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

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VOEST - ALPINE INDUSTRIEANLAGENBAU
Ges.m.b.H.
Linz / Austria

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Department of Process Automation

STUDY - Computer Applications in Iron and Steel Industry

UNIDO

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Consultant: Alfred KROPF
Backstop Off: Mr. Kroulek, IO/IIS/MET

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1. INTRODUCTION

VOEST ALPINE INDUSTRIEANLAGENBAU prepared this study for UNIDO to show the application of industrial automation to Iron and Steel Industry.

Industrial automation is a necessary precondition for introduction of new advanced technologies and materials.

Computerized production - process control, quality control, production control, production planning, integrated information system, etc. - is a must for competitive advanced technology products.

Therefore the demand of developing countries for industrial automation and computer applications is forthcoming.

The study covers the main fields of computer applications for integrated automation systems of metallurgical industries, i.e. process optimization, production control and production planning.

This study should help to transmit results of industrial automation achieved in advanced developed industrialized countries to developing countries.

1.1. Motivation for Automation

The general development of the iron and steel market from a producer's market into a buyer's market calls for a reduction of production costs and optimal utilization of production facilities.

This involves a technical and technological rationalization of the production processes and a reorganization of administration and organization.

The respond to this demand was the development of complex automation systems for control and optimization of metallurgical processes.

Therefore the reasons of applications of computers for the automation of industrial processes are strong economical requirements. The economics are very attractive.

The benefits of industrial automation to Iron and Steel Industry are mainly:

- improved product quality
- improved productivity
- increased production (throughput)
- increased yield
- increased raw material utilization
- increased plant availability
- decreased specific energy consumption
- decreased specific utility consumption
- reduced manpower and personnal costs

Complex automation systems are distributed and hierarchically structured.

It is used to structure the automation system into logical levels of automation.

These levels are:

level 1: basic automation
level 2: production automation
level 3: production control
level 4: production planning
level 5: management information system

Precondition for successful operation of a higher level of automation is proper function of all subordinated levels of automation.

Therefore implementation of high level automation is only efficient, if all lower levels are realized.

The savings by a certain automation system depend on the level of automation.

Large savings can be obtained by lower level automation due to improvements of main production processes.

The typical return of investment period for lower level automation systems is in the range of one to three years.

For higher level automation the sources of savings are an accumulation of many minor contributions, a fraction of a percent here, a fraction of a percent there ....

The typical return of investment period for high level automation systems is two to five years.

But with higher level of automation the management gets more and more reliable information from the plant.

The possibility of unsuccessful management decisions due to little or unreliable information will be decreased.

1.2. Automation System Architecture

Integrated automation systems are very complex, hierarchically structured and distributed.

They may consist of several computers or computer systems, a large amount of distributed control systems and a lot of related subsystems.

To cope with their complexity the automation functions have not only to be identified but also to be clearly structured and appropriately distributed in an automation system.

For a clear structure, the functions are divided into logical levels and within the levels into logical groups.

1.2.1. Level 1 - Process Control Basic Automation (Instrumentation and Control)

Level 1 comprises functions which are usually performed by programmable logical controls (PLC), microprocessors and instrumentation systems. The hardware performing level 1 functions is called distributed control system (DCS). All contacts, sensors, actuators,etc.are connected to level 1 hardware.

Functions of level 1 are:

- direct acquisition of on-line data (measured values, status of contacts, etc.)
- direct output of setpoints
- sequencing
- direct control
- interlocking
- change of mode of operation

With level 1 functions each partial process can be controlled. Production with level 1 automation system only is possible. In this case all higher level functions must be performed by operators, if possible.

Typical for level 1 is signal processing (sensors, contacts, actuators, etc.). Response times are few milliseconds to seconds.

Level 1 is connected to level 2 via serial interface and/or via data highway.

1.2.2. Level 2 - Process Optimization Production Automation (Process Optimization and Control)

Level 2 comprises functions for which process computers are used.

These computers coordinate and control production units like sinter plant, LD-plant, ladle metallurgy, continuous casters, etc.

They are linked to the corresponding level 1 systems. They are connected to each other to perform transmission of information and acknowledgement of results between production units.

Functions of level 2 are:

- process monitoring
- process models
- coordination of partial processes
- recipe management
- operator guidance
- data gathering
- short range data storage
- quality control

With level 2 functions each production unit (i.e. LD-plant) can be operated autonomously.

Typical for level 2 is information (and not signal) processing.

Level 2 is connected to level 1, to other level 2 computers and to level 3 computers via serial interfaces and/or via data highway.

1.2.3. Level 3 - Production Control
Production Automation
(Production and Quality Control)

In many cases the optimization of the individual production units or processes is insufficient.

An optimization of the entire plant is required. This calls for planning and coordination of all individual production units or processes. Level 3 systems are performing these tasks.

They are concerned with coordination of all processes in one plant, scheduling, production control, quality control and control of operation sequence.

Generally are these functions superimposed to several level 2 systems of one plant.

Functions of level 3 are:

- entry of production orders
- scheduling
- mill pacing
- control of material flow
- control of production
- quality control
- operation sequence control
- determination of production conditions (process and product parameters)
- medium range data storage

Level 1 through level 3 systems are real time oriented. Response times and/or updates are in the order of magnitude of milliseconds to minutes.

Level 3 systems are information oriented.

Level 3 is connected to level 2 and level 4 via serial interface and/or via data highway.

1.2.4. Level 4 - Production Planning
Production Planning System
(Production and Quality Planning)

Level 4 comprises long range planning as well as superoriented task.

Functions of level 4 are:

- entry of customer orders
- generation of production orders
- long range planning
- planning of plant utilization
- generation of production plans
- definition of lots
- long range data storage
- evaluation of production data
- statistics
- quality control

Level 4 system is transaction oriented and response times are not critical (few minutes to hours).

Level 4 is connected to level 3 and to level 5 via serial interface and/or via data highway.

1.2.5. Level 5 - Management Information Management Information and Planning System (Business Computer)

Level 5 comprises relevant information from procurement, operation, sales, controlling etc. and strategic planning.

Functions of level 5 are:

- strategic planning
- optimization models (economic)
- final data storage
- statistics

Level 5 system is a transaction oriented and response times are not critical (few minutes to days).

Level 5 is connected to level 4 via serial interface or via data highway.

2. FUNCTIONAL DESCRIPTION

The following major functional areas and their main functions are briefly described:

- production planning,
- production control and
- production optimization.

As examples for production optimization systems, production automation systems for the main production processes of iron and steel industry are described. The following plant automation systems are discussed:

- sinter plant
- blast furnace
- LD-plant
- EAF-plant
- ladle treatment plant
- continuous caster plant
- rolling mill.

These examples show the state of the art of computer applications in metallurgical industries.

2.1. Production Planning System

Production planning is an information processing and decision making process for the implementation of production, with the objective of achieving an economical realization of the concrete production program.

The main advantages of a production planning system are:

- improvement of plant utilization
- improvement of material throughput
- reduction of work for personnel.

The main functions are:

- order entry
- quality planning
- production planning
- production scheduling, mill pacing
- warehousing and shipping
- information and reporting system.

2.1.1. Order Entry

Customer orders are entered to the planning system. All relevant data, e.g. product type, steel grade, dimensions, weight, special customer requirements, required delivery date, terms of payment, shipment etc. are covered.

The system validates the consistency of data entered by crosschecking it against standard data and limitation tables, thus ensuring data integrity.

Customer orders are then subjected to a rough check against the free capacity of the main production facilities; initial allocations are made. In case of capacity problems, the system reacts immediately.

Changes and updates to customer orders are possible.

2.1.2. Quality Planning

For each customer order entered, the system automatically determines the relevant quality parameters, i.e.

- chemical analysis
- mechanical and technological properties
- testing instructions

by comparing customer order parameters (e.g. steelgrade) with corresponding standard data tables.

Most important part of quality planning is the determination of the required chemical analysis, used as instruction for the melt shop and for comparison with the achieved actual values in continuous casting application. For this purpose, the system not only contains the chemical setpoint values but also the allowed tolerance intervals.

The mechanical and technological properties are used for quality control, mainly in connection with material testing. Required quality parameters for semi-finished material (e.g. slab quality code for continuous casting) are also covered.

Furthermore, the system contains material testing and test piece removal instructions.

2.1.3. Production Planning

A first step in production planning is already done in order entry by the rough free capacity check and reservation described above.

The next step in production planning after order entry and quality planning is the technical elaboration of the customer order to obtain a completely specified manufacturing plan.This elaboration covers the

- required production process,
- required sequence of production operations,
- production instructions,
- semi-finished product numbers, dimensions and masses,
- average processing time, earliest and latest starting date per production operation.

These fully specified manufacturing plans are optionally combined on different production stages to obtain optimal production lot sizes (e.g. optimal slab length).

These production orders are then planned for production on the different production units on a weekly basis by making definite capacity reservations. In case of capacity problems, the system reacts immediately.

Thus, the result of production planning is a production sequence plan for each planned or existing product. These plans form a sequence of production orders which means they exactly specify the production steps to be taken, the production instructions and the weeks these production steps have to be done. These production orders are the basis for production scheduling.

2.1.4. Production Scheduling - Mill Pacing

Production scheduling is done separately for each related group of aggregates. E.g., the melt shop and the hot mill form such a related group concerning hot charging.

Production scheduling is done on a shift basis. Appropriate production orders with planned production date within the actual week are selected by various criteria and put into a desired sequence. The proposed production order sequence can be modified and completed.

For the hot mill and the melt shop, there are two major types of production schedules: hot charging and cold charging.

Hot charging schedules take into account all relevant parameters from hot mill to melt shop and include sequence casting and heat building.

Production orders that do not fit into hot charging are scheduled for cold charging.

For subsequent production steps, separate schedules are generated.

The comprehensive production schedules described above are now ready for use for the subsequent facilities (i.e. wire rod mill).

For the melt shop, they have to be refined by mill pacing Functions to form an aggregate related production schedule. Mill pacing functions try to optimize the overall throughput by assigning the scheduled production orders to the available equivalent aggregates, taking into account different aggregate capacities and production speeds.

The production schedules and, for the melt shop, the aggregate schedules are then transferred to the involved production control and process control computers for production, together with the relevant production instructions.

2.1.5. Warehousing and Shipping

After the last production step and final quality control, the finished products are managed by the warehousing system. The system supports inventory and shipping functions, such as

- indication of all products ready for transfer to warehouse;
- display of free storage locations, apply free storage locations to incoming products, maintain product storage locations;
- stock information by various criteria, e.g. product, steel grade, size, customer order, storage location;
- reserve free stock and apply it to customer orders;
- generate loading lists and delivery notes;
- various queries, reports and statistics.

2.1.6. Information and Reporting System

The production planning system and the production control system are using a central database where all relevant data are stored.

This central database contains all data needed for actual production planning and control purposes:

- order related data
- product related data
- relevant data taken over from process control systems (production records)
- permanent data, e.g. steelgrade tables.

The data are partly condensed for reports. The system generates daily, weekly and monthly reports for all relevant parts, e.g.

- order statistics
- plant production statistics
- quality statistics
- warehouse statistics
- etc.

The system supports specially condensed reports for management information system.

2.2. Production Control System

The production control system serves as a connecting link between higher level production planning and other management functions and the process control of individual production plants.

It provides the advantage of an integrated solution and the flexibility of a modular system.

Through actual information, the production events are made clear, the effects of decision known and the necessary measures can be undertaken immediatly.

The main advantages of a production control system are:

- improvement of plant utilization
- improvement of material throughput
- reduction of work for personnel.

The main functions are:

- production control (changes of production plans)
- quality control
- production recording.

2.2.1. Production Control

After each production step, the process control computers send back relevant production data, diversions and changes in aggregate status to the production control computer. Thus, the production control system is able to give the operator an entire overview of the actual plant status and the actual manufacturing status of each product.

There are two major kinds of reactions:

- Immediate reactions, if there are changes in material or aggregate status within an already scheduled, paced and active production step (e.g. in the melt shop)

- Less time critical reactions, in product disposition after a finished production step (e.g. after wire rod rolling)

In the first case of major unforeseen changes in aggregate status or additional production processes needed, the operator can modify the production sequence plans or the process instructions and use the scheduling and, for the melt shop, the mill pacing functions again to reschedule the changed production orders.

In the second case, after each finished production step, the operator has the following possibilities:

He can either confirm that the product has been properly manufactured. In this case, production goes on as planned, and the next production steps can be scheduled.

In case of process deviations or bad quality results, the operator can

- modify the planned subsequent production steps by adding further steps, e.g. repair works or additional quality testing, or modifying process instructions. These modifications are automatically taken into account in subsequently generated schedules.

- degrade the product and disconnect it from the original customer order. Thus, the product becomes a free semi-finished or finished stock material, or, in extreme cases, even scrap. This product will not appear in subsequently generated schedules.

- search for another customer order for the degraded product; apply the degraded product to the other customer order.

- search for another free semi-finished or finished product that fulfills the original customer order requirements; apply the other product to the original customer order.

- generate new production orders (repetition orders) for the original customer order, if the search for another free product fails.

Furthermore, the system gives the operator several status overviews, for example

- customer order status
- material production status
- production schedule status
- facility loading overview
- capacity overview
- etc.

2.2.2. Quality Control

Quality control supports the three major parts:

- quality control for chemical analysis in the melt shop
- quality control for surface and internal quality of continuous casted products
- quality control for mechanical, technological and chemical properties of semi-finished and finished products.

Quality control for chemical analysis in the melt shop:

After the chemical analysis of the final melt shop sample has been determined, the chemical lab computer transfers it to the production control computer. This actual analysis is then automatically checked against the tolerable lower and upper limits determined by quality planning. If all chemical elements are within limits, the system automatically confirms the heat application to the original customer orders. If not, the actual and the prescribed analysis are shown for quality disposition. The metallurgist has the options to

- tolerate the deviations
- demand additional testings
- modify the production sequence plan, or modify production instructions, e.g. for rolling or annealing
- degrade the heat.

In case of degrading, the appropriate production control options described above have to be taken.

Quality control for surface- and internal quality of continuous casted products:

For quality control of continuous casted products special software packages are available. Such a computer aided quality control (CAQC) package covers not only final quality control, but also the determination of the best suited continuous casting production practice with respect to surface and internal quality, tracks the casting process, and makes predictions on quality based on a metallurgical model.

This CAQC- package leads to significant reductions in scarfing and testing and is of special importance for hot charging.

Quality control for mechanical, technological and chemical properties of semi-finished and finished products:

Test piece removal steps and instructions have been determined in quality planning and are part of the production sequence plan, thus displayed at the aggregates where test pieces have to be taken. After material testing, the resulting quality characteristics are transferred to the production control computer.

The actual and the prescribed values and tolerance intervals are compared automatically. The results are used for quality disposition; negative comparison results are marked. In this case, the metallurgist has the options to

- tolerate the deviations
- demand additional testings
- for semi-finished products, modify the production sequence plan, or modify production instructions, e.g. for rolling or annealing
- for finished products, demand additional production steps, e.g. extra annealing
- degrade the product.

The system supports the preparation of test certificates by collecting all available data, e.g. chemical analysis, mechanical and technological properties, customer order and shipment data, etc.

All stored quality data are available for queries, statistics and comprehensive quality reports.

2.2.3. Production Recording

After each production step, production data and status information are taken over from process control computers or from shop floor production recording terminals, checked for consistency and stored.

This enables the production control system to track the materials through the mill. The data can also be used for reports and statistical evaluation and can be accessed by other systems that are not part of the production control system, e.g. cost accounting.

2.3. Process Optimization Systems

The optimization of production processes is done by process computers. These computers control and optimize production units like sinter plant, blast furnace, LD-plant, ladle metallurgy, continuous casting, rolling mill, etc.

In the following chapters the functions of the process computers for the individual production units are described.

These general functions are:

- plant monitoring
- process monitoring
- process optimization (models)
- process control
- quality control
- operator guidance
- plant information

2.3.1. Sinter Plant

For quality and production control of sinter plants automation packages have been prepared. These packages can be used for new plants as well as for modernization of existing plants. They can be adapted to each production practice.

2.3.1.1. Aims

The following advantages are achieved by automatic control and quality control of a sinter plant:

- stabilization of production conditions
- sinter quality improvement
- increase of sinter production rate
- relief of operating staff
- plant management information.

Stabilization of production conditions

Sintering is a continuous process and the precondition for reaching optimal production is a control system, which prevents disturbances of the process. The combination of automatic and computer control achieves stable production conditions.

Sinter quality improvement

Under stable plant operation the sinter quality is controlled automatically by the computer. Using analysis data for sinter and raw materials as well as target values for sinter quality the raw material ratios are calculated and transmitted together with other setpoints to the automatic control level.

Increase of sinter production rate

An optimal use of the available sinter surface can be reached by keeping the burn through point at the end of the sinter strand. A pallet speed control based on charged raw material permeability allows a precalculation of optimum pallet speed, which is used for total material feeding. By this combined control loops the material charging conditions are kept stable though changing the pallet speed for controlling the burn through point. Additionally the material moisture is controlled by water additions in the mixing drums.

Relief of operating staff

All essential process data, production data, and analysis data for raw materials and sinter product are displayed and reported using an operator guided man-machine dialog. By activating special functions the operator can recognize changes in sinter quality or emission data and can find out the reasons easily. The operator can select different modes of operation - manual, automatic and full computer controlled.

Plant management information

Important data concerning plant operation, production, sinter quality, and emission data are concentrated in reports and displays for sinter plant management decisions. Maintenance scheduling is supported by the computer.

2.3.1.2. Functions of Sinter Process Automation

The main functions are:

- data acquisition
- raw material feeding calculation
- control functions
- special functions.

2.3.1.2.1. Data Acquisition

Data acquisition combines all data flows from and to the level 2 system. These data are:

Process data from level 1 (weights, levels, speeds, pressures, temperatures, etc.)

Analysis data from laboratory (chemical components, size distributions, etc.)

Raw material handling station (material indications, chemical components, blended ore composition, etc.)

Blast furnace (sinter consumption data)

Technical section (target values for sinter production, raw material supply conditions)

Calculated data (return fines ratio, raw mix moisture,density, permeability, burn through point, burn through time,etc.)

2.3.1.2.2. Raw Material Feeding Calculation

The mixing of raw materials including blended ore, special ore, return fines, fluxes, and coke is controlled by the process-computer and additional feedback calculations for basicity and coke/return fines and coke/FeO are performed, respectively.The dry raw material ratios and the calculated desired raw mix are the setpoints for level 1, where feed weigher control is performed.

2.3.1.2.3. Control Functions

The sinter process control is based on a process model, which is decomposed into connected control loops. For full computer control optimal and stable sinter production is achieved. The most important process setpoints are transmitted periodically to level 1.

The connected control loops are:

- raw material ratio control
- raw mix moisture control
- surge hopper level control
- burn through point (BTP) control.

Raw material ratio control

Based on the raw material feeding calculation the raw material ratios on dry base are prepared including basicity calculation and coke / return fines (FeO) control.

Raw mix moisture control

Calculation of water addition to mixing and rerolling drum and desired raw mix moisture.

Surge hopper (SH) level control

Calculation of desired total raw mix based on actual material charging to sinter strand modified by future pallet speed calculation values, raw mix flow between feeding station and SH and SH level deviation.

Burn through point (BTP) control

The calculation of the pallet speed is based on the actual burn through time and the desired BTP position. Additionally the pallet speed is influenced by the calculated raw mix, the preceding wind box temperatures and the actual waste gas temperature and pressure.

2.3.1.2.4. Special Functions

- sinter machine standstill and action records
- coke line data
- shatter test data calculation
- correlation functions
- diagnostic data preparation
- graphic display functions

2.3.1.3. Process Models (Optimization)

For process optimization and computer control the following calculation models have been developed:

- permeability/burn through time
- burn through point
- material ratio
- raw mix moisture.

2.3.1.3.1. Permeability/Burn Through Time

A linear dynamic model with an identification algorithm is used to get the influence of permeability on pallet speed control.

2.3.1.3.2. Burn Through Point

Calculation of burn through point based on a polynomial approximation of measured wind box temperatures is performed continuously.

2.3.1.3.3. Material Ratio

The material ratios are calculated from actual and desired chemical components considering both actual material moisture, actual material flow, and burning losses.

2.3.1.3.4. Raw Mix Moisture

An optimal desired raw mix moisture is calculated under consideration of maximal permeability.

2.3.2. Blast Furnace

The blast furnace control philosophy is based upon the fact that the most efficient way of running it is a steady state operation.

Any change in operation in the furnace operation, either due to a control action or a disturbance, usually results in an increase in heat losses and a decrease in gas utilization ratio.

2.3.2.1. Aims

The following advantages are achieved by automatic control and quality control of a blast furnace:

- stabilization of production conditions
- stable hot metal composition
- relief of operating staff
- plant management information.

Stabilization of production conditions

The steady operation of the blast furnace process is realized by feed forward control strategy, keeping the Carbon/Iron ratio as well as blast parameters constant. The required changes are made to the aim C/Fe ratio. Due to the stable operation the changes are small and infrequent.

Stable hot metal composition

Under stable operation and smooth running process the hot metal production is controlled by the computer. Using analysis data as well as target values for hot metal composition the burden is calculated and transmitted together with other setpoints to basic automation system. The result of the stable controlled operation is characterized by:

- high productivity
- low fuel rate
- stable hot metal production and composition.

Relief of operating staff

All essential process data, production data, and analysis data for burden and hot metal are displayed and reported using an operator guided man-machine dialog. The operator can select different modes of operation - manual, automatic and full computer controlied.

Plant management information

Important data concerning blast furnace operation, production, hot metal composition, and emission data are concentrated in reports and displays for blast furnace management decisions. Maintenance scheduling is supported by the computer.

2.3.2.2. Functions of Blast Furnace Automation

The main functions are:

- data acquisition
- burden calculation
- control functions
- special functions.

2.3.2.2.1. Data Acquisition

Data acquisition combines all data flows from and to the level 2 system. These data are:

Process data from level 1 (weights, levels, pressures, temperatures, moisture, etc.)

Analysis data from laboratory (chemical components, size distributions, hot metal and slag analysis, etc.)

Sinter plant (sinter production data)

Technical section (target values for hot metal production, burden supply conditions)

Calculated data (burden composition and distribution, reduction rate, heat balance, etc.)

2.3.2.2.2. Burden Calculation

Covers burden planning, burden calculation and distribution.
Burden planning is used to determine the burden required for specific production targets and to calculate the costs.
Burden calculation evaluates slag and hot metal analysis, basicity, volume, etc.
Burden distribution calculates stock line geometry, layer formation, size distribution, C/Fe ratio, etc.

2.3.2.2.3. Control Functions

The blast furnace process control is based on process models and corresponding control loops. For full computer control optimal and stable blast furnace operation is achieved. The most important process setpoints are transmitted periodically to level 1.

The connected control loops are:

- charging control
- blast furnace control
- hot stoves control

2.3.2.2.4. Special Functions

- operator guidance (action records)
- energy management guidance
- cast management guidance
- correlation functions
- diagnostic data preparation
- graphic display functions

2.3.2.3. Process Models (Optimization)

For process optimization and computer control the following calculation models have been developed:

- burden charging model
- shaft model
- thermodynamic model
- hearth model
- hot stove optimization model.

2.3.2.3.1. Burden Charging Model

Calculation of stock line geometry, layer formation, coke/ore distribution etc. as function of furnace geometry, charged material and charging sequence.

2.3.2.3.2. Shaft Model

The shaft is subdivided into a number of horizontal zones (layer).It is used to overcome the long time delay from charging to tapping by tracking the coke rate, slag rate, basicity,production rate, etc. down through the blast furnace shaft.

2.3.2.3.3. Thermodynamic Model

For each layer heat and mass balance is calculated based on physical and chemical equations. The results are aerodynamic data (gas flow, mass flow, velocity, pressure losses, etc.), thermal and chemical data (fuel rate, heat reserve, direct reduction rate, combustion, etc.). These data give information about the process and enable control actions.

2.3.2.3.4. Hearth Model

This model calculates the hot metal and slag accumulation in the blast furnace hearth. It is used as a tool for casting control.

2.3.2.3.5. Hot Stove Optimization Model

This model optimises energy consumption of hot stoves. It calculates the optimum operational conditions of each individual stove for the gas and blast periode.

2.3.3. LD - Plant

The LD-automation system covers the range from hot metal and scrap supply to the transfer of full ladle to the casting area.

2.3.3.1. Aims

The automation system of the LD-process is intended to serve the following purposes:

- improvement of hitting rate
- increase of the number of heats
- improvement of the yield
- prolongation of lining life
- standardization of operational practice
- improved flexibility
- reduction of operating errors
- operator guidance
- management information
- improvement of production process.

Improvement of hitting rate

By using modern metallurgical models and automation systems for the blowing process an improvement of hitting rate is achieved.

Increase of the number of heats

With modern automation systems the tap to tap time can be decreased and waiting periods can be avoided. The throughput can be increased without loss of quality.

Improvement of the yield

With long time evaluation of production data, operational practices and metallurgical models defined methods can be achieved for production of desired steel quality as well as optimum yield.

Prolongation of lining life

Lining life can be prolongated if standardized and optimized production conditions are used. By recording lining history preventing maintenance can be done, which increases lining life.

Standardization of operational practice

Standardized mode of operation including standardized treatment of production irregularities improve LD-plant production.

Improved flexibility

The flexibility for changing conditions of production can be improved, due to better and more reliable information gathered by an automation system.

Reduction of operating errors

The classical LD-production process is characterized by a lot of human interference and by the fact that operators can decide at any time to use the equipment in a different way as planned. This is the main source of operating errors.

Operator guidance

All process data, production data, analysis data, planned data and production and operational practices are shown to the operator.

Management information

Important data, status information etc. are shown on request for supporting plant management decisions. Maintenance scheduling is supported by the computer.

Improvement of production process

By statistical evaluation of collected long term data improvements of production process can be achieved.

2.3.3.2. Functions of LD - Process Automation

During all phases of the production process many different functions are performed by the automation system. They cover the range

- support of operating staff
- process guidance
- process control
- model calculation
- data logging.

The following functions are described:

- hot metal pretreatment
- preparation of hot metal
- preparation of scrap
- oxygen lance
- vessel addition
- bottom stirring
- sublance
- tapping.

2.3.3.2.1. Hot Metal Pretreatment

In the pretreatment station the operator requests the desulfurization calculation on arrival of the ladle. The operator proposes the treatment agent and the computer calculates the necessary amount. The setpoint is given to the addition system of the treatment station and addition is started. The amount of agent added are acquired and transmitted to the process computer.

2.3.3.2.2. Preparation of Hot Metal

According to the hot metal preparation schedule for the desired weight, the necessary amount of hot metal is prepared and the actual values are acquired by means of the hot metal weighing system.

2.3.3.2.3. Preparation of Scrap

According to the desired weight, the necessary amount scrap is prepared and the actual values are acquired by means of the scrap weighing system. The scrap can consist of several qualities with different analysis.

2.3.3.2.4. Oxygen Lance

The oxygen blowing lance is supervised according to a preselected lance scheme. A lance scheme for normal blow consists of up to 7 different positions.

Each lance scheme contains the following information:

- lance position above bath level
- oxygen flow
- duration of the position

2.3.3.2.5. Vessel Addition

According to the desired weights for the vessel additions (slag building agents, cooling material, fluxes) the charging of the materials into the vessel is supervised and the actual weights are acquired.

The charging of the materials is performed according to a predefined charging scheme. A charging scheme comprises the timing for charging and the break down of total quantities into batches.

2.3.3.2.6. Bottom Stirring

The process computer determines setpoints for the blowing period (total flow rate, type of gas, time for change over to another gas if applicable) and for post stirring (after the end of blow). The setpoints are taken from tables or entered manually.

2.3.3.2.7. Sublance

The sublance measurement equipment is activated at the precalculated moment. Based on the calculated bath level the process computer determines the height of the sublance and transmits the setpoints to the sublance subsystem.

The sublance takes a sample of liquid steel during the blowing process and evaluates the actual temperature and carbon content. This is the basis for corrections during the blowing process.

2.3.3.2.8. Tapping

Before start of tapping, alloying calculation is performed. Based on a calculated or an actual analysis at the end of blow the necessary alloying materials are calculated by a model.

2.3.3.3. Process Models (Optimization)

For LD-automation the following models are used:

- model for hot metal desulfurization
- first charge calculation
- second charge calculation
- sublance model
- C-T-diagram model
- correction model
- feedback calculation
- model for prediction of tapping analysis
- model for alloying during tapping.

2.3.3.3.1. Model for Hot Metal Desulfurization

An important item in the specification of a steel grade is the sulfur content. The necessary amount of desulfurizing agent is calculated by the model. The input to the model is the weight of the hot metal, the type of desulfurization agent (if there is more than one) and the desired reduction of sulfur.

The parameters of the model, which are specific for an actual application, have to be adjusted.

2.3.3.3.2. First Charge Calculation

The most common practice is that the model calculates the required amount of hot metal and scrap. Basis for the calculation are the target steel analysis, the desired steelweight and steel temperature at turndown, the hot metal analysis and the hot metal temperature. The selection of the scrap types and/or ore types to be used is performed using steel grade dependent instructions.

Temperature losses of hot metal caused by desulfurization in the charging ladle are taken into account by the model.

The following setpoints are calculated and transmitted to the pertinent stations:

- desired weight for hot metal
- desired weight for scrap
- desired scrap grades.

2.3.3.3.3. Second Charge Calculation

This model calculates based on the actual amounts of hot metal and scrap the amounts of lime, limestone, fluxes,iron ore, heating agent and oxygen necessary to obtain steel of the desired analysis and temperature.

The model also calculates the time for sublance measurement (in-blow measurement).The amount of oxygen is calculated depending on the desired final carbon content of the steel. Temperature and analysis of the steel bath expected from the sublance measurement are also calculated.

The following setpoints are calculated and transmitted to the pertinent equipment:

- desired value for slag building agents and fluxes
- desired values for cooling materials
- desired amount of oxygen to be blown until sublance measurement
- desired amount of oxygen to be blown.

2.3.3.3.4. Sublance Model

After the amount of oxygen calculated by the second charge calculation has been blown the in-blow sublance measurement is started to determine carbon content and temperature of the steel bath. In general this is two minutes prior to the end of blow.

Based on the measured values the model calculates the quantities of cooling agent or heating agent and lime and oxygen required to achieve a final carbon content and a temperature within their respective ranges.

Before the corrections are calculated the heat is recalculated considering the actual weights of all materials discharged into the vessel and the sublance measurement. This calculations delivers the complete actual analysis of the steel bath and the slag and also the weight of steel and slag. By this the initial state for the iron, heat and oxygen balance covering the rest of the blow is defined. This balances are used for the determination of corrections.

The actual values of this correction are considered by the feedback calculation.

2.3.3.3.5. C-T-Diagram Model

This model is started first as soon as the actual values for carbon content and temperature of the steel bath are known from the in-blow sublance measurement. Subsequent starts are executed cyclically until the end of blow. The actual value of oxygen blown and all additional materials discharged into the vessel (ore, heating agent, lime,...) since the in-blow measurement are input to the model. Starting from the state of the heat at the time of the sublance measurement the temperature and the carbon content of the bath is calculated and displayed.

2.3.3.3.6. Correction Model

After the end of blow the correction model is started,if expected target values could not achieved.The model calculates the required quantities of cooling or heating agent, lime and oxygen to achieve the required temperature and carbon content.

If only temperature and carbon content or oxygen potential of the steel bath is known, the model proposes measures to obtain the desired temperature and carbon content.

2.3.3.3.7. Feedback Calculation

As soon as after end of blow the analysis and the temperature of steel are known, actual and target values are compared. Deviations are used for the adaptation of parameters of the converter models.For next start of a converter model the new parameters are used.

2.3.3.3.8. Model for Prediction of Tapping Analysis

As soon as the analysis of the sample taken by the sublance at the in-blow measurement is known (in general about two minutes after the end of blow) the model can be started and calculates the complete analysis of the steel. This analysis can be used for the calculation of the quantities of agents required for alloying during tapping. The model can also be called after any necessary reblow.

2.3.3.3.9. Model for Alloying during Tapping

To obtain a steel analysis within the required limits alloying agents (FeMn, FeSi,...) are added into the teeming ladle. This addition is mainly performed during tapping as large quantities can be added into the tapping beam.

The required quantities of alloying agents and the final steel weight are calculated by material balances starting with the analysis of the steel bath prior to tapping and the final analysis. The analyses of the alloying agents and the agent specific losses are taken into account.

After the required quantities of alloying agents have been added and the actual analysis after alloying is known, a recalculation is performed to evaluate the actual losses of alloying agents by comparing the desired and the actual analysis. The new values for losses are used in the alloying model for the next calculations of quantities of alloying agents.

2.3.4. EAF - Plant

Recently almost every new built electric arc furnace has been supplied with a process automation system. Even in modernisation of existing plants advanced automation concepts are installed. The automation system performs production and quality control.

2.3.4.1. Aims

The main advantages of electric arc furnace automation are:

- high availability
- quality improvement
- increase of productivity
- control of energy consumption
- relief of operating staff.

High availability

High availability will be achieved, due to automatic control, thermal supervision of EAF and preventive (computer aided) maintenance.

Quality improvement

With help of models, alloy and deoxidation agent calculations steel production process and steel quality are improved.

Increase of productivity

Is achieved by reduction of tap to tap time due to automation system.

Control of energy consumption

Prevents overdrawing of tariff limit and saves money.

Relief of operating staff

All data which are relevant for the actual process state are shown to the operator. The handling of EAF process is simplificated due to automation system.

2.3.4.2. Functions of EAF Automation

During melting process in an electric arc furnace following technological and metallurgical modes of proceeding are done:

- scrap melting
- sponge iron melting
- alloying
- oxygen blowing.

During all phases of the production process many different functions are performed by the automation system. They cover the range

- support of operating staff
- process guidance
- process control
- model calculation and
- data logging.

The following functions are described:

- support of operating staff
- scrap yard and bin management
- process control functions
- calculations
- special functions.

2.3.4.2.1. Support of Operating Staff

All data, which are relevant for the actual process state,are shown to the operator on a monitor form, which is updated cyclically.

If the process computer recognizes a change in operation state a new set of data, important for this state, is shown.

Additional the operator can get other important information of heats, like planning data, scheduled heats, etc.

If the process computer recognizes, that a certain reaction of the operator must be done because of the actual situation, a respective message is shown.

Furthermore every deviation of the actual operation state from the preset operation state is detected and a respective message is shown to the operator.

2.3.4.2.2. Scrap Yard and Bin Management

Scrap yard management:

Whenever a scrap bucket is loaded or scrap is delivered, the information of scrap type and weight is used to update the actual stocks in the scrap yard.

This ensures that actual scrap data (weight and type) and stored scrap data are up to date. This information is used for scrap bucket loading orders.

Bin management:

The additions and alloying materials are stored in bins.

The process computer stores the amount and typ of material stored in each bin. All changes (inputs and outputs) are recorded.

The content of every bin can be computed and if a certain minimum content is reached, recharging of the bin is requested.

Furthermore bin managemant ensures, that for alloy calculation only available amount of alloying material is taken into account.

2.3.4.2.3. Process Control Functions

From the moment of charging of the first scrap bucket or from the first electrical energy input until tap the melting process in the electric arc furnace is guided and controlled by electric arc furnace process computer.

The following reactions which are responses to certain events are initiated by process computer:

- request for charging of next bucket
- request for start/stop of sponge iron feeding
- request for measurements (temperature, carbon, sample)
- charging of alloys
- request for tapping.

For sponge iron technologie sponge iron feed rate control is used.

Sponge iron and lime is fed continuously by a feeding system.

The process computer calculates the setpoints for sponge iron and lime feed rate, cyclically.

2.3.4.2.4. Calculations

Charge calculation:

Linear optimization technique is used to minimize charge costs (scrap types, alloying materials, etc.).

The availability of scrap and alloying materials is considered by scrap yard and bin management.

Alloy calculation:

For each steel quality a target analysis is defined.To check the actual analysis of the steelbath, samples are taken during production process.

A metallurgical model calculates the necessary alloying materials to reach the target analysis.

The calculated values are shown to the operator and used as setpoints for feeding system.

Oxygen calculation:

An aim of the melting process at electric arc furnace is to get a certain carbon content of the steel bath at tap.

The actual carbon content is determined by sample taking or a quick carbon measurement.

Based on these data the amount of oxygen is calculated to obtain the target carbon value.

2.3.4.2.5. Special Functions

Wall temperature supervision:

A special control function for electric arc furnaces is the thermal supervision of wall temperatures. If local overheating of water cooled panel is measured the power consumption of responsible electrodes or burners will be decreased.

Energy consumption supervision:

The energy consumption of the furnace is supervised to prevent overdrawing of upper energy limit of actual tariff period of the energy supplier.

A message alerts the operator to decrease the power consumption of the furnace or to switch off the furnace.

2.3.4.3. Process Models (Optimization)

For electric arc furnace automation the following models are used:

- thermal model
- metallurgical model
- oxygen - carbon computation
- sponge iron feedrate computation.

2.3.4.3.1. Thermal Model

The thermal model is used for the computation of energy balance, steel bath temperature and mass balance of the electric arc furnace.

It consists of the cyclic and the acyclic thermal model.

Cyclic thermal model:

This part takes all continuous energy inputs and energy losses into account.

The result of the calculation is the actual energetic state of the furnace and the steel bath temperature. Further the amount of continuously fed sponge iron is integrated and the mass balance is actualized.

Acyclic thermal model:

This part takes all non periodical events, like heat start, charging of a scrap bucket, etc. into account.

Whenever a plausible temperature is measured, the thermal model is dynamical synchronised by starting the acyclic thermal model.

2.3.4.3.2. Metallurgical Model

The metallurgical model is started after receiving the actual analysis results from laboratory computer.

The result are the weights of alloying materials for target analysis.

The simplex algorithm of linear optimization is used.

2.3.4.3.3. Oxygen - Carbon Computation

After quick carbon measurement the amount of oxygen is calculated for target carbon content.

Carbon, which will be added by continuous sponge iron charging, is taken into account.

2.3.4.3.4. Model for Sponge Iron Feed Rate Computation

During sponge iron melting and continuous sponge iron feeding the deviation of bath temperature from target bath temperature is computed.

This temperature deviation and the actual energy input is used to calculate the setpoint for the sponge iron feedrate, periodically.

2.3.5. Ladle Treatment Plant

Recently almost every new built ladle treatment facility has been supplied with a process automation system. Modernization of existing steel plants by later installation of secondary metallurgical equipment is always combined with installation of advanced automation concepts.

2.3.5.1. Aims

The main advantages of automation of a ladle treatment facility are:

- quality improvement
- increase of productivity (yield)
- high availability
- relief of operating staff.

Quality improvement

With help of models, alloy, deoxidation and desulfurization calculations steel production process and steel quality are improved.

Increase of productivity (yield)

The desired steel quality can be produced more reliable and more accurate, if ladle treatment facility is equipped with modern automation system. Downgrading of produced steel due to operation or operational disturbances is unlikely.

High availability

High availability will be achieved, due to automatic control and preventive (computer aided) maintenance.

Relief of operating staff

All data which are relevant for the actual process state are shown to the operator. The handling of ladle treatment facility is simplified due to automation system.

2.3.5.2. Functions of Ladle Treatment Automation

During treatment of steel in a ladle treatment facility following technological and metallurgical procedures, which are supported by the automation system, are done:

- alloying
- deoxidation
- adjusting of carbon content
- desulfurization
- homogenization
- cooling by scrap charging.

During all phases of the production process many different functions are performed by the automation system. They cover the range:

- support of operating staff
- model calculation and
- data logging.

The following functions are described:

- support of operating staff
- bin management
- alloy calculations
- special functions.

2.3.5.2.1. Support of Operating Staff

All data, which are relevant for the actual process state, are shown to the operator on a monitor form, which is updated cyclically.

If the process computer recognizes a change in operation state a new set of data, important for this state, is shown.

Additionally the operator can get other important information of heats like planning data, scheduled heats, etc.

If the process computer recognizes, that a certain reaction of the operator must be done because of the actual situation, a respective message is shown.

Furthermore every deviation of the actual operation state from the preset operation state is detected and a respective message is shown to the operator.

2.3.5.2.2. Bin Management

The additions and alloying materials are stored in bins.

The process computer stores the amount and typ of material stored in each bin. All changes (inputs and outputs) are recorded.

The content of every bin can be computed and if a certain minimum content is reached, recharging of the bin is requested.

Furthermore bin managemant ensures, that for alloy calculation only available amount of alloying material is taken into account.

2.3.5.2.3. Alloy Calculation

For each steel quality a target analysis is defined.To check the actual analysis of the steelbath; samples are taken during production process.

A metallurgical model calculates the necessary alloying materials to reach the target analysis.

The calculated values are shown to the operator and used as setpoints for feeding system.

2.3.5.2.4. Special Functions

Adjusting of Carbon Content

An important aim of the treatment process is to reach the carbon content which is defined for the respective steel quality.

If the carbon content is below the target value due to previous production steps, carbon must be added.

The necessary amount of recarborisation agent is computed by a model and shown to the operator. The acknowledged value is used as setpoint for carbon content adjustment.

Desulfurization

The kind of desulfurization agent depends on the respective steel quality.

The necessary amount of desulfurization agent is computed by a model and shown to the operator. The acknowledged value is used as setpoint for desulfurization agent.

Deoxidation

The amount of deoxidation agent, which is necessary to reduce the oxygen content of the steel bath, is computed by deoxidation model.

The calculated value is shown to the operator. The acknowledged value is used as setpoint for deoxidation agent.

Cooling Scrap Calculation

After temperature measurement the operator starts the cooling scrap model. Thereby the necessary amount of cooling scrap is calculated and shown to the operator.

The acknowledged value is used as setpoint for cooling scrap addition.

Acquisition of Stirring Gas Data

The process computer receives data of the stirring gas system from basic automation system.

These data are shown on the terminal in control pulpit and stored for further data processing.

2.3.5.3. Process Models (Optimization)

For automation of ladle treatment facility the following models are used:

- metallurgical model
- carbon computation
- desulfurization model
- deoxidation model
- cooling scrap model.

2.3.5.3.1. Metallurgical Model

The metallurgical model is started after receiving the actual analysis results from laboratory computer.

The result are the weights of alloying materials for target analysis.

The simplex algorithm of linear optimization is used.

2.3.5.3.2. Carbon Computation

After a carbon content measurement the carbon computation is started. The amount of recarbonisation agent is calculated, considering the the actual and the target carbon content of the requested steel quality.

2.3.5.3.3. Desulfurization Model

The kind of desulfurization agent depends on the target steel quality and is defined in respective tables.

The model computes the amount of desulfurization agent, which is necessary to reach the desired value for the planned steel quality.

Beside the actual and target sulfur content, the actual temperature and the oxygen content of the steel bath are used as input data.

If the oxygen content of the steel bath is too high, deoxidation should be performed first. Otherwise the loss factor for desulfurization agent is too high.

2.3.5.3.4. Deoxidation Model

This calculation is based on target analysis of the planned steel quality, the analysis of the last sample and charged alloying materials since last sample.

The oxygen content and the temperature of the steel bath are measured.

The amount of deoxidation agent is computed based on chemistry considerations and the target oxygen value for the planned steel quality.

2.3.5.3.5. Cooling Scrap Model

The actual steel bath temperature and the desired temperature at treatment end are used to calculate the amount of cooling scrap.

Thereby the chemical analysis of the steel bath may not be influenced when cooling scrap is added.

2.3.6. Continuous Caster Plant

In modern steel works, continuous casting of steel has become of increasing importance in the last years.Simultaneously with a continuous increase of the output, also the demands with respect to quality have become higher and higher.

These requirements will be strongly supported by automation.

2.3.6.1. Aims

The main advantages of continuous casting automation are:

- relief of operating personnel
- increase of availability
- quality improvement
- increase of output.

Relief of operating personnel

By storing, evaluating and showing operation, production and plant specific data. Operating personnel is supported by controlled and concentrated information, provision of decision aids and alarms.

Increase of availability

The plant availability is increased by automatic control, monitoring of limit values, machine protection function, uniform operation and preventive (computer aided) maintenance.

Quality improvement

The quality is improved by secondary cooling model and quality assurance model.

Increase of output

The output is increased by heat pacing function and length optimization.

2.3.6.2. Functions of Continuous Casting Automation

The description of the main functions of continuous casting automation is limited to the explanation of the conceptual formulation, indicating the purpose and the basic consideration of the functions. The following described functions are standard for slab and jumbo bloom casters.Most of them are also applicable for bloom and billet casters.

The main functions are:

- acquisition of planning data
- data acquisition
- heat pacing
- material tracking
- process control
- special functions.

2.3.6.2.1. Acquisition of Planning Data

Production planning is carried out on a higher level computer system (level 3 and/or level 4), either for one day or for one shift in advance.

Each of the heats to be produced corresponds to a production plan containing the essential planning data such as steel grade, dimensions and caster practices for a heat.

Short term modifications of production plan such as cancelling, rearranging or modifications can be done by available forms and dialog functions.

Progress of production is recorded and shown on displays.

Creation of Cutting Schedule

At the casting start for each heat the appropriate cutting schedule is worked out. The basis for the cutting schedule is the production plan which contains the specified cutting lengths.

After each cut the measured length of the actual slab is used to update the cutting schedule.

2.3.6.2.2. Data Acquisition

Acquisition, allocation and storage of product and plant specific data is of special importance. The data are cyclically acquired,received from other computers via coupling lines or input by operating personnel via screen forms.

All data are checked for plausibility. In case lower or upper limit values are not reached or exceeded, respectively, alarms are released and default values are generated.

Trending

Important process parameters and measured values are cyclically stored. They are shown to the operators in data groups like:

- Ladle data
- Tundish data
- Mould data
- Cooling data
  etc.

2.3.6.2.3. Heat Pacing

For sequence casting the melting shop and the treatment stations have to be synchronized with the process at the continuous casting machine. This is done already during planning.

An adaption to the actual situation at the casting machine can be achieved with the heat pacing function.

According to actual times (start and end of ladle treatment), the actual casting speed, the steel mass in the ladle and empirically determined plant constants (transport duration of the ladle from the treatment station to the turret,duration for a ladle change, minimum steel mass in the tundish, etc.) the optimum time of departure from the treatment station and a setpoint for the casting speed are cyclically calculated.

The results are displayed and serve as decision aid for the operator.

2.3.6.2.4. Material Tracking

With signals from the basic automation system,event messages from other process computers and manual inputs the actual position of the material in the plant is created and stored together with characteristic data.

These data are checked for plausibility, updated at each operation and serve as a basis for further functions.
The following tracking functions are performed:

- heat tracking
- strand tracking
- slab (billet, bloom) tracking.

Heat Tracking

The heats are tracked starting at melting shop, via the treatment, up to the point where material leaves the runout area of the casting machine.

Strand Tracking

Strand tracking comprises the area between tundish and cutting machine.

The events start of cast, heat change, begin and end of a width change, tundish change and end of cast are assigned to the respective strand. The exact position of those events is calculated cyclically on the basis of the strand movement signals transmitted from the basic automation system.

Slab Tracking

For each slab cut off a data set is created and passed over to the slab tracking system.

Material movements signalled by the basic automation system are checked for their plausibility.The slabs are tracked from the cutting machine to the end of the monitored area.

Gathered data like slab length, marking number and slab mass in the course of tracking are automatically assigned to the respective slab and stored.

2.3.6.2.5. Process Control

Planned, calculated or manual setpoints are transmitted from the process computer to the lower level distributed control system. The correct sequencing of all setpoints is controlled by using the process tracking function.

The process computer determines setpoints for the following control loops:

- primary cooling control
- secondary cooling control
- mould width change
- cutting control
- marking control
- casting speed control
- mould oscillation frequency control
- powder feeder control
  etc.

Primary Cooling Control

Based on steel quality, casting speed and tundish temperature setpoints for the mould waterflow are cyclically calculated.

Secondary Cooling Control

With secondary cooling model setpoints for the water flow for the cooling loops are cyclically calculated.

Mould Width Change

The process computer supports the operator to perform mould width change.

Cutting Control

The process computer determines the cutting length using the production plan and the modifications from functions 'Cutting Schedule Generation' and 'Length Optimization'.

Marking Control

According to the production plan and the actual production the slab number (marking characters) is defined and transmitted to the marking machine.

Casting Speed Control

The setpoint for the casting speed is cyclically calculated using the stored caster practice tables and the results of the heat pacing function.

Mould Oscillation Frequency Control

The oscillation frequency is evaluated using stored quality dependent curves and the actual casting speed.

Powder Feeder Control

Type and quantity of the casting powder are selected from stored tables. The setpoints are a function of the carbon content.

2.3.6.2.6. Special Functions

The following functions are part of continuous casting automation:

- set-up-check
- machine protection
- nozzle check
- maintenance functions.

Set-up-check

With set-up-check the operator obtains a general view on the actual plant situation before starting the casting operation.

The following parameters are indicated :

- cooling water flow
- cooling water pressure
- open disturbances.

Missing important information (e.g. strand thickness) must be input by the operator. The correct execution of the set-up checks is stored, otherwise an alarm is generated.

Machine Protection

This function serves to protect the casting machine from excessive loads. Thus, the life of the machine or of individual equipment is increased and production losses due to machine overloads are reduced.

Nozzle Check

At selectable intervals, the nozzles are checked for clogging and leakage water on the basis of a computer calculation. In case the preset limit values are exceeded or not reached an alarm is generated.

Maintenance Functions

Plant specific data such as service life, throughputs, etc. of individual aggregates are acquired and evaluated, thus forming the basis for the maintenance functions.

2.3.6.3. Process Models (Optimization)

For continuous casting automation the following models are used:

- model for secondary cooling
- length optimization model
- model for machine protection
- quality control model.

2.3.6.3.1. Model for Secondary Cooling

The secondary cooling system has an important influence on the surface and internal quality of the casted steel. The most important requirements from a metallurgical point of view are :

- sufficient heat removal on the surface to guarantee a constant shell growth and to prevent a reheating of the shell (bulging, break out)
- homogeneity over width and length to prevent thermic tensions
- automatic setpoint control of the water quantities for all steel qualities and casting speeds.

These requirements are served best by a computer controlled shell growth model, which calculates the correct water quantities to guarantee a constant shell growth and a homogeneous temperature field to prevent thermic tensions.

Cooling curves, related specific water flow rates and shell thickness, are stored in the form of tables for each group of steel grades. These tables can easily be modified or created.

2.3.6.3.2. Length Optimization Model

The task of the length optimization is to minimize the formation of scrap or the production of not planned slabs, respectively.

In general the steelmass in the ladle does not exactly coincide with the ordered mass which is required for optimum compliance with the production plan. Therefore, the cutting schedule must be corrected. This correction is performed at the following events:

- steel grade change
- tundish change
- start of mould width change
- end of mould width change
- end of cast
- wrong cut.

The cutting lengths in the schedule are corrected according to a specified optimization procedure.

2.3.6.3.3. Model for Machine Protection

The aim of the model is to protect the machine against roll overloads. The protection is done by warning and guiding the operator in dangerous situations.

At the straightening zone, the stiffness of the strand must not exceed a certain limit and also the solidus point must not reach the cutting machine.

Based on the strand residence time calculation, the computer checks cyclically stiffness of each strand element. If stiffness of any strand element exceeds a given limit an alarm will be generated.

2.3.6.3.4. Quality Assurance Model

The economical production of high quality steel products is the main goal of iron and steel industry. Therefore a powerful and consistent quality assurance method is indispensable. Important advantages of a quality assurance system are:

- adherence to product specifications to decrease the expense of the production
- reliability and consistency of operation
- availability of detailed process information for each small section of produced material
- automatic determination of the proper production parameters to reduce manipulation and inspection.

A Computer Aided Quality Assurance (CAQA) Model improves quality and productivity. The CAQA system offers information about actual process conditions during production. Reports about deviations from optimum casting practice for each slab, bloom or billet provided by the system are a reliable basis for correct decisions and dispositions.

The functions of CAQA are:

- determination of process parameters
- process tracking
- calculation of process deviations
- disposition.

Determination of target production parameters

The determination of of target production parameters is done with stored tables containing the optimum production parameters for each steel quality.

A set of target parameters is selected for each heat.

Process Tracking

All data necessary for quality control (measured values, disturbances, ...) are collected and related to the corresponding production segments. A complete set of data is stored for each segment.

To track the process data the strands are divided into segments of a certain length (1 m).

The actual data are assigned to those segments which are affected by the particular process parameter.

A complete set of data is stored for each segment to be available for off-line investigations, reporting and for calculation of process deviations.

Calculation of Process Deviations

Deviations between the target and the actual parameters tracked during production are calculated and reported.

Disposition

Deviations of actual process values from the target production parameters are evaluated and used for disposition.

2.3.7. Rolling Mill

If direct rolling or hot charging is not intended the production and shift schedules for hot strip mill and steel/ slab plant are only loosely coupled via the slab yard, which is used as a buffer. Produced slabs are stored in the slab yard.The stored slabs are used to establish the shift schedule for hot rolling mill starting from reheating furnace to end of rolling.

If direct rolling or hot charging is intended hot strip mill and steel/slab plant are strongly coupled. The casted slabs must be available just in time for rolling. Therefore the production process is much more complex.

Production of defect-free products and the coordination of the production in the steel plant, continuous caster and hot strip mill are preconditions for economical hot charging or direct rolling. The plant coordination is necessary for short term aspects, such as output coordination and long term aspects, such as coordination of maintenance shifts

The short term plant coordination comprises quality coordination, output synchronization and matching of dimensions (width wedge).

2.3.7.1. Aims

The main advantages of hot strip mill automation are:

- relief and reduction of operating personnel
- increase of efficiency
- energy saving
- quality assurance

Relief and Reduction of Operating Personnel

With the aid of the automation system the operators are able to infer correct decisions from the multitude of data in the time available. Due to automated functions operating personnel can be reduced.

Increase of Efficiency

The efficiency is increased by shortening of processing times (e.g. shortening of time between passes of roughing train), automatic width control, etc.

Energy Saving

Energy saving is the main advantage of direct rolling or hot charging. By process optimization of reheating furnace a remarkable amount of energy can be saved.

Quality Assurance

The desired quality is derived by quality planning,monitoring of production conditions, evaluating of deviations and correct decision making. The desired production conditions are derived from the end use of the product. A large number of data influencing the quality from all processes are logically evaluated and correct decisions are derived therefrom.

2.3.7.2. Functions of Hot Strip Mill Automation

This description is limited to the main functions of usual equipped hot strip mills.

The automation system consists of:

- Furnace System
- Mill-Pacing and Mill-Tracking System
- Finishing Train and Cooling Section System

The main functions are:

- acquisition of planning data
- data acquisition
- material tracking
- mill pacing
- process control
- special functions

2.3.7.2.1. Acquisition of Planning Data

Production planning is carried out on a higher level computer system (level 3 and/or level 4), either for one day or for one shift in advance.

The production plan for convential hot rolling mill contains following important data:

- actual slab dimensions
- slab weight
- planned transfer bar dimension
- actual steel grade
- reheating curve number
- actual furnace charging temperature
- planned furnace extracting temperature
- roughing mill pass schedule number
- finishing train pass schedule number
- planned strip dimensions
- planned final rolling temperature
- planned coiling temperature

Short term modifications of production plan such as cancelling, rearranging or modifications can be done by operators via dialog functions.

2.3.7.2.2. Data Acquisition

Acquisition, allocation and storage of product and plant specific data is of special importance. The data are cyclically acquired,received from other computers via coupling lines or input by operating personnel via screen forms.

All data are checked for plausibility. In case lower or upper limit values are not reached or exceeded, respectively, alarms are released and default values are generated.

2.3.7.2.3. Material Tracking

Furnace System

The task of the material tracking function is the creation of a material map of the furnace allocation. This material map contains the sequence and the position of the charged slabs within the furnace.

The material map is updated by the receipt of related data messages which occures in cases of

- charging a slab
- extracting a slab

Mill Tracking and Mill Pacing System

The material tracking function covers the mill area from the furnace roller table to the coiler. For this reason the mill area is devided into several sub-tracking areas as

- reheating furnace
- roughing mill
- finishing mill
- cooling section
- coiler

Each material which is present within the above defined mill area will be tracked in relation to the above mentioned sub-tracking areas. The necessary basic information for the update of the material map is transmitted from the basic automation system.

The following event messages are used:

- slab charged into furnace
- slab extracted from furnace
- start of pass at the roughing mill
- end of pass at the roughing mill
- first stand of the finishing train loaded
- last stand of the finishing train loaded
- start of coiling
- all stands of the finishing train are unloaded
- end of coiling
- coiler ready

The mill personnel has the possibility to correct the material map manually.

2.3.7.2.4. Mill Pacing

The mill pacing function calculates a time schedule for each slab which is charged into the furnace. This time schedule is based on the required processing time of the main mill components as

- furnace - reheating time
- roughing mill - rolling time
- finishing mill - rolling time

The basic information for this time schedule is the minimum reqired processing time in each main mill component which will be supplied by the basic automation system.

The time schedule takes also into consideration planned stops and stops caused by disturbances. The planned or estimated duration of such stops must be entered by mill personnel.

The result of the mill pacing is the indication of the shortest theoretical time interval for slab extraction (charging) for the furnace.

2.3.7.2.5. Process Control

Reheating Furnace

The control of the reheating process is done in accordance to stored reheating curves. When a slab enters the furnace a selected reheating curve is allocated to the slab. During the reheating process the furnace computer computes for each slab in the furnace the planned temperature in dependence of the slab location and the troughput.

The ideal zone temperature setpoints will be derived by comparison of the planned slab temperature with the actual calculated slab temperature. The real furnace zone temperature will be calculated by weighted average of the ideal setpoints for the slabs within this furnace zone.

The furnace zone temperature can also be influenced by a temperature feed-back from the rougher temperature.

Set-up by fixed pass schedules

The finishing train and cooling section system handles the set-up of roller tables, crop shear, finishing mill, side guides, looper and cooling section.

The setpoints for the subordinated control systems depend on strip and stand characteristics and are selected from stored rolling schedules before the transfer bar enters the finishing mill.

The relevant strip data, such as

- thickness of transfer bar
- width of transfer bar
- temperature of transfer bar
- final strip thickness
- final strip temperature

and stand characteristics are used to select setpoints for

- rolling force for each stand
- rolling speed
- thickness for each stand
- speed up
- cooling pattern.

These values are transferred in due time to the basic automation.

2.3.7.2.6. Special Functions

Ghost Rolling

This simulation function can be activated on the computer for finishing train and cooling section system. It is used for simulation of the model functions.

Adaptive threading

After threading of the transfer bar in the first stands of the finishing mill the rolling force is measured. The actual rolling force of the stands, which are under load, can differ from the planned rolling force.

To reach the desired final strip thickness the rolling gaps of the last stands, which are not yet loaded, are updated after the measurement of rolling force of the first stand is available (feed-forward).

2.3.7.3. Process Models

Temperature model

The final temperature of the strip is influenced by the temperature of the transfer bar, the rolling force and the rolling speed.

Due to adaptive threading, as described above, the final strip temperature can differ from the planned final strip temperature.

To reach the desired final strip temperature the rolling speed is adjusted accordingly by temperature model while threading.

Cooling model

Before a strip enters the cooling section the setpoints for coiling temperature and an initial cooling pattern are selected.

During rolling process the amount of cooling medium is calculated by cooling model using actual strip temperature and actual speed of the strip.

3. BENEFITS of AUTOMATION SYSTEMS

Modern steel production technologies require integrated automation systems. New production methods, like hot charging and direct rolling cannot be performed without computer assistance.

The following example demonstrates the chances offered by an integrated automation system in combination with modern or modernized production equipment. It shows the necessity to use high level automation to be economical and successful.

In conventional steel mills the processing time from start of tapping at melting shop to end of rolling is about six (6) days. This time includes complete cooling down of slabs followed by reheating.

For hot charging with partial reheating the processing time is reduced to about 6 hours.

For direct rolling with edge temperature compensation the processing time is further reduced to about 90 minutes.

Hot charging saves about 45% and direct rolling about 84% of energy consumption of conventional rolling.

Furthermore the capacity of reheating furnaces, size of slab yards and processing time for orders can be reduced. All these facts lead to additional savings.

But hot charging and particularly direct rolling need measures and precautions in the equipment to be possible and feasible.

These production technologies have significant consequences for material flow, quality and operating personnel.

The material flow and the processes from melting shop, treatment shop, casting and rolling have to be accurately planned, synchronized and controlled. In addition for direct rolling short transport routes are necessary to minimize thermal losses.

The quality must be determined during each production step of the production processes (in line) to be sure that defect-free products are produced ('just in time') for the next production step. Therefore a vast number of data influencing the quality have to be evaluated and correct decisions have to be derived.

The operating personnel have to infer correct decisions from the multitude of data in the short time available.

The full scale of advantages offered by new technologies can be realized only in new plants.

For existing plants compromises have to be made. They can be modernized and perfectioned with good results and cost savings and an increase in product quality.

But anyhow, without aid of computers included in an integrated automation system the new technologies cannot be used efficiently and the above mentioned problems cannot be solved.

3.1. Results Achieved by Integrated Automation

3.1.1. Process Optimization Systems

3.1.1.1. Sinter Plant

The general benefits from sinter plant process automation and optimization are improvements in quality and quantity and saving of operating personnel.

The installation of computer controlled and optimized return fines control has decreased coke consumption in the sinter plant (saving of 1.5 kg coke per 1 ton sinter product).

The precalculation of the strand speed and the connection between burn through point control and surge hopper level control results in a stabilization and optimization of the sintering process and in 30% energy saving for sinter cooling.

3.1.1.2. Blast Furnace

The general benefits from blast furnace process automation and optimization are improvements in quality and quantity and saving of operating personnel.

The iron making economy has been improved by saving 20 kg coke per ton hot metal.

The hot metal production and composition have been stabilized.

3.1.1.3. LD - Plant

The general benefits from LD-plant process automation and optimization are improvements in quality and quantity and saving of operating personnel.

An improvement of the hitting rate by process optimization has been achieved (reduction of standard deviation by 50%).

The productivity has been increased by 2 heats per day and vessel.

3.1.1.4. Continuous Caster Plant

The general benefits from continuous caster process automation and optimization are improvements in quality and quantity and saving of operating personnel.

The following results have been reached by integrated automation and quality assurance system:
- Increase in yield by 0.6%
- Reduction of scarfing losses by 50%
- Increase in hot charging by 10%
- Saving of operating personnel (2 men per shift)

3.1.1.5. Hot Strip Mill

The general benefits from hot strip mill process automation and optimization are improvements in quality and quantity and saving of operating personnel.

The quality of the finished products has been improved by reducing the temperature deviations of the slabs after reheating. These deviations could be reduced by reheating furnace automation and skid mark compensation to a standard deviation of 7.5 K.

The energy saving by reheating furnace automation was 3.5% and one operator per shift could be saved.

The following results have been achieved by integrated automation of roughing train:
- Increase in efficiency by about 15%
- Saving of 2 operators per shift
- Saving in trimming scrap (approx. 1.400 tons per year)

3.1.2. Mill Wide Systems

The developed new technologies, like hot charging, direct rolling, thin slab casting and strip casting require a very high level of production coordination and production planning. For these technologies the production processes of steel plant, continuous caster and hot rolling mill must be synchronized. Therefore they are called mill wide.

The main differences between usual cold charging, hot charging and direct rolling are:

Cold Charging	Hot Charging	Direct Rolling
BOF	BOF	BOF
CC - plant	CC - plant	CC - plant
Slab Yard	Hot Slab Storage	
Reheating Furnace	Reheating Furnace	Edge Temperature Compensator
Hot Strip Mill	Hot Strip Mill	Hot Strip Mill
140 hours Process Time	6 hours Process Time	1.5 hours Process Time

The main advantages of hot charging and direct rolling are figured out in comparison with conventional cold charging. The economy of the methods mentioned is compared on the basis of the operating cost for forming the slabs into coils by an annual production of approx. 4.2 million tons.

3.1.2.1. Hot Charging

The main advantage of hot charging is energy saving. The energy consumption for slab reheating is reduced by about 45%.

The processing time is reduced to 6 hours, the capacity of reheating furnaces and slab yards can be reduced. These facts lead to additional savings.

The operating cost can be reduced by 6% in case of 80% hot and 20% cold charging.

3.1.2.2. Direct Rolling

The main advantage of direct rolling is energy saving. The energy consumption for slab reheating is reduced by about 85%.

Furthermore, conventional slab reheating is not required for direct rolling. Therefore, scale formation is reduced by 0.5%.

The processing time is reduced to 1.5 hours, the capacity of reheating furnaces and slab yards can be reduced. These facts lead to additional savings.

With 60% direct rolling and 40% cold slab charging the operating cost can be reduced by approx. 10%.

When combining 60% direct rolling, 20% hot slab charging and 20% cold slab charging the operating cost can be reduced by 11%.

4. EXAMPLES

4.1. Hardware Suppliers

In the following chapters hardware system suppliers for the different levels of automation are listed.
These lists are only for reference.

4.1.1. Level 1 Hardware Suppliers

AEG	Germany
ABB	Sweden/Switzerland
Allen Bradley	USA
Ferranti	Great Britain
Fisher Controls	USA
Foxboro	USA
Fuji	Japan
Hartmann & Braun	Germany
Honeywell	USA
Landis & Gyr	Germany
Philips	Netherland
Rosemount	Switzerland
Siemens	Germany
Toshiba	Japan
Valmet	Finland
Westinghouse	USA
Yokogawa	Japan

4.1.2. Level 2 Hardware Suppliers

AEG	Germany
DEC	USA
Ferranti	Great Britain
Fuji	Japan
Hewlett Packard	USA
Hitachi	Japan
Honeywell	USA
IBM	USA
Philips	Netherland
SEMS	France
Siemens	Germany
Sperry Univac	USA
Westinghouse	USA

Also Personal Computers (PC) are used for process control.

4.1.3. Higher Level Hardware Suppliers

Control Data Corp.	USA
Data General	USA
DEC	USA
Fuji	Japan
Hewlett Packard	USA
Hitachi	Japan
IBM	USA
Siemens	Germany
Sperry Univac	USA
Tandem	USA

4.2. VOEST ALPINE INDUSTRIEANLAGENBAU Ges.m.b.H. Reference List

4.2.1. Automation Projects in Europe

VOEST ALPINE STAHL
Austria

1983	Blast Furnace
1983	Sinter Plant
1990	Sinter Plant
1983	LD - Plant
1989	LD - Plant
1982	Slab Caster
1989	Slab Caster
1989	Slab Caster
1982	Plate Mill
1986	Hot Strip Mill
1986	Wire Rod Mill
1987	Hot Galvanizing Line
1988	Electrolytical Strip Galv.
1989	Bar and Wire Rod Mill
1989	Coil Coating Line

SOCIETE METALLURGIQUE COCKERILL-SAMBRE
Belgium

1984	Combi Caster (slab/bloom)

KREMIKOVZI
Bulgaria

1990	Ladle Furnace
1991	Slab Caster

VEB EISENHÜTTENKOMBINAT OST
GDR

1984	LD - Plant
1984	Slab and Bloom Caster

VEB WALZWERK ILSENBURG
GDR

1991	Reheating Furnace

SOCIETA EURCPEA TUBIFICI E ACCIERIE S.p.A. (SETA)
Italy

1986	Bloom Caster

TERNI SOCIETA PER L'INDUSTRIA E L'ELETTRICITA S.p.A.
Italy

1987	Slab Caster

HUTA KATOWICE
Poland

1980	LD - Plant

AVESTA OY
Sweden

1991	Steckel Mill

BJELORUSSKI METALLURGITSCHESKIJ ZAVOD
USSR

1987	EAF - Plant
1987	Ladle Furnace
1987	Bloom Caster
1987	Billet Mill

4.2.2. Automation Projects in Africa

MISURATA STEEL COMPLEX
Libya

1988	EAF - Plant

SOUTH AFRICAN IRON & STEEL INDUSTRIAL COR. LTD. (ISCOR)
South Africa

1987	Corex Plant
1987	Slab Caster

4.2.3. Automation Projects in America

ALGOMA STEEL Corp.
Canada

1990	Ladle Furnace
1990	Round bloom and bloom caster

ALTOS HORNOS DE MEXICO S.A. (AHMSA)
Mexico

1983	LD - Plant

BAYOU STEEL CORP.
USA

1982	EAF - Plant

BETHLEHEM STEEL
USA

1986	Combi Caster (slab/bloom)
1986	Combi Caster (slab/bloom)

US STEEL USX
USA

1990	Slab Caster

4.2.4. Automation Projects in Asia

POHANG IRON & STEEL CO. LTD. (POSCO)
Republic of Korea

1981	Sinter Plant
1987	Sinter Plant
1988	Sinter Plant
1990	Sinter Plant
1992	Sinter Plant
1987	LD - Plant
1988	LD - Plant
1991	LD - Plant
1992	LD - Plant
1981	Slab Caster
1987	Slab Caster
1989	Slab/Bloom Caster
1989	Billet Caster
1989	Slab Caster
1989	Slab Caster (Stainless)

ANSHAN IRON & STEEL COMPLEX
PR China

1988	LD - Plant

SHANGHAI STEELWORKS
PR China

1988	Combi Caster (slab/bloom)

SAUDI IRON & STEEL COMP.
Saudi Arabia

1982	EAF - Plant
1980	Billet caster

CHINA STEEL CORP.
Taiwan

1989	LD - Plant
1987	Slab Finishing Plant

EREGLI
Turkey

1985 Sinter Plant

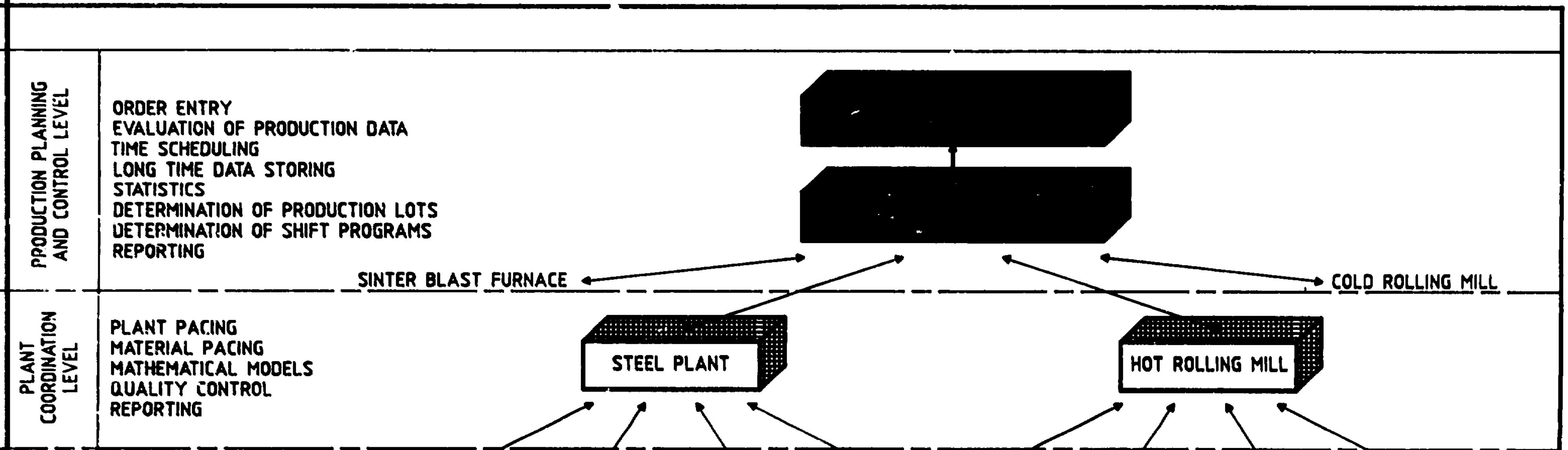
4.3. Hardware Configurations

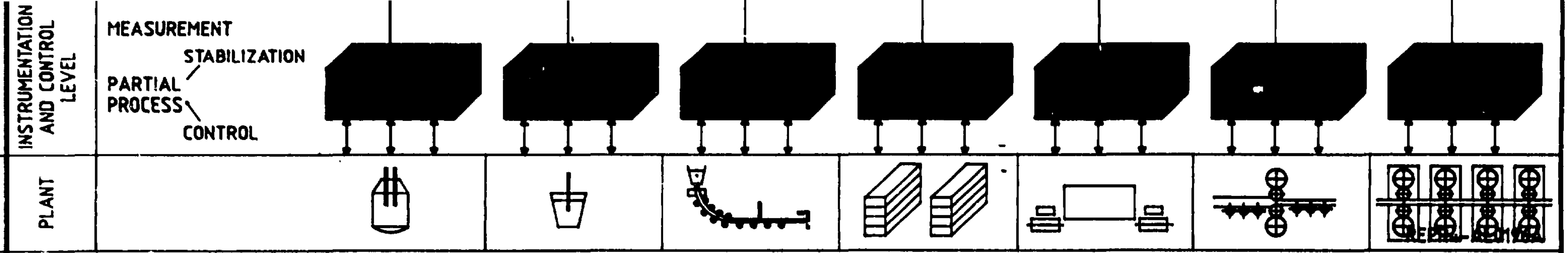
The following examples are hardware configuration drawings of automation projects realized by VOEST ALPINE INDUSTRIEANLAGENBAU Ges.m.b.H.

4.3.1. Integrated Automation System

The following drawings show:

- Industrial Automation, Integrated Automation System
- Shlobin Cord Manufacturing
- PERWAJA Automation Concept

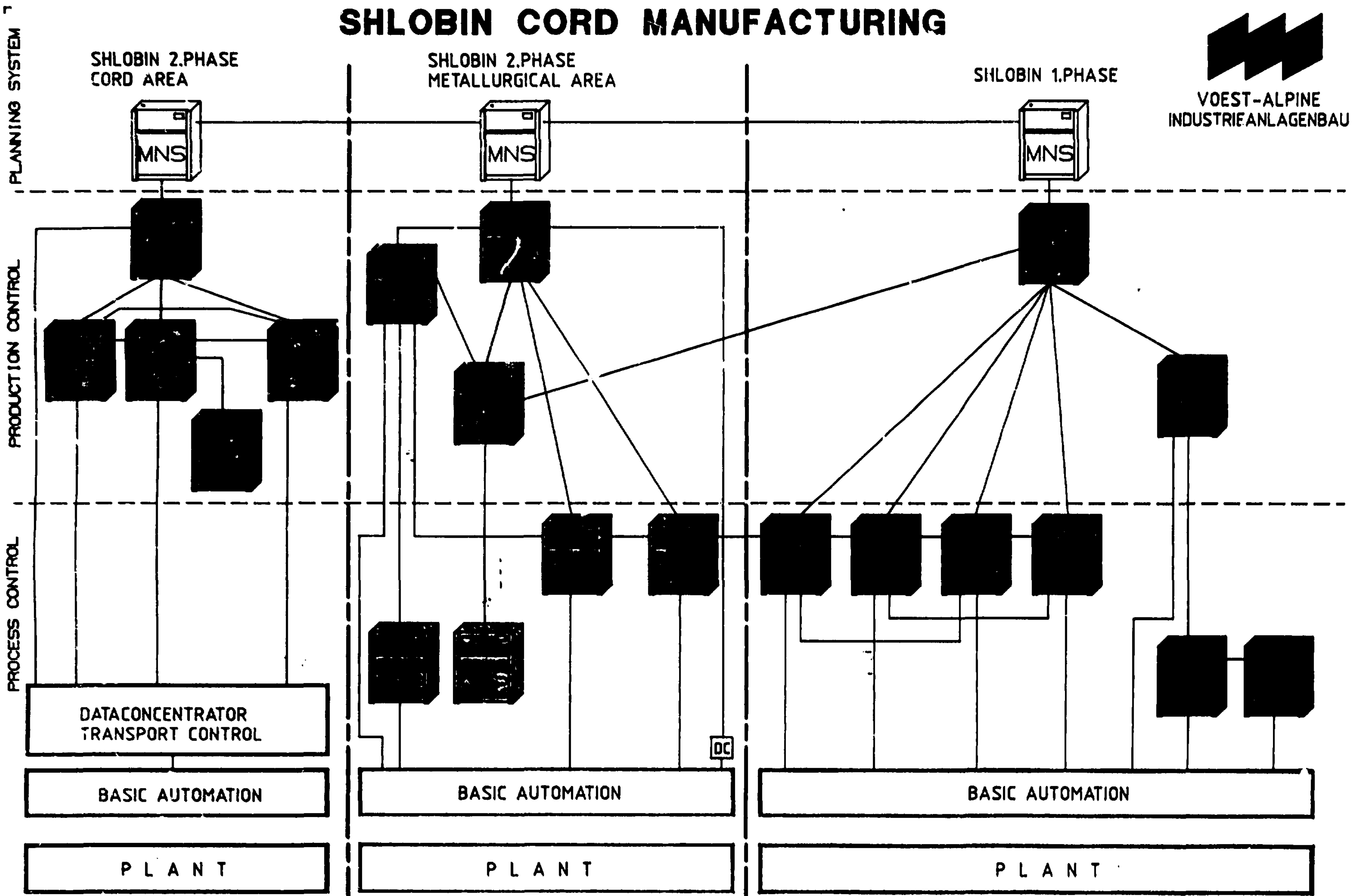

PRODUCTION PLANNING AND CONTROL LEVEL
ORDER ENTRY
EVALUATION OF PRODUCTION DATA
TIME SCHEDULING
LONG TIME DATA STORING
STATISTICS
DETERMINATION OF PRODUCTION LOTS
DETERMINATION OF SHIFT PROGRAMS
REPORTING
SINTER BLAST FURNACE
COLD ROLLING MILL
PLANT COORDINATION LEVEL
PLANT PACING
MATERIAL PACING
MATHEMATICAL MODELS
QUALITY CONTROL
REPORTING
STEEL PLANT
HOT ROLLING MILL



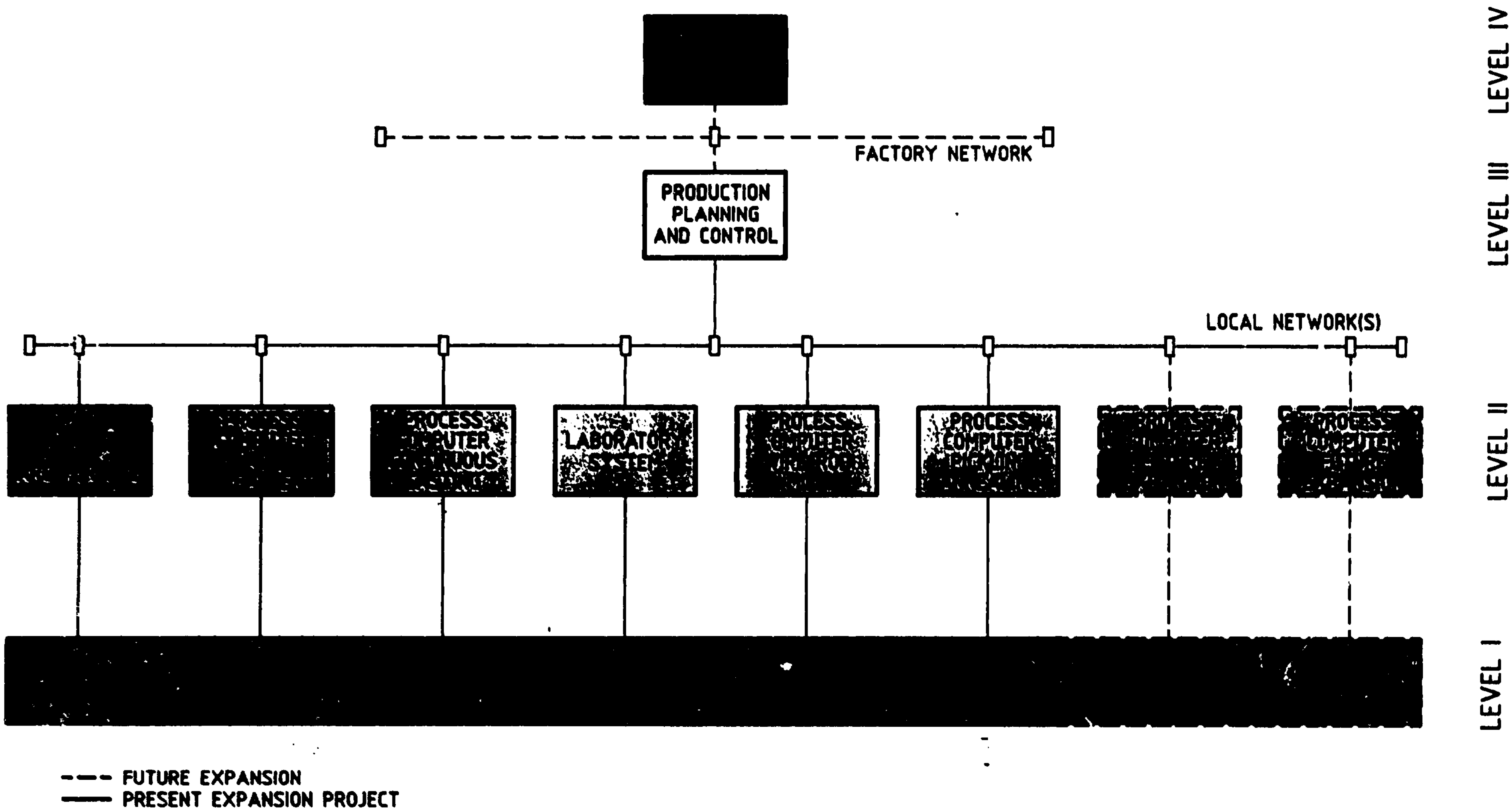
VOEST-ALPINE

INDUSTRIAL AUTOMATION
INTEGRATED AUTOMATION SYSTEM

SHLOBIN CORD MANUFACTURING



REPR4-AL0308A



VOEST-ALPINE INDUSTRIEANLAGENBAU

PERWAJA

AUTOMATION CONCEPT (HARDWARE ARCHITECTURE)

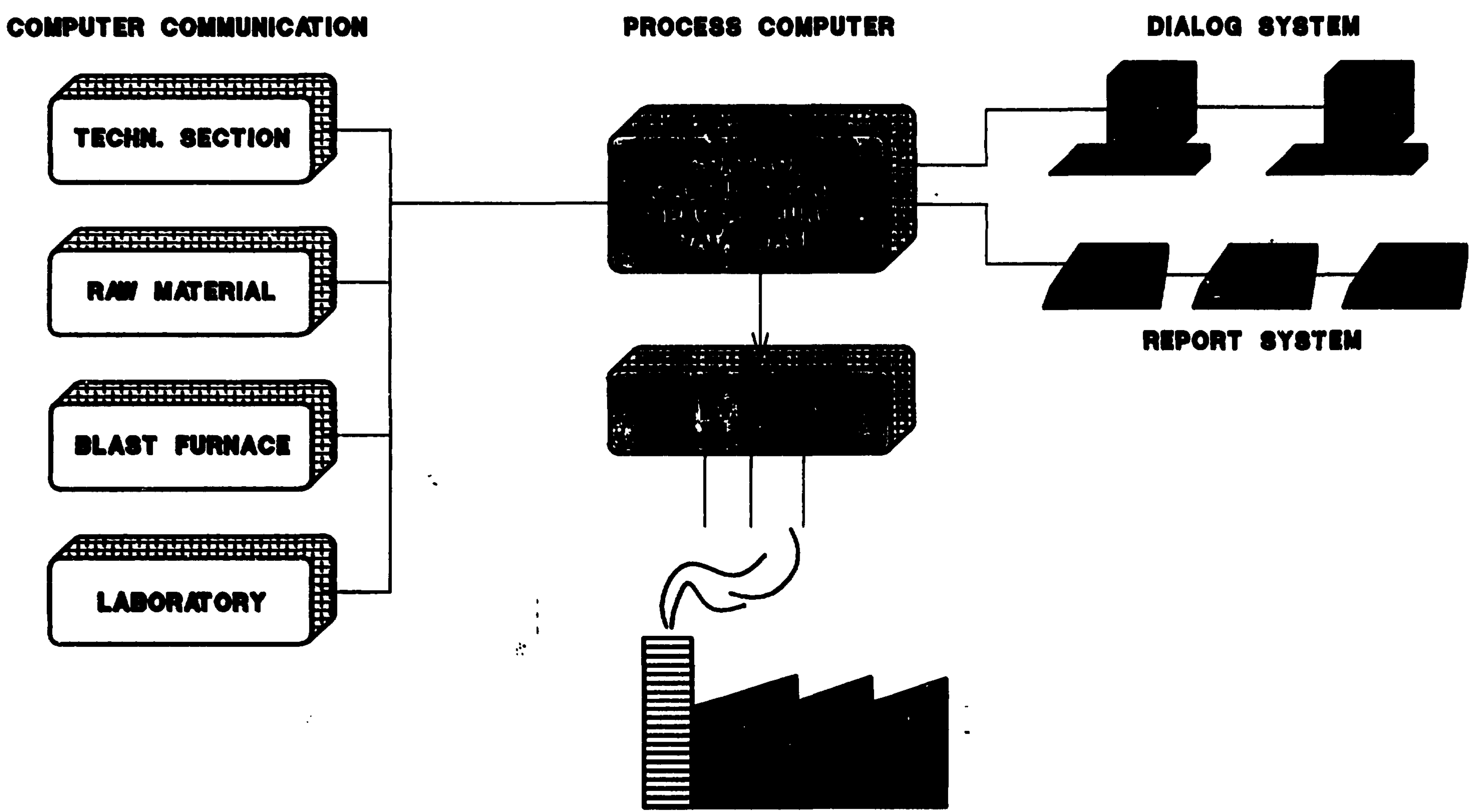
REPRA-AL0191A

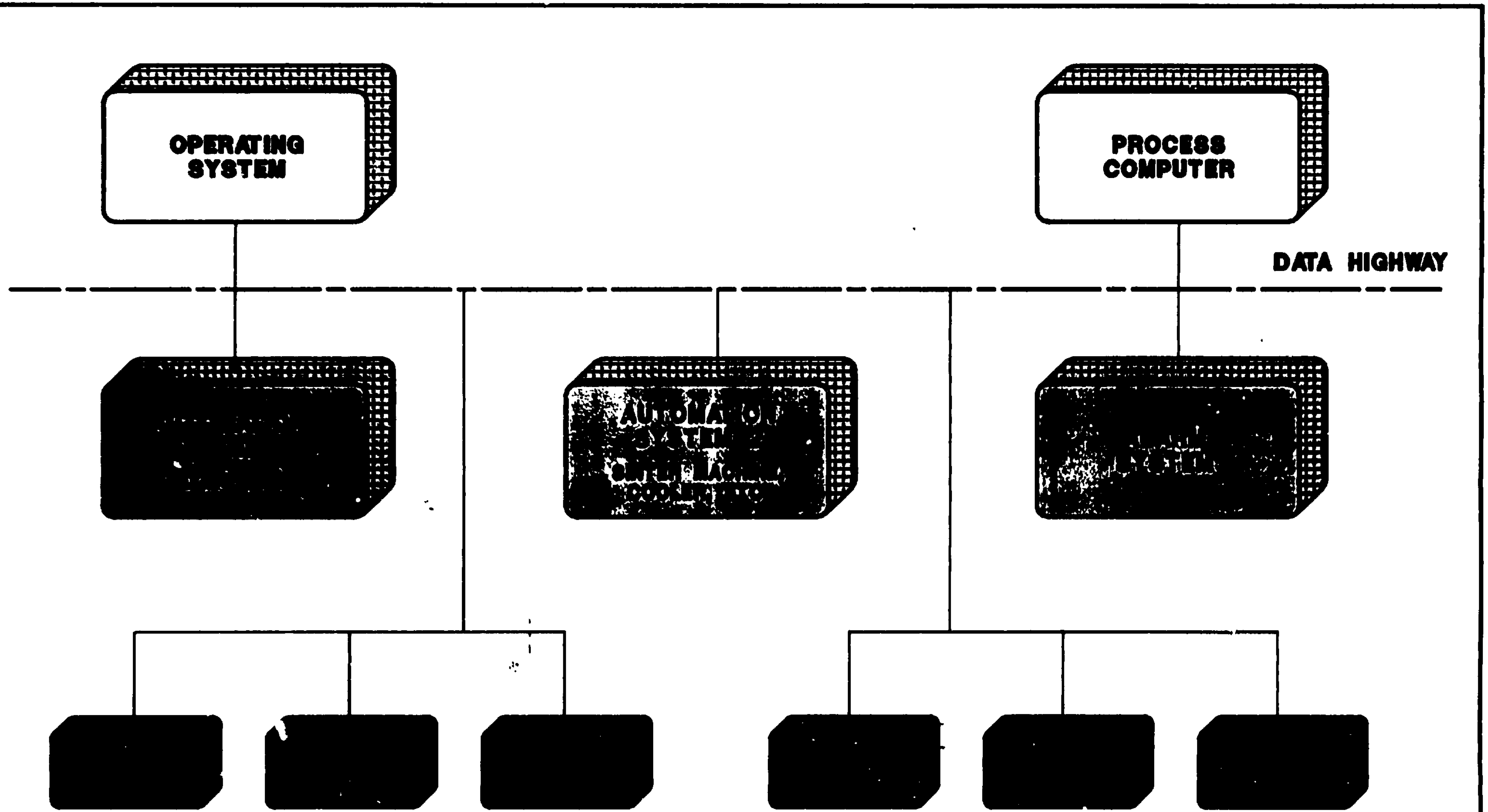
4.3.2. Sinter Plant Automation

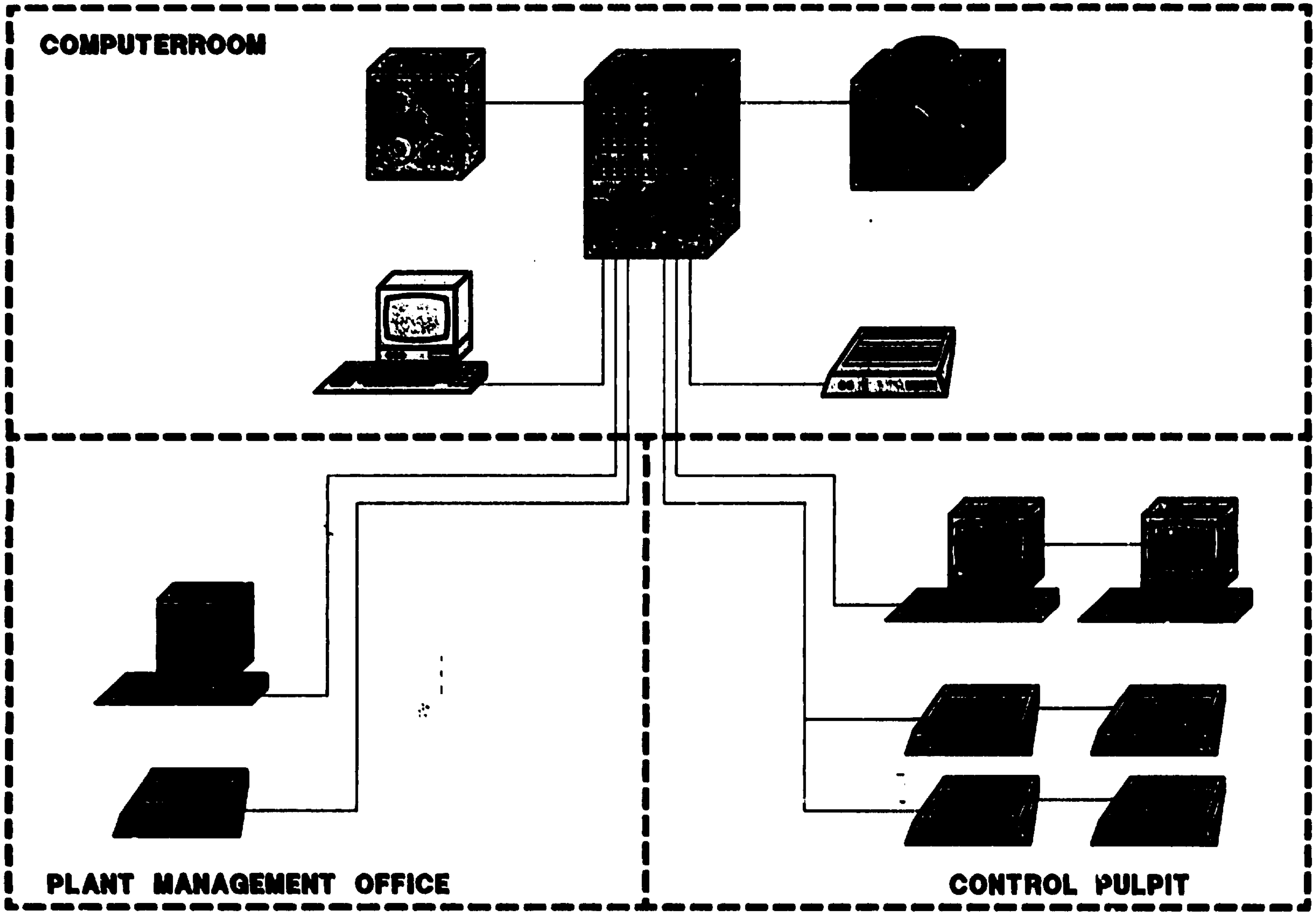
The following drawings show:

- Automation Area
- Configuration
- Hardware Configuration

of Sinter Plant automation.


COMPUTER COMMUNICATION
PROCESS COMPUTER
DIALOG SYSTEM
TECHN. SECTION
RAW MATERIAL
BLAST FURNACE
LABORATORY
REPORT SYSTEM

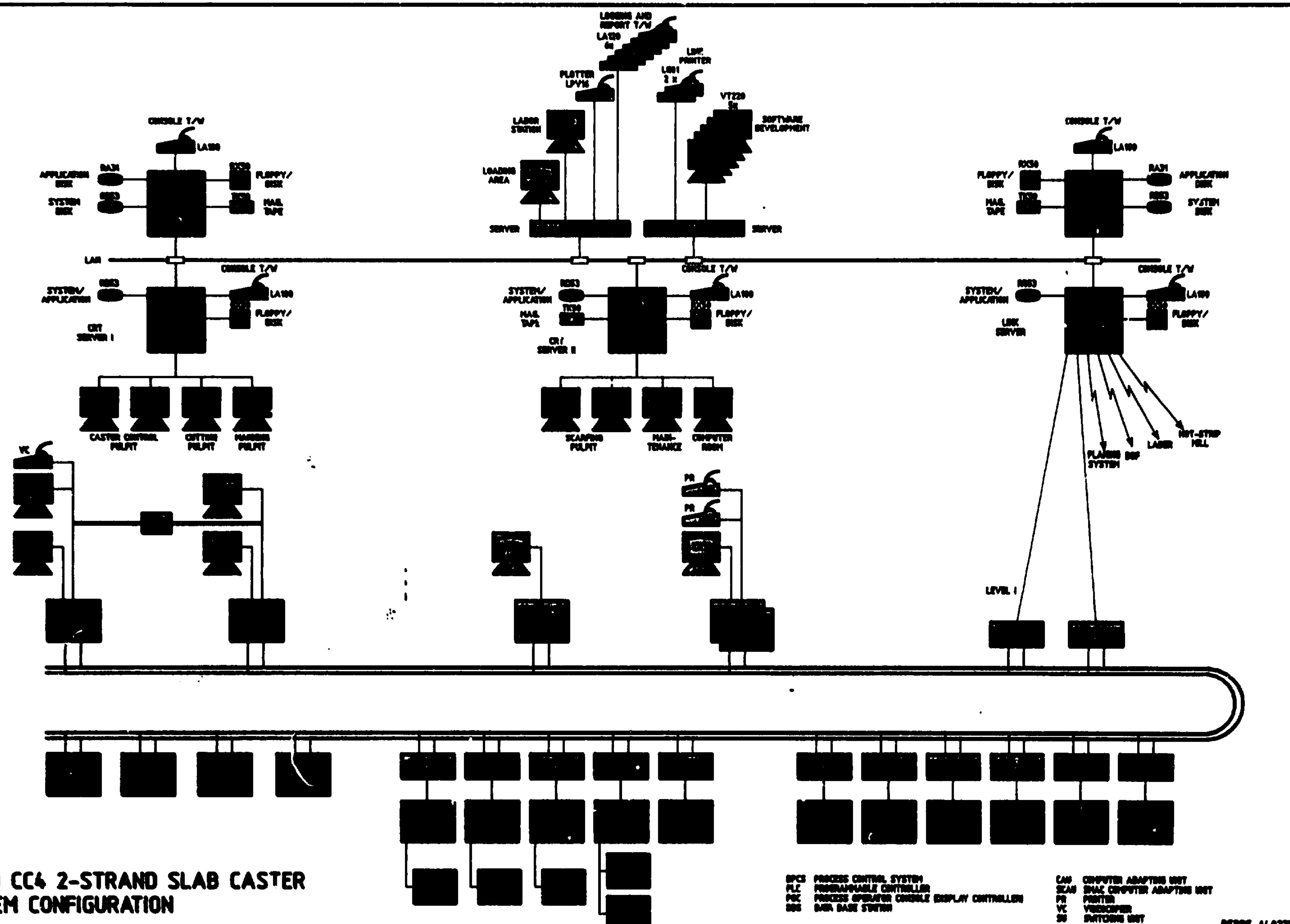

OPERATING SYSTEM
PROCESS COMPUTER
DATA HIGHWAY



COMPUTERROOM
PLANT MANAGEMENT OFFICE
CONTROL PULPIT

4.3.3. Continuous Caster Plant

The following drawing shows the hardware system configuration of the automation system of a two strand slab continuous caster plant.



POSCO CC4 2-STRAND SLAB CASTER SYSTEM CONFIGURATION