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INDIA

Technical report: Current Trends in Process Automation of Continuous Casting Machines in the Steel Industry*

Prepared for the Government of India by the
United Nations Industrial Development Organization,
acting as executing agency for the United Nations Development Programme

Based on the work of Nicholas Rickard,
expert in Process Automation of Iron and Steel Manufacture

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United Nations Industrial Development Organization

Vienna

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[*] This document has not been edited.

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CURRENT TRENDS IN PROCESS AUTOMATION OF CONTINUOUS CASTING MACHINES IN THE STEEL INDUSTRY

ABSTRACT

The paper presented at the Modelling, Optimization and Process Control seminar describes recent trends in the automation and process control of the continuous casting process of steel slab manufacture. Methods of controlling the pouring process, mould level control, spray water control, slab cutoff, and data logging are discussed.

In addition to a description of the operating process, a discussion of Level One system hardware, software, and sensing devices is offered. Additionally, the interface of Level one systems with higher level supervisory control and Management Information Systems is explored.

The advantages of process automation of the continuing casting process in energy consumption, quality control, and yield savings is discussed. Examples of recent installations are discussed with predictions of future trends in casting technology. Extensive use of illustration will support the material presented in the paper.

SUMMARY OF OTHER CONSULTANT ACTIVITIES

In addition to the presentation of a paper at the conference, the expert was requested to travel to Bhilai Steel Plant and review progress in the Continuous Casting area. Several suggestions for improvement in operating practices were submitted at the last visit in March of 1989 and a review of progress attained was requested. Additionally, specifications for installation of process automation of mould level control and secondary spray water were reviewed.

Specific operating and maintenance comments were solicited and furnished by the expert to the Bhilai Steel Plant personnel. These comments regarded ladle shrouding, surface quality, and internal cracking.

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I. Description of Conference and Observations on Papers

The Seminar:

MODELLING OPTIMISATION AND ADVANCE
CONTROL TECHNIQUES FOR PROCESS PLANTS,

was held at the India International Centre in New Delhi. The attendance for the conference numbered in excess of 150 registrants. The two-day conference was devoted to papers describing efforts of modelling and process automation in the Fertilizer, Steel, and Cement industries.

The conference was sponsored by the Appropriate Automation Promotion Programme, a division of the Department of Electronics of the Indian Government. The Appropriate Automation Promotion Programme was established in order to promote the use of modern technologies such as Distributed Digital Control with the ultimate objective of bringing about a cultural transformation in the Indian industrial sector.

In the past several years the AAPP has sponsored numerous training programmes, workshops, and seminars such as MOS 89. These activities have generated considerable interest and application of new technologies such as Robotics, Expert systems, and process automation.

Following opening remarks by the Conference organizers, the first day included papers describing techniques in use at fertilizer plants. The afternoon session was the first of two sessions devoted to steel industry topics and included papers on Basic Oxygen Furnace modelling and Blast Furnace simulation.

Day two opened with a second session on steel related papers and concluded with a section on automation efforts in the cement industry. The paper topics were well selected for the group attending; a mixture of academia, industrial suppliers, and operating personnel.

The papers were universally of excellent quality, and described new advances in automation or computerization of industrial processes. Lengthy question and answer sessions followed each of the presentations and plans were announced to publish the questions and answers in a separate volume.

The logistics and preparations for the conference were excellent. All papers were pre-published and distributed to registrants prior to the conference. A listing of all papers presented is included in Appendix I of this report.

II. Description of Activities with AAPP in New Delhi

In addition to activities related to the Modelling, Optiuization, and Process Control seminar, the expert assisted the AAPP in the following activities:

A. Assistance was provided to the AAPP in the review of their request for purchase of a feasibility study for MIS applications at VIZAG and the Raurkela Steel Plant of S.A.I.L. This feasibility study will determine the optimum course of action for computer automation of management and production information systems at these plants.

An additional request for purchase was reviewed regarding feasibility study for process automation enhancement at the TATA Steel works in Jamshedpur. This feasibility study will determine the location and type of process automation to be added to TATA's operating units for improvements in yield, quality control, and productivity.

B A request was made of the expert (see letter from Varadan in Appendix III) to facilitate the visit to the United States of two Engineers from the Bhilai Steel Plant. This visit would e of 6 to 8 weeks duration and involve them in the computer activities of various industrial sectors, primarily steel plants.

The AAPP office has requested that I assist in the scheduling of these visits to the U.S. While I will make preliminary contacts of major plants, I cannot be responsible for a complete schedule. I will endeavor to place the AAOO in contact with a major Engineering firm who can fulfill their needs.

C A report to the AAPP on the visit to Bhilai Steel Plant was presented with recommendation as to further actions suggested for improvements to the continuous caster process.

D A discussion held with Bhilai Steel Plant regarding the establishment of a plant-wide capacity planning model was relayed to the AAPP. This model, capable of being developed internally at Bhilai, would allow planners to investigate the effects of equipment outages, change in product mix, and changes in heat sizes processed.

III Description of Visit to Bhilai Steel Plant

Departed New Delhi for Bhilai Steel Plant on Saturday, 2 December. Arrived in Bhilai and proceeded to Continuous Caster. Spent the afternoon with representatives of the operating, maintenance, and instrumentation sections discussing operations and planned improvements to continuous casting operations. Notes on observations include:

1. Operations on cast floor were much improved from my previous visit in March. The operations were being handled in a very professional manner and without undue movements. The housekeeping of the cast floor was extremely orderly.

2. Discussed current operating practices with cast floor personnel. Specific changes noted since March visit included the improved application of lubricant to the mould, the construction (scheduled

to be completed in several days) of a "roll-gap" measuring device, the completion of digital instrumentation of no.3 slab machine, and the initiation of trials utilizing a shroud to protect the ladle stream entering the tundish.

3. Reviewed the inputs and design characteristics of a planned secondary spray water control device. This device will require the conversion of all present analog controls to digital which is currently in progress. All aspects of the proposed secondary water plan seemed feasible, including inputs to the model, changes in zone control, and output variables.

4. Reviewed the design characteristics of a proposed mould level control device. This system would utilize an eddy-current device for steel level detection and generate a signal to speed up or retard steel flow from the tundish to the mould. The only drawback noted and reported to the Bhilai operators, was the continued reliance upon the present stopper rod mechanism for tundish pouring.

   Stopper rods have numerous mechanical linkages and, over a period of time, tend to become sloppy with resulting poor control of tundish stream. It was suggested that Bhilai investigate the current types of throttling slide gate devices available to see if any would fit their needs.

   An additional question was raised as to the desirability of automating the flow of steel from the ladle to the tundish. With the addition of tundish weigh cells and a scoreboard reporting weights, an operator will be able to do a good job of keeping the tundish level constant. The addition of this system would not result in the removal of labor since an operator is required to be positioned on the ladle platform in any case due to safety requirements.

5. Discussions were held the following Monday with operating management of the continuous caster to discuss the observations of Saturday and to review current quality items. Some suggestions given to the Bhilai operating personnel include:

   a. Investigate technique of chrome plating moulds for increased wear resistance and reduced withdrawal force.

   b. Change mould oscillation speed to make it proportional to caster line speed.

   c. Investigate using different mould power lubricants for steels of different carbon ranges.

   d. Improve the incidence of "free-opening" ladles at the caster in order to improve the effectiveness of ladle shrouding. Methods to improve "free-opening" were presented.

Additional meetings were held with the General Manager (maintenance and Services) and the Managing Director. At these meetings the expert's comments on his observations were given verbally and items of general steel plant design and operation were discussed.

APPENDIX I

CONFERENCE SCHEDULE

MOPS-89

Seminar on

Modelling Optimisation & Advance Control Techniques for Process Plants

1.	**Prof. K.P. Madhavan** *IIT, Bombay*	**Training Simulators & their applications in the Fertiliser Industry**
2.	**Mr. N.K. Jena &** **Mr. S. Venkatesan** *PDIL, New Delhi*	**Ammonia synthesis loop optimisation at Rourkela Fertilizer Plant**
3.	**Mr. P. Jayabal** *Madras Refineries Ltd.*	**Implementation of Modelling & Optimisation at MRL FCCU**
4.	**Dr. Brahma Deo** *IIT, Kanpur*	**Modelling of Basic Oxygen Furnace**
5.	**Prof. A. K. Lahiri** *IISc, Bangalore*	**Simulation models of Blast Furnace**
6.	**Mr. George Verkey** *ER&DC, Trivandrum*	**Process automation in steel melting shop—from static modelling to Expert Systems**
7.	**Dr. V.R. Radhakrishnan** *IIT, Kharagpur*	**Distributed Control System with set point supervision application in Integrated Steel Plants**
8.	**Mr. D.B.V. Sarma** *VSP, Vizag*	**Computerisation in VSP and Planning & Scheduling concepts of a Steel Rolling Mill**
9.	**Mr. Akhil Pandey** *TISCO, Jamshedpur*	**Information Systems Planning**
10.	**Mr. Nicholas Rickard** *USA*	**Current trends in process automation of Continous Casting machines in the Steel Industry**
11.	**Dr. K. Viswanathan** *Particle Tech. Consult. &* **Dr. K.C. Narang** *Dalmia Cement, New Delhi*	**Ball Mill Grinding system Simulation & Optimisation**
12.	**Dr. (Mrs.) H. Khurana** *DoE, New Delhi*	**Expert Systems in Process Control**

APPENDIX II

PUBLISHED COPY OF EXPERT'S PRESENTATION

MOPS-89

Current Trends in Process Automation of Continous Casting Machines in the Steel Industry

Presented at

Seminar on Modelling Optimisation
and Advanced Control Techniques
for Process Plants

NEW DELHI, 27-28 NOVEMBER 1989

Organised by

APPROPRIATE AUTOMATION PROMOTION PROGRAMME
DEPARTMENT OF ELECTRONICS
GOVERNMENT OF INDIA

Current Trends in Process Automation of Continuous Casting Machines in The Steel Industry

NICHOLAS RICKARD

PRINCIPAL

NICHOLAS L. RICKARD AND ASSOCIATES
UPLAND, CALIF.

1.0 INTRODUCTION

This paper describes recent trends in the automation and process control of the continuous casting process of steel slab manufacture. Methods of controlling the pouring process, mould level control, spray water control, slab cutoff, and data logging are discussed.

In addition to a description of the operating process, a discussion of Level One system hardware, software, and sensing devices is offered. Additionally, the interface of Level one systems with higher level supervisory control and Management Information Systems is explored.

The advantages of process automation of the continuing casting process in energy consumption, quality control, and yield savings is discussed. Examples of recent installations are discussed with predictions of future trends in casting technology. Extensive use of illustrations will support the material presented in the paper.

2.0 HISTORY OF CONTINUOUS CASTING AND PRESENT TRENDS

Since steel was first produced in liquid form it has been almost invariably the practice to cast it into rectangular blocks, from which the desired finished shape is obtained by subsequent hot or cold working. These blocks or ingots were originally very small in weight, but as the output of steelmaking furnaces increased, so have both the weight produced at each cast and the ingot weight; so that 15-ton or 30-ton ingots are now common practice. These ingots are rolled in primary mills to produce blooms or slabs which receive further processing.

This method of producing primary products is characterized by the following disadvantages:

- Large amounts of capital invested in moulds, stools, ingot buggy cars and locomotives.
- Additional capital invested in buildings and cranes needed for stripping the ingots and resetting the moulds on ingot cars, soaking pits for ingot heating, and primary mills for rolling ingots to slab shapes.
- Ingots are chemically segregated, a disadvantage in all steels. Hot tops are required for certain grades which necessitate large yield losses such as crops, with a consequent high loss as scrap. The larger the ingot, the more severe the segregation. Each ingot needs a discard to be removed at top and bottom after primary rolling.
- Large energy losses are incurred as the latent heat of liquid steel is allowed to escape during ingot solidification with subsequent energy usage to restore heat in the soaking pits prior to primary rolling.

Starting in the 1930's efforts were directed to perfecting a method of continuously casting steel in to a semi-finished shape. The early work resulted in the development of continuous billet casting machines producing material for rolling into bar and rod products. The problems of casting large slab shapes proved more difficult to master due to the problems of supporting a large shell and preventing a breakout of the liquid steel.

The technical problems were eventually solved and with the first commercial production of cast slabs in the 1960's, continuous casting now produces a majority of all semi-finished steel production in the world. Cast slab sizes now range from 18 to 30 cm. in thickness and up to 270 cm. in thickness. Currently, efforts are underway to produce cast slabs as thin as 3 to 4 cm. in order to further improve the energy and operating savings resulting from elimination of some of the downstream operations. More information will be delivered on these efforts later in this presentation.

3.0 DESCRIPTION OF THE CONTINUOUS CASTING PROCESS

The basic process of continuous casting is the forming of a rectangular shape by pouring liquid steel into a mould and causing the outer periphery of the shape to freeze solid. The slab section, composed of a liquid center and a solid outer wall, is then slowly and continuously withdrawn from the mould and supported while the center section is allowed to solidify under controlled conditions.

Typically, continuous casting machines contain the following elements necessary to slab production:

- **Ladle** - A large vessel containing liquid steel poured from a steelmaking furnace and transported to the casting machine. Before casting, the steel in the ladle is frequently stirred to promote thermal homogeneity and additives such as aluminium are added to promote final chemistry.
- **Tundish** - an intermediate vessel used to contain the steel poured from the ladle and, in turn, provide steel poured to the mold. The purpose of the tundish is to "cushion" the ferrostatic force of steel poured from the ladle and also to provide a "residence time" to allow impurities to float to the surface in the tundish before the steel enters the mould.
- **Mould** - a rectangular open ended box (or square for billets) consisting of a copper face backed up by steel supports containing passages for water cooling. Moulds for slab machines are usually constructed of separate plates for the broad and narrow faces and can be adjusted for different slab widths. During casting the mould continually oscillates to prevent sticking of the steel cast shell to the mould wall.

Moulds are constructed either straight or with a curvature equalling the radius of the containment strand depending upon manufacturer's design.

- **Containment Strand** - a series of support guides and rollers whose function is to guide and contain the product from its formative period in the upper spray zones until it is completely solidified and discharged horizontally.
- **Torch Cut-off** - One or more gas cutting torches which separate the cast slab into desired lengths. Typically these torches ride on a machine which travels at the same speed as the cast slab.
- **Starter Bar** - a chain-type device of the same thickness as the desired cast slab which facilitates the start of the casting process. The Starter Bar head receives the

initial pour of molten metal from the tundish and withdraws the strand through the containment section.

4.0 PROCESS AUTOMATION IN STEEL PREPARATION AND POURING

Prior to being transported to the casting machine, a ladle of steel usually is placed at a facility termed a "trim" station. Here the temperature of the steel is taken and, if too hot, is cooled by use of scrap additives or cooling slabs. Chemistry analysis is also taken and necessary adjustments (usually to aluminum or carbon) are performed. Additionally, stirring of the steel through the bubbling of an inert gas is accomplished in order to give homogeneity to the temperature of the steel in the ladle.

Steel temperatures which are too cold at furnace tapping, or which have become cold due to delay, are increased by the use of an electrode similar to that found in electric melting furnaces. The finished temperature of the steel in the ladle is extremely important to the casting process and is typically controlled within plus or minus 5 degrees F.

Temperature and chemical analysis results are typically entered by direct sensor reading to the heat data log and are immediately available to the caster operators. Time spent at the trim station is also captured as part of the process log.

Slab casting machines normally are equipped with machines which allow the placement of two ladles adjacent to the casting process. One ladle is in the pouring position, while the next ladle is capable of being moved into position quickly, facilitating the continuous casting of multiple ladles. Frequently the machines holding the ladles are equipped with load cells for displaying the initial weight of steel in the ladle as well as continuously monitoring the remaining amount during casting. These weights can be integrated with casting speed to predict the amount of time (or cast feet) remaining in the ladle being poured.

Tundishes are similarly equipped with load cells to display the amount of steel in the tundish during the casting process. Since most tundishes are covered to minimize re-oxidation, this feature allows the operators to monitor remaining steel in the tundish; a feature which is essential at a ladle change when the flow of steel to the tundish is interrupted.

The temperature of steel in the tundish is obtained frequently throughout the cast using hand-held temperature probes. If cooling of the steel is observed in the tundish, the cast speed is normally increased in order to put more hot steel from the ladle into the tundish. This can only be accomplished up to certain limits, however, and if the steel continues cold, the cast must be terminated. Tundish temperatures and weights are recorded on the cast data log and form a significant record for quality control.

The balancing of liquid steel flow from ladle to tundish to mould must be carefully integrated with the casting or slab withdrawal speed. Additionally, it is extremely important from a quality standpoint, that the level of steel in the mould be a constant level throughout the cast. Two general philosophies of process automation are employed by different casters to accomplish this task. Both techniques utilize a sensing device to measure the level of liquid steel in the mould on a continuous basis. Radiation sensors (Gamma or Beta), eddy current sensing, or thermocouples buried in the copper walls of the mould are some of the more common sensing devices. Their output is signaled to a processor for integration with other inputs.

In the first philosophy of pouring control, a fixed orifice in the tundish (slide gate) allows a constant amount of steel to enter the mould. The line speed is set manually to match this liquid steel input and keep a constant mould level. Should variations in steel entry to the mould occur (due to wearing of the orifice or changes in the tundish ferrostatic head) the line speed is automatically adjusted by a signal from the mould level sensing device in order to keep the liquid level in the mould constant. If these variations allow a line speed that is too slow or fast, a different orifice size is inserted into the tundish, and the flow and line speed are again balanced.

The second philosophy of pouring control also utilizes a mould level sensing device but directs it's output signal to a variable orifice device in the tundish (stopper rod) which controls steel input to the mould in order to maintain a constant level. The line speed is completely independent of the control loop and is set manually by the operator. Obviously, whatever line speed is set will act as an in- lieu of set point for steel flow and tundish orifice opening.

Both of these philosophies have their proponents and both will produce a quality cast slab superior to machines equipped with no process automation of the pouring process. One of the determining factors of selection of type is that the variable orifice (stopper rod) mechanism is generally limited to casts of three to five heats (dependent upon steel chemistry) due to the erosion of the stopper rod and the inability of replacement while casting. Some machines overcome this drawback by replacing the entire tundish (with a new stopper rod mechanism) while the cast is progressing.

It is extremely important for purposes of quality control and engineering records, that all variables of the pouring process be recorded. Such items as temperatures, ladle weights, tundish weights, mould level, tundish orifice size, and line speed should be recorded against an index of slab footage produced. This allows for future investigation of quality or machine anomalies and aids greatly in their remediation.

5.0 PROCESS AUTOMATION IN THE STEEL SOLIDIFICATION MECHANISM

The mechanism of slab solidification is accomplished in two separate stages; through primary cooling in the mould and secondary cooling by means of spray water in the containment section. Primary cooling will normally provide a shell thickness of three to five centimeters when the slab exits from the bottom of the mould. Complete solidification by means of heat loss through spray water will take place approximately 20 metres beyond the mould dependent upon withdrawal speed.

Primary cooling takes place by introducing large volumes of water into passages of the copper mould support structure opposite to the mould face containing the liquid steel. Water flows of approximately 15,000 liters/min are normally distributed through the passages behind the four faces of the mould. Normally this water is contained within a closed system and is cooled by external heat exchangers. Control valves to adjust the flow to each mould face are utilized and magnetic flowmeters indicate and record the flows throughout a cast.

Both inlet (to the mould) and outlet temperatures are indicated and recorded for each mould face and the differential (Delta T) is used as an indicator of mould cooling efficiency. Pressure measurements in both the supply and discharge lines provide, along with the Delta T measurements, an early warning system for any catastrophic mould cooling system failure.

Secondary cooling of the cast slab normally accounts for about 75% of the solidification and is accomplished by water spray nozzles directed upon the cast slab between openings in the support rollers of the containment section. The purpose of the secondary sprays is to create a gradually decreasing slab surface temperature while allowing complete solidification to occur. The surface temperature of the product in the secondary cooling zone is an important process variable and is controlled to:

- Ensure that solidification is always completed within the containment section at the maximum design casting speed.
- Minimize the risk of breakouts due to excessive surface temperatures, particularly in the location directly below the mould.
- Ensure product cooling rates consistent with obtaining satisfactory product quality.

An auxiliary function of the secondary cooling system is to provide the necessary cooling of guide rolls that make up the containment section.

Typically the containment section will be divided into several zones of secondary cooling, with individual controls for each zone. The greatest amount of nozzles and spray water will be located in the section directly below the mould, with the nozzle amount and flows decreasing down the strand. Minimal process automation would normally consist of set-point controllers for each sector (normally 8 to 12) which would allow the desired volume and pressures to be maintained. This method has the disadvantage of not being reactive to changes in the casting process and usually is only a back-up mode to a computer operated supervisory control.

In the computer operated mode, various inputs of the casting process are integrated including:

- Tundish Temperature
- Mould Temperature
- Slab Temperature (several points from pyrometers)
- Grade of Steel Cast
- Line Speed
- Mould Cooling (Delta T's)
- Incoming Spray Water Temperature

From these inputs a supervisory model calculates and controls the actual spray water pressures and amounts to each sector. All variables are recorded upon the cast data log for later analysis if desired.

Computer controlled spray models are an essential to quality casting and form the basis of a newly emerging technique in quality control; that of inspector-less caster production. In this technique, now being adopted by several American and Japanese producers, cast logs are scrutinized for any abnormalities in the process. Such conditions as low tundish weight, acceleration or deceleration of the casting speed, use of oxygen in the tundish or mould, and out-of- specification temperatures or water flows are noted. When such conditions exist, the portions of the strand exiting the mould at that point in time are directed for further inspection. All other slabs are shipped directly to the next unit without inspection, relying upon the past history of proper engineering units to guarantee proper quality. This concept, while saving manpower and time, requires a dedication to data recording of the process engineering and operating variables.

6.0 PROCESS AUTOMATION IN SLAB CONTAINMENT

As the cast strand exits the mould bottom in the secondary cooling zone, it loses the mechanical support of the mould, yet the shell formed in the mould is too weak to support the liquid core by itself. Thus, the containment section below the mould provides this needed support. It consists of idler and drive rolls, sized and spaced to give as much casting support as possible and also to allow room for sufficient spray water cooling to increase the shell thickness. The further the shell is from the bottom of the mould, the less containment is required because the shell is thicker and stronger. Therefore, the support rolls grow larger in diameter and are more widely spaced further down the containment section.

It is extremely important that the gap opening of the various roll clusters in the containment section be set and maintained to exact standards. If the roll gap is too small, the solidifying slab shell will be "rolled" resulting in undesirable line stresses and possibly leading to cracking of the slab shell and loss of containment of the liquid core (i.e., a breakout). Correspondingly, a roll gap too large will allow the shell to expand to the detriment of internal slab quality.

Many modern casters monitor the pressures exerted against the roll clusters by utilizing load cells contained within the roll housings. These load cells will, by measuring the outward component of the ferrostatic pressure exerted by the column of liquid steel in the shell, display any abnormalities resulting from improper roll gap spacing. They also serve the function of indicating the point in the containment section where complete solidification is achieved.

In the past, proper setting of the roll gaps in the containment roll clusters required a considerable amount of downtime. Special curved templates were inserted into each roll gap and measurements made of the actual setting. Adjustments were then made and the process repeated for the next roll cluster. This time has been cut down considerably through the use of a device called a "roll gap sled" which measures all gaps and alignments in a single pass through the line.

The device, consisting of air-operated micrometer devices and an integral inclinometer, is connected to the head end of the starter bar. Connections are made between the device and a computer model for it's operation. As the "roll gap sled" is passed through the line the computer records the position of the device, the gaps between rolls that it measures, and the actual angle of the roll cluster to horizontal. These measurements are compared to established standards, and a printout is issued which details the corrective action to be taken to return the containment section to original standards. This device is credited with saving many man-hours in verifying an important component of slab caster quality.

7.0 PROCESS AUTOMATION IN HEAT SCHEDULING AND PRODUCTION REPORTING

Heat building and scheduling of continuous casters is normally done with the aid of a computer, operated and controlled by the Production Planning section. The heat schedule for the furnaces and the continuous casters is made available through CRT's in the operating stations. This system keeps track of heats of steel as they are tapped from [illegible] furnace and subsequently cast.

To facilitate instantaneous decision making and changes, direct telephone "hot lines" are provided in the Furnace and Caster operating stations that link them with production planning. If the Furnace has problems with a particular chemistry, consultation with Production Planning takes place and a new heat is chosen. All stations on the system are immediately updated on the schedule change. Similarly, if the Caster has problems with the machine or any equipment, they inform Production Planning over the "hot line" and the Caster schedule can be revised accordingly.

The torch cut-off station of the continuous caster receives a schedule of slab sizes to cut based upon order requirements. In some systems, once the cast is completed (cap-off) and the remaining slab length accurately known, a computer subsystem calculates the slab lengths to cut in order to maximize yield in the cast slab. The revised cutting schedule is displayed in the torch cut-off operating station.

Measurement of the cast slab cut length is normally accomplished by an integral slab tracking device which, after reading the computer or manually generated cut length order, engages the cutting torch machine and severs the slab to the desired length. System accuracies of plus or minus 2 cm. are typical.

Identification of cast slabs can be accomplished utilizing a variety of types of steel stamping devices. Some of the most modern utilize a computer generated identification number which is transmitted to either a rolling or an impact type die stamper. Both the heat number and individual slab number are recorded. While these systems are quite reliable, a second identification mark, manually applied, is frequently used in order to eliminate downstream problems resulting from mixed steel grades.

Transmission of production data including heat number, cast width, number and length of slabs cut, and inspection data are relayed by computer keyboard directly to the production planning section. Disposition of cast slabs are thus immediately made to scheduled orders for further rolling. Attempts are currently being made to transfer hot slabs directly from the slab caster to the rolling mills in order to conserve the latent heat in the cast slab. Insulated conveyance devices are utilized for this purpose.

8.0 DESIGN AND FUNCTIONS OF PROCESS CONTROL AND COMPUTER SYSTEMS

Process control on modern continuous casters typically utilizes digitalized distributed control systems incorporating CRT's and keyboards to control and display process information. The control loops are configured in the software and can be changed quite easily through the keyboard. These types of systems do away with multitudes of hard-wired relay panels, controllers, and other devices. They also have the capability of communicating with other process control systems.

A level One distributed control system for modern continuous casters includes field sensors to capture all necessary process information. Normally their analog signal is processed through Input/Output interface units and directed to a programmable logic controller. The resultant digitalized signals are transmitted to a data highway for use at adjacent process controllers or displayed at operator or engineering work stations and recorded in operations, trending, and alarm logs.

A typical distributed control system would include an operating station with two or three CRT's. These CRT's are used to display the process information which is being controlled or simply monitored for use by the operators. One CRT is generally dedicated to monitoring process deviations (alarms) while the others can be switched to display parameters of current interest.

The hardware of the controllers and its *microprocessors* is mounted in cabinets generally located in or near the electrical control room. Normal hardware includes controllers, data entry panel, miscellaneous auxiliaries, and a battery back-up for system protection in case of electrical power failure.

The primary control system on a continuous caster is normally the secondary spray water loop which normally contains up to four zones and 10 to 15 separate controller units. In addition control loops may exist for mould level control, tundish weight, and slab cut-off.

In addition to these control loops, numerous process variables are monitored and recorded for purposes of alarm notification and later analysis. Some of these functions include:

Spray Nozzle Pressures
Spray Water Supply Pressure
Mould Water Flows
Spray Water supply Temp.
Spray Water Ph
Mould Water Delta T's

Mould Water Pressures
Strainer Back Pressures
Mould Liquid Level
Line Speed
Drive Loads
Ladle Weight
Load Cell Values
Spray Chamber Fan
Strand Hydraulic Pressures
Expansion Tank Level
Mould Water Ph
Mould Level Sensor Outputs
Mould Oscillator Speed
Drive Pressures
Tundish Weight
Roll Gap Sled Values
Slab Surface Temp.
Hydraulic Temp.

A very important function served by a a distributed control system is that of process alarms. Process variable deviations beyond previously set alarm limits (either on an absolute value or deviation basis) are displayed and sounded for operator information and correction.

One important function of data logging in continuous casting is the use of the cast data for evaluation and improvement of cast slab quality. Most caster process control data logging systems record process variables in both a real-time basis and indexed by cast slab length. With this index system, process excursions can be evaluated by their effect upon slab quality. Changes in line speed, mould level, tundish weight, spray water practice, etc. can be pinpointed to specific slab imperfections.

Additionally, with the use of load cells in the slab containment section, internal quality can be predicted while the cast is in- process. Abnormal open or closed roll gaps will show in the finished slab as disturbances in the internal solidification pattern.

This analysis of the relationship between process deviations and resultant slab quality can be extended, over a period of investigation, into a predictive quality control system. This system, now being utilized by some U.S. and Japanese casting machines, utilizes data logging of process variables to predict the resultant quality of each unit of the cast slab. Slabs predicted to be of satisfactory quality are directed immediately to downstream units. Those slabs deemed to require corrective action are sent to conditioning locations for remediation.

Level Two control of the continuous casting process utilizes supervisory computers for integration of mathematical models as set point initiators. These supervisor computers also perform the function of compiling data transmitted by process control devices, heat scheduling systems, production reporting systems, and quality control inputs. Additionally, these Level Two devices are used to communicate with a plantwide Management Information System and supply data required for production administration.

In summary, modern continuous casting facilities are aided greatly in their operation by intelligent usage of process control devices and supervisory computers. Control of functions of continuous casting such as mould level, line speed, slab cooling, and slab cut-off are better performed than with traditional manual methods. These improvements typically lead to increased yield due to improved operating practices, decreased energy consumption attributed to closer control of heating processes, and lower operating cost resulting from a greater percentage of prime product ready for further processing.

9.0 FUTURE OF CASTING PROCESS TECHNOLOGY

New developments in casting technology are occurring at an extremely rapid pace. As the technology of continuous casting has passed it's infancy, numerous improvements and process modifications are being developed or conjectured. Some of these developments include:

- Predictive Quality Control. As indicated earlier in this paper, extensive use of data logging of process variables is enabling manufacturers to predict slab quality based upon casting practice. This allows the shipment of approved slabs directly to their next destination without further inspection or conditioning.
- Reduced Section Casting (Thin Casters). A newly emerging technology is allowing the casting of wide product in extremely thin sections, nominally 3 to 8 Cm. These sections can be rolled directly in finishing stands of Hot Strip Mills without the use of continuous or reversing roughers for slab thickness reduction. A further advent will be the physical connection of thin section casters to rolling mills in order to minimize the energy loss required in re-heating the product.
- Continuous Steelmaking. This technology, still very much in the development stage, would use processes of manufacturing steel in a continuous mode, rather than the present batch manner. If this can be accomplished, the resultant product can be fed directly to casting machines as it is made.
- Variable Width Casting. Technology is currently available to vary the width of the cast slab as the slab is being produced. This enables the caster to satisfy small order quantities without yield loss required in cutting slab sizes to fit.
- Fully Automated ("Hands Off") continuous casting. Some casting machines are presently operated in a completely automated mode. Process control regulates ladle and tundish pouring rate, mould level control, line speed, and torch cut-off activities without operator intervention. In addition to superior slab quality, some of these casting machines have set records by operating continuously for 160 hours or more, producing over 30,000 tons in a single cast.

APPENDIX III

COPY OF G.S. VARADAN'S LETTER REQUESTING UNDP ASSISTANCE IN ARRANGING A VISITATION TO THE U.S.

भारत सरकार
GOVERNMENT OF INDIA
इलेक्ट्रॉनिकी विभाग
DEPARTMENT OF ELECTRONICS
लोक नायक भवन, (तीसरी मंजिल)
LOK NAYAK BHAVAN, (3rd Floor)
खान मार्केट, KHAN MARKET,
नई दिल्ली/NEW DELHI-110003
TLX. Nos. 31-65108 & 31-66536
Gram : DEPTELECTRON

G.S.VARADAN
ADDITIONAL DIRECTOR.
TELE.NO 362811

अ॰शा॰ पत्र सं॰.............

D.O. No..................

December 6, 1989..................

DATED..........................

Dear Mr. Rickard,

Thank you very much for accepting our invitation to visit India as a consultant through our UNDP Assisted Project, Appropriate Automation Promotion Programme. Your presentation during the Seminar on Modelling & Optimisation particularly on the subject of applying computer control for the continuous Casting Machine was highly appreciated by the participants of the Seminar who were largly drawn from the steel industry. We also appreciate your visit and valuable suggestions made at the Bhilai Steel Plant.

We are proposing to depute 2 engineers from the Bhilai Plant on a training fellowship to USA for a period of 6 to 8 weeks. This visit is aimed at exposing our engineers to the Steel Industry and other computer installations so that they can obtain first hand information on the same. In this connection, I would greatly appreciate if you could arrange for the visit of the 2 engineers to some of the leading industries. You may kindly note that as this visit is being sponsored by the UNIDO Vienna, there will be no financial commitment on the part of the US Organisation who they would visit. It is also oposed to organise this visit during Feb.-April,1990. As you are well aware of the Indian situation and the needs of the Indian Steel Industry, I am seeking this help from you.

With kind regards,

Yours sincerely,

gs Varadan

(G.S.VARADAN)

Mr. Nicholas Rickard
UNDP Consultant
USA

APPENDIX IV

ITINERARY OF UNDP CONSULTANT

THUR	11/23/89	DEPART UPLAND CALIFORNIA, USA
FRI	11/24/89	ENROUTE
SUT	11/25/89	ARRIVE NEW DELHI INDIA IN AM MEET WITH AAPP IN PM
SUN	11/26/89	AT REST
MON	11/27/89	ATTEND MOS SEMINAR - INDIA INT'L CENTRE
TUES	11/28/89	PRESENT PAPER AT MOS SEMINAR
WED	11/29/89	AT AAPP OFFICES
THUR	11/30/89	AT AAPP OFFICES
FRI	12/01/89	AT AAPP OFFICES
SAT	12/02/89	TRAVEL TO BHILAI STEEL PLANT IN AM TOUR CONTINUOUS CASTERS IN PM
SUN	12/03/89	AT REST
MON	12/04/89	MEET WITH BHILAI STEEL PLANT PERSONNEL TO DISCUSS PLAN FOR MODIFATIONS TO CASTERS
TUES	12/05/89	RETURN TO NEW DELHI. MEET WITH AAPP
WED	12/06/89	CLOSING CONF. WITH AAPP DEPART NEW DELHI FOR LOS ANGELES
THUR	12/07/89	ARRIVE UPLAND CALIFORNIA, USA