the amount the mill flexes during the rolling process are known. Since the mill is equipped with instrumentation to measure roll opening and rolling force, or mill loading, it is relatively simple, by means of Hook's law, to calculate the actual roll gap, which is the steel thickness.

In another example, it is necessary to know the average of temperature of a steel piece being rolled because of the effect of this temperature on the resistance to rolling deformation, or reduction, because surface temperatures are difficult to measure reliably under operating conditions and because average temperature in this case is more important than surface temperature, mathematical relationships are developed that relate the initial temperature of the piece, the time of furnace discharge, the changing geometric form of the piece, and the energy added during rolling. These calculated temperatures are then used as an indirect measurement for mill control. Although the use of computers may in some cases increase the demands on instrumentation, these are examples in which the computer can minimize or reduce the instrumentation requirements.

FUTURE CONTROL TRENDS IN IRON & STEEL INDUSTRY

As in other process industries, other aspects of control in the iron and steel industry being considered are only in the very formative stages. In Great Britain an installation is presently under way in which not only the process is under the direction of computers, but several in-line processes are also tied together through what, at present, must be considered fairly loose control links. In this installation, control is extended to include process control, and the regulation of information between process, such as product specification and product and machinery requirements.

The use of computers in data processing, production planning, and decision making is quite common. The industry can look forward to the day when these functions will be combined with the process control functions. Production planning scheduling, customer orders, and production orders will all be coordinated to the actual process operation and process machinery. This coordination constitutes a form of multilevel control that will take into account the overall system economics in planning company wide objectives, as well as the individual process requirements.

Extensive efforts are being made by the iron and steel industry through research, development, and application to continually improve its position. In the area of process control, or overall plant control, these efforts are demonstrated by the examples that have been given. However, much remains to be done. A great deal of effort is still required in the area of developing new means for process measurements. Process control equipment is readily available, ranging from individual analog controllers through large scale digital control computers. However, such equipments must be tested under actual operating conditions. One of the most promising avenues though, for increasing the level of process control comes from the chemical, metallurgical and

process research presently under way. The development of more intensive knowledge of processing functions makes practical many computer type predictive controls that seem, at present, to be most needed for the industry.

In the following presentation, we will be discussing future improvements and advancements in the control techniques of various departments

THE COKING DEPARTMENT

Consider the idealised plant of the future and begin in the conventional iron and steel way with the coke ovens. Very little automation, in any sense whatever, of coke ovens proper (i.e. excluding by-product plant) has been attempted since approximately 1926, though one or two plants are equipped for pre-drying of coal and some experimentation is being carried out on "formed" coke. The product of the coke ovens today is neither very uniform nor is it in the form the blast furnace requires, nor is the operation in any way continuous. Unless somebody can invent a continuous coke oven with a higher output per man-hour, lower capital cost per ton, and a closer size range, it seems inevitable that the pressure will be for developing means of injecting other fuels at an increasing rate. It is, however, worthwhile to consider to what extent the present-day coke oven can be automated in the sense of producing a more uniform product, if not perhaps in other ways. Blast furnace practice is always improved if the fuel charged is reactive, uniform in size, low in ash, low in sulphur, with a uniform moisture content. A few coke ovens in the world are equipped with coal preparation plant which, by bedding techniques, produce absolutely consistent coal analysis supplied to the ovens. The extension of this practice would seem far more worthwhile than applying computers to the problem of blending large numbers of wagons of coal of varying sources and analysis at the tippler.

Examination of the coke ovens of today does not lead one to suppose that there will be any major change in which the whole of the oven practice is altered. Nevertheless, it is possible that electronic data processing could be used to decide whether a coal-buying programme would not be better devised employing coals hauled from a distance which were cheap, consistent in quality but perhaps slightly lower in coking index, blended with others of much higher coking index, more expensive, but perhaps more local.

THE SLABMAKING DEPARTMENT:

It seems likely that many slabbing mills will continue to exist for years to come, but a comprehensive study is required before it can be decided whether it would pay to design a complex computer control. As yet, no-one has linked a production control computer to even a programme-controlled slabbing mill, although, since this seems to be one of the simpler jobs to attempt, perhaps start might be made.

A true on-line computer designed to take full advantage of the capabilities of a slabbing mill would be a more complex device and should yield higher outputs together with better quality. Such a computer would measure the temperature and hot strength of the steel from the roll force, or torque, required at the second pass, to avoid misleading readings caused by pipe on the first, and select the best rolling programme to fit the quality of the steel, the dimensions required, and the hot strength of the steel. It would, in addition, be designed to reverse the moment the roll force, or torque, fell off as the piece was issuing from the mill, and would thus be anticipating in the same way that a good driver already does on a slabbing mill.

THE HOT STRIP MILL:

The coupling together of the hot mill production-control automatic data processing with an on-line computer has not yet been attempted in any plant in the world. Nevertheless, it obviously remains the dream of the future, and with more and more mills being fitted with on-line computer control, no doubt attempts will soon be made to achieve this,

including the printing out of what is actually rolled compared with what was originally intended, when in scheduling the hot mill production-control computer, such problems as cobbles and unexpected roll changing have been surmounted.

THE STEEL MAKING DEPARTMENT:

The capital cost of replacing open hearths factories by L.D. vessels would be greater than the saving that would result.

Nevertheless, the industry must ceaselessly watch the point at which the replacement of some of its older steelmaking plant by modern plant of large capacity will pay, even in spite of fresh capital expenditure. It is understood that in America, as yet, no modern open-hearth plant is being scrapped in favour of large L.D., although open-hearth plants built some years ago with furnaces of around 180 tons are being replaced by L.D.

The overall scrap/pig-iron ratio of all the plants today is approximately 34 scrap: 66 pig. The improved yields in a fully automated L.D. plant would result in less mill scrap being available, so that the inability of the L.D. plant to use more than about 30 per cent. of scrap would be no severe handicap. There is also the possibility that the use of fuel oxygen guns in L.D. converters may be extended to the point where the scrap percentage on an L.D. vessel could be increased.

One of the major points in the fully automated plant would be the consistency of yield from ingoing product, consistency of performance, and consistency of outgoing product. One would attempt to have the pig-iron analysis contained within very close limits indeed. An on-line computer controlling the pig-iron analysis would be most valuable to the steel plants. The careful preparation of scrap so that the alloy content of every charge was the same would also be a fundamental part of the process. Data logging, with large-scale display operator guides, is already in operation on some large L.D. plants but total control of the L.D. processes has yet to be perfected. Once again, the sensing devices,

in the shape of weighing and temperature, are unreliable. Studying the problem of full-scale automation of any steelworks shows how vital it is that this problem of weighing and recording the weights be accurately mastered. A brief description of this fully automated L.D. plant would be as follows: the hot metal would arrive from blast furnaces on a short direct track in what might be described as a mobile mixer. A computer would be used to determine the weight for each charge, the weight of scrap and pig-iron to achieve the maximum yield of full-length ingots of the size required if a slabbing mill is still in use. The computer, having calculated the required charge, would then calculate the flux additions, the quantity of oxygen to be blown, the rate at which it was to be blown and the height of the lances above the charge, all based on the weight analysis of the charge and the final analysis required.

The computer control of charge weights and teeming temperature will result in less skull, but ends, and other pit scrap. Thus the yield from scrap and pig-iron to prime ingot may well increase by 4 per cent. over present-day practice. Similarly, the use of refractories is estimated at an average of 40 lb. per ton of ingot in the flat product works of today. This would decrease to 6 lb. per ton of ingot and these refractories might be much cheaper than those now used.

The fuel oil used today averages approximately 20 gallons per ton of ingots. As far as steelmaking is concerned, this would decrease to practically nil, although there will undoubtedly be a big increase in the amount used in ironmaking. The oxygen used today is approximately 1,200 cu. ft. per ton of ingot, and this will rise to, say, 2,000 cu.ft. per ton; owing to the immense bulk of the oxygen plants, however, together with a big reduction in waste oxygen, the cost per ton of ingots will probably be no more. In addition, low-purity oxygen will be required to enable 3 cwt. of oil to be injected per ton of pig-iron.

The percentage of cast within the limits specified today will very nearly be 100 per cent., but with such a fully automated plant it is probable that the tolerance will be closed in the interests of providing even closer analysis specifications for the customer.

THE BLAST FURNACE

The blast furnace of the future will be more successful if more attention is paid to burden preparation uniformity by computerised bedding techniques before materials arrive at the charging point than to an on-line computer to achieve uniformity through many belts and bunkers.