INFACON 7, Trondheim, Norway, June 1995
Eds.: Tuset, Tveit and Page
Publishers: FFF, Trondheim, Norway

INTELLIGENT CONTROL OF SUBMERGED-ARC FURNACES

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ABSTRACT

This paper is devoted to the discussion of an intelligent submerged-arc control system that relates the metallurgical and electrical parameters to the control loops. Futhermore, the system provides guidance on critical aspects such as electrode management, feed materials and their effects on the metallurgy, electrical characteristics of the furnace and overall plant management.

Keywords: Ferroalloys, control, optimization, artificial intelligence, operator guidance

INTRODUCTION

In spite of the many advances in the process control of submerged-arc furnaces, a large degree of human input is still required. This human input by the operator and the metallurgist is largely done by the innate 'feel' for the process although there are some modern methodologies available, e.g. artificial intelligence (AI) techniques [1-2], that could assist in these activities.

Mintek has worked in the area of furnace control for many years, and developments have evolved progressively. The Minstral control system [3-4], for example, was developed for the specific purpose of handling the control of electrodes and the transformers. Industrial installations in various countries have proved that the Minstral is a very good control system for the electrical side of submerged-arc furnaces. Not only does it provide a stable resistance control, resulting in more equal electrode penetration and consumption, but it also reduces variation in the electrical operating conditions. This provides a point of reference from which the metallurgy may be optimized by relating the critical electrical parameters such as electrode tip to bath resistance to metallurgical parameters. Anyone familiar with submerged-arc furnaces knows that this is a formidable task, which is very difficult to formalize in a phenomenological model.

From Mintek's interaction with the ferroalloy industry, major points of concern have been identified with regard to furnace operation. These center mostly around electrode management issues, such as on-line measurement of electrode length and the prediction of electrode breaks. It also appears that general logging, SCADA and DCS systems are not high priorities by themselves, probably due to the many such systems that are available. Most of these systems, however, do not really address the specific problems related to managing a submerged-arc furnace operation. With this in mind, Mintek is in the process of developing a system (FurnStar) as an expansion to the Minstral control system, to meet the above-mentioned requirements.

ARCHITECTURE OF THE SYSTEM

The basic philosophy that has been adopted is to use software packages that are commercially available and to integrate these in the most functional manner, rather than trying to develop everything from basics. This approach offers the following advantages

- The generic system architecture is independent of hardware, SCADA software and operating system.
- One can focus on issues that are important to the operation of the furnace (e.g. building of metallurgical models), rather than on system development.
- Users can integrate their own or commercial software packages. This permits modules of the software to be updated with new versions as they are released, without the risk of upsetting the performance of the whole system.
- This open architecture accommodates many different types of submerged-arc furnace i.e. each system can be customized for each application and can be updated and maintained by plant personal, if so required.

The basic architecture of the system consists of a SCADA system communicating with the Minstral control software. The SCADA system acts as a front end to various sub-processes which, together with the Minstral control system, comprise of the intelligent control as well as various sub-programs providing the guidance. A schematic overview of the basic architecture is given in Figure 1 below.

From Figure 1 it is clear that the electrical input provided by Minstral to the FurnStar system interacts with various other inputs, ranging from raw materials (preferably from a batching system), furnace conditions, as well as inputs from process models such as expert systems, neural nets, mass and energy balances etc.

The operating and metallurgical complexity of most submerged-arc furnace processes does not lend itself to the use of complex metallurgical models. A more empirical and heuristic approach (e.g. AI methodologies) was therefore opted for. This has the benefit of addressing the important practical production issues, as will be seen below, and no time is wasted building complex (and sometimes impractical) process models containing numerous, often dubious, parameters that have to be tuned to represent a certain window of operation.

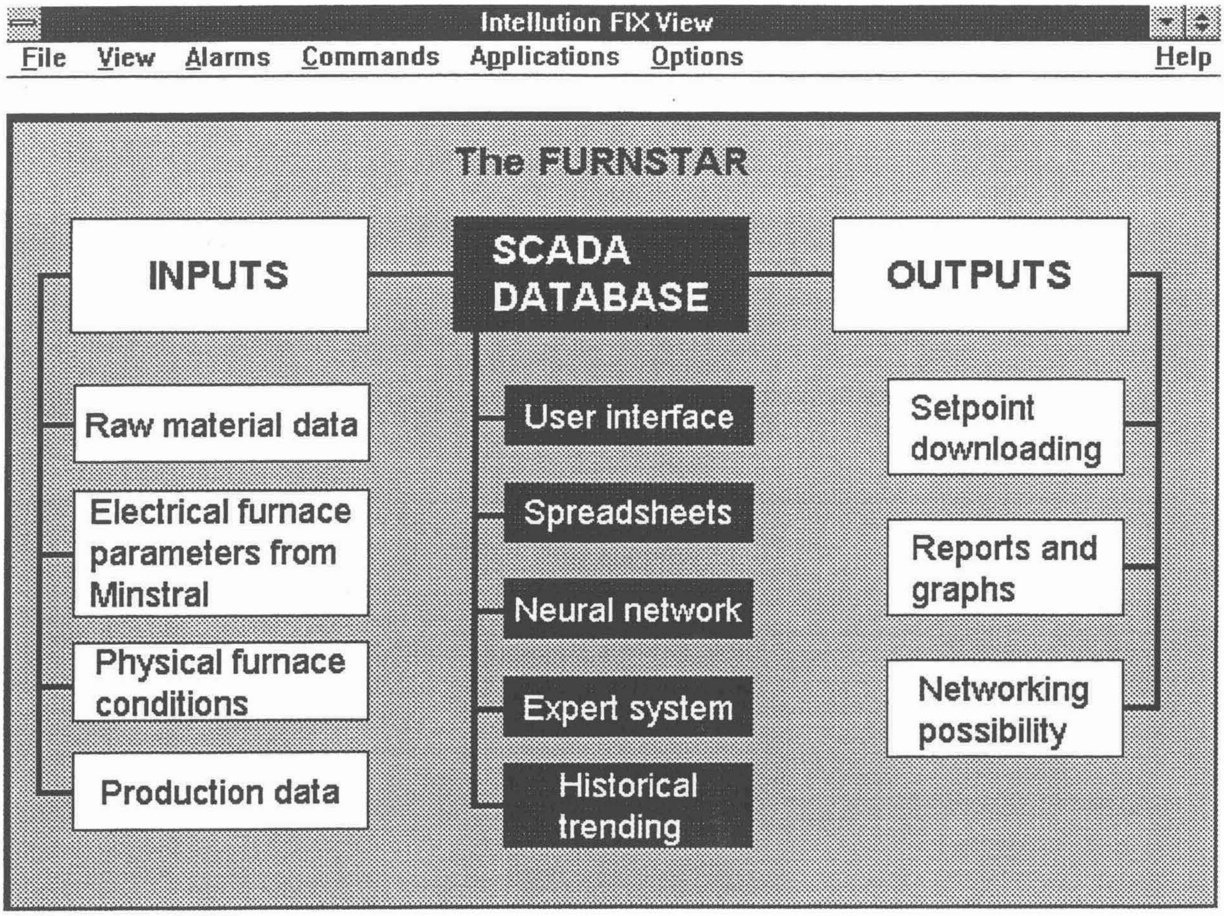

FIG. 1. Architecture depicted by a menu screen permitting access to the various sub-processes of FurnStar

The direct link to the Minstral controller enables datalogging of all the important electrical variables of the furnace. These variables are shown on a screen for easy viewing by the operator (Figures 2 and 3) and stored in the SCADA database. This database is then accessed by the Historical Trending function, which allows the user to trace trends back in time. The system provides features such as:

- an expert system offering expert advice on critical metallurgical and electrical issues, and also providing guidance on the selection of set-points
- neural nets which relate metallurgical and electrical parameters to control parameters
- a model of the electric circuit (as also used in the Minstral control system) to determine characteristic curves, which provides important information on the electrical operating point
- an electrode management system, giving assistance to the operator on issues such as baking, as well showing temperature profiles within the electrodes
- automatic load scheduling by downloading predetermined setpoints to the Minstral at the appropriate times

- trends of important operating parameters by the application of neural nets
- mass balances by the application of, among others, data-reconciliation methods and energy balances.

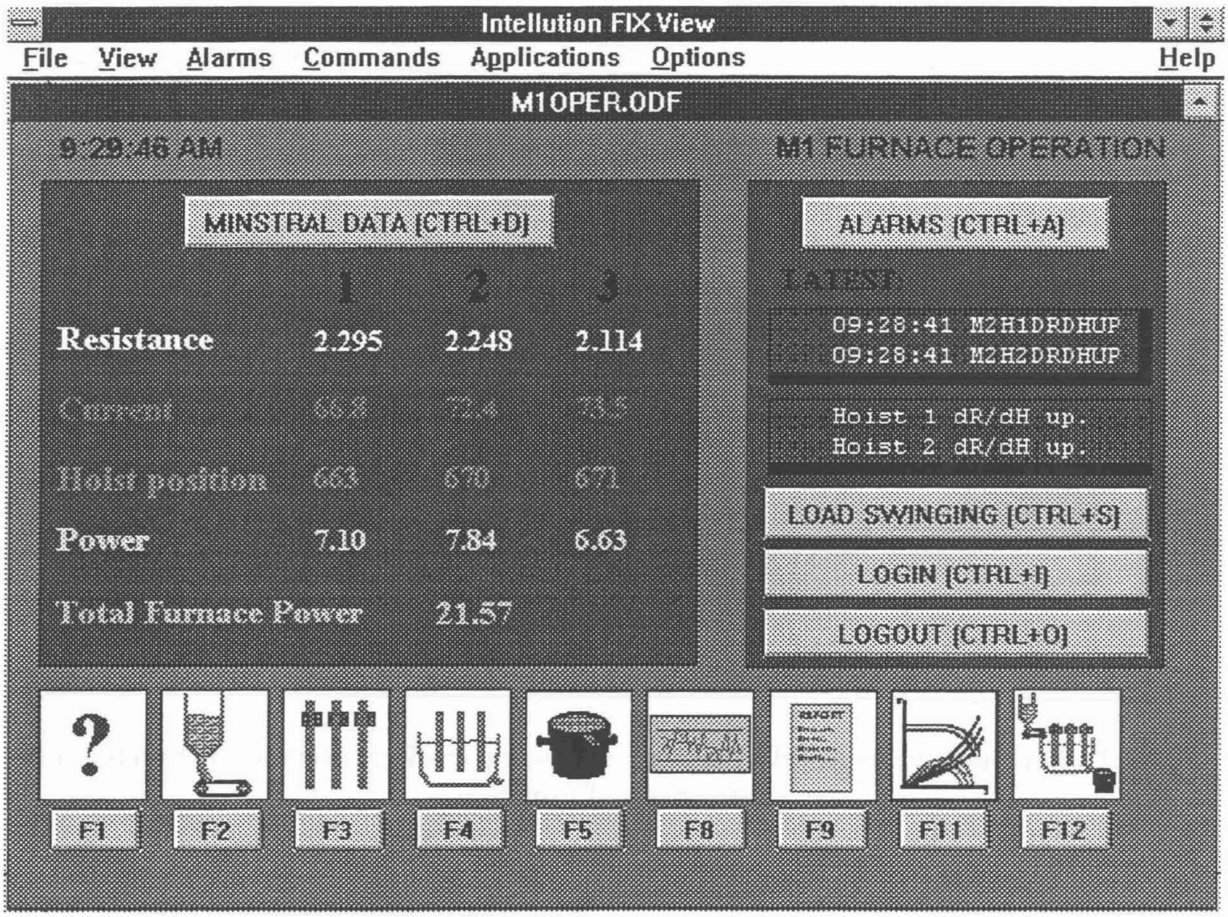

FIG. 2. Furnace operation screen (icon F3)

These features are directly accessible from the SCADA operator interface via the set of icons on the different screens, as can be seen in Figures 2 and 3. A number of these features will be discussed in more detail in the following section.

SYSTEM FEATURES

This section will be devoted to discussing the various features that are accessed by the various icons given in Figure 3.

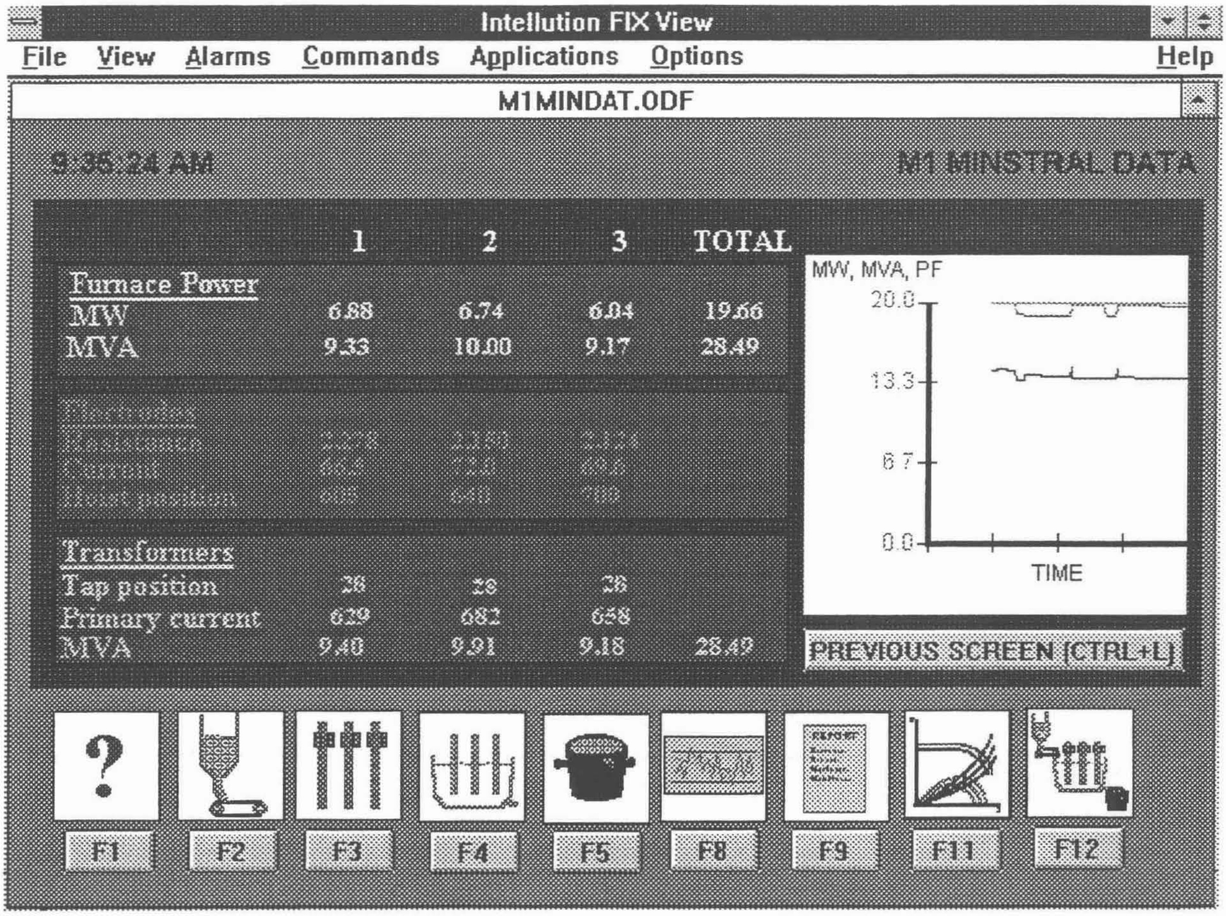

FIG. 3. Data screen in FurnStar summarizing various Minstral data

Characteristic Curves

The F11 icon is the direct link to the generic application that calculates a furnace's characteristic curves online as a function of voltage, resistance, power and current [3].

Given a specific resistance setpoint, the Minstral will control the power input to the furnace to a maximum within the constraints of available voltage and MVA as determined by the physical characteristics of the transformers and the current constraint due to the size of the electrodes. Figure 4 below shows the characteristic curves for a typical furnace. This enables the operator to see at a glance all the electrical limits or constraints to which the Minstral is controlling and optimizing power input to the furnace.

At the operator's disposal is also the Minstral data screen (Figure 3) summarizing the salient electrical data of the furnace.

Set-points and other control-related aspects are accessed and depicted by the operating screen iconized and driven by function key F4.

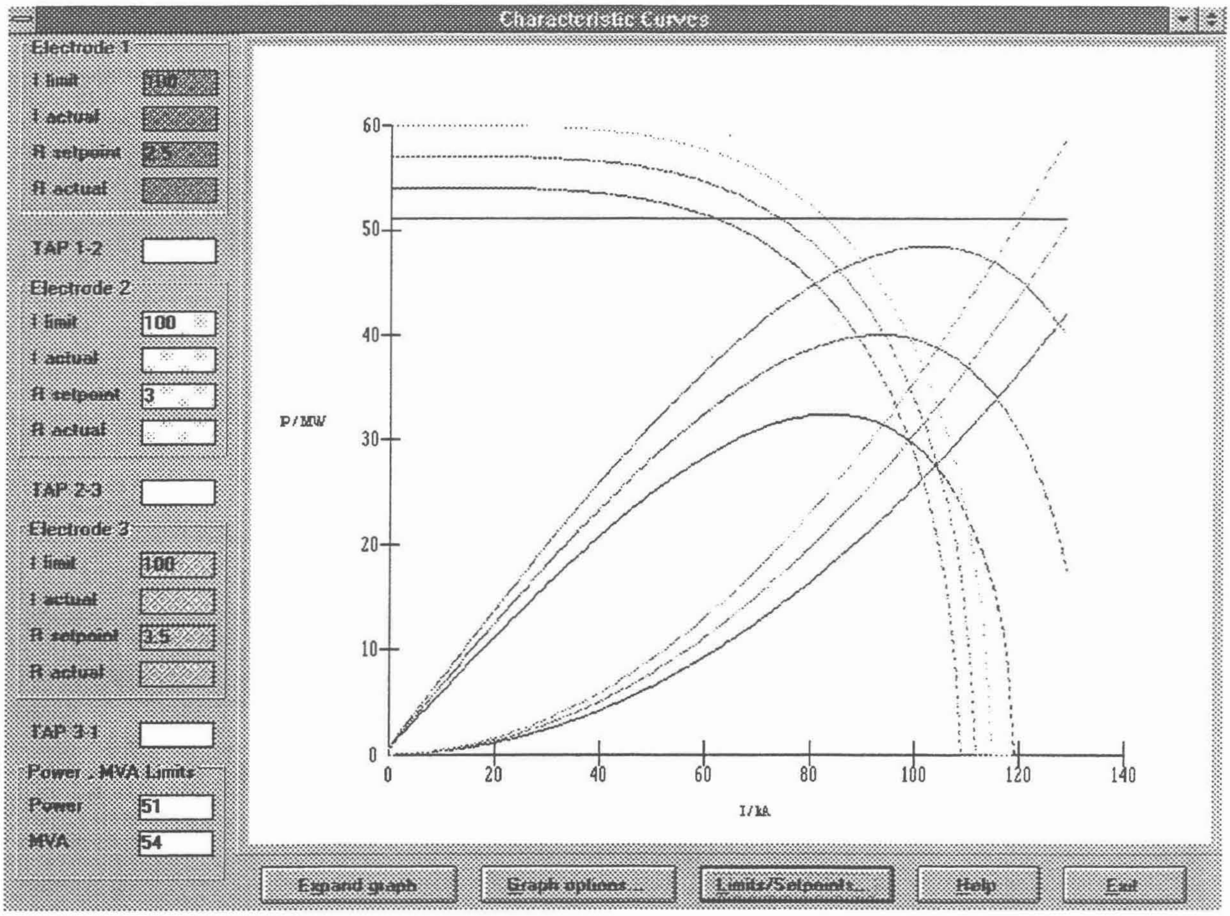

FIG. 4. Characteristic curves screen

All the electrical information on the furnace summarized by the characteristic curves, together with the metallurgical information on the specific process as described in the next paragraph, forms the basis of the expert system that advises the operator and metallurgist on specific setpoints and other issues for the furnace operation. The system has the ability to download the electrical setpoints and limits to the Minstral on command or automatically.

Load Scheduling

The ability to download setpoints to the Minstral via a serial link has made it possible to have a Load Schedule feature incorporated in the FurnStar system. Since the furnace operation changes with a difference in load, this intelligent control system determines a new optimum operating point in terms of power limits and resistance setpoint, taking the metallurgy and furnace conditions into consideration. This information is then downloaded to the Minstral at the appropriate time according to the load schedule.

Raw Materials and Production

The F2 and F5 icons takes the user to various Raw Material and Production screens, which are interfaced to a spreadsheet. With the aid of a suitable interface, access is achieved to the following features via the Data Input menu option in Figure 5:

- an interface to input raw material and raw materials analyses into a database (Figure 5),
- an interface to input production data, metal and slag analyses etc.,
- mass and energy balances as a function of the above,
- features to produce daily production reports and files that interface to the neural net, expert system and other software.

These data, as well as electrical data from the Minstral, can be combined and subsequently modelled by the application of techniques such as neural nets.

Figure 6 depicts one such result in which the recovery of Si in a silicon furnace is correlated to the carbon-to-SiO_2 ratio of the feed and electrode tip to bath resistance by the application of neural nets [1-2]. From Figure 6, it is clear that an optimum exists for the furnace under consideration, which in turn can be used to optimally tune the control system.

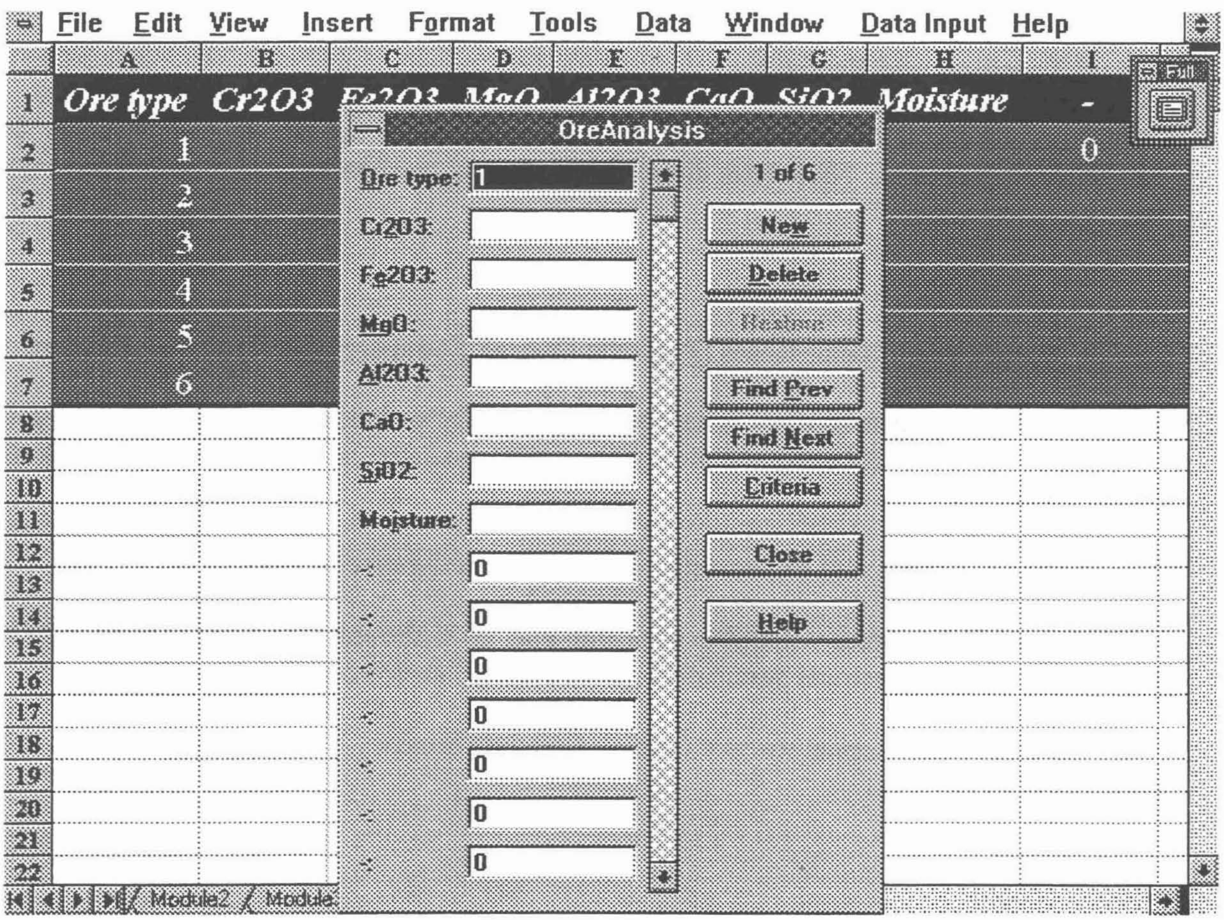

FIG. 5. Macro-driven interface to a spreadsheet to input raw materials, production and other relevant metallurgical data

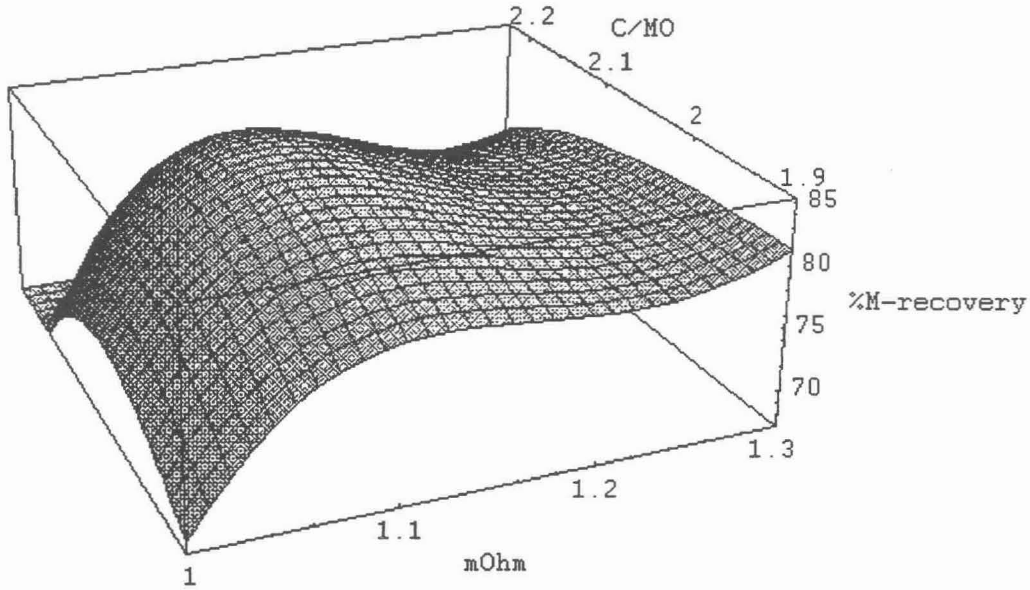

FIG. 6. Neural net relationship of silicon recovery as a function of C/MO of the feed and electrode tip to bath resistance

Historical Trending and Reporting

Function keys F8 and F9 drive these functions and make use of the facilities provided by the applied SCADA software. Numerous different trends may be accessed. Figure 7 depicts one of these.

Electrode Management using Roses (Realistic Overall Söderberg Electrode Simulator)

Guidance on electrode management is another important factor in the operation of submerged-arc furnaces. As a consequence, the Roses electrode simulator is being developed with the following features:

- electrode baking may be simulated using a finite difference model,
- temperature profiles within the electrode may be determined as a function of various electrode and electrical parameters, as well as the burden conditions, and
- the analysis of thermal stresses causing electrode breaks.

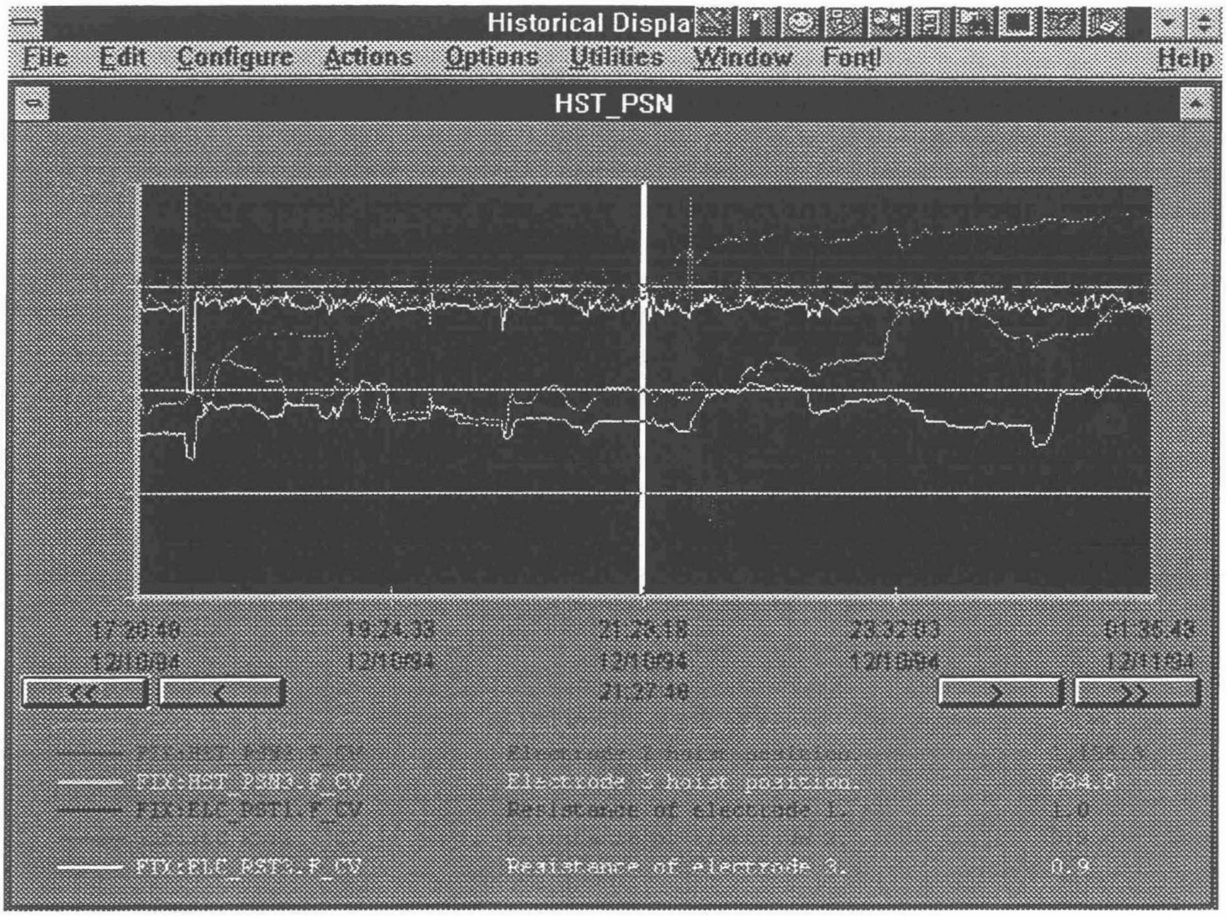

FIG. 7. Historical display of hoist position and resistance (one of numerous different screens)

OPERATIONAL BENEFITS

From the above, it is evident that the system provides the following benefits as a supervisory system to the Minstral furnace controller.

- furnaces can be controlled as a function of parameters not usually possible with standard control theory as applied in the Minstral software
- electrical and metallurgical parameters are simultaneously incorporated into the control algorithm, providing a basis for optimizing the furnace as a function of both the electrical and the metallurgical conditions
- a basis for managing the electrodes is provided
- an electrically and metallurgically balanced furnace operation is obtained under different load and metallurgical conditions
- an intelligent basis is provided for operator guidance and training, ultimately leading to better furnace operation, management and maintenance

- the effect of different feed materials on the control of the furnace and production can be modelled and incorporated into the control algorithm.

These benefits are not only available to furnace operators, but also to metallurgists and managers, especially if the network facilities of the SCADA software are enabled. This would permit the plant manager to view the furnace operation from his office.

Operators would have various tools at their disposal enabling them to infer furnace operation and obtain guidance on electrode management. Likewise, the operators would be able to formalize their innate feel of the process in terms of neural net models, expert system rules etc., and take part in the customizing of the system, hence tapping their vast practical knowledge.

Guidance is provided by the system on electrical aspects such as (i) suggestions on how, why and when furnace operating limits set by Minstral can/may be changed, (ii) reasons why and how to combat electrodes climbing out etc. Metallurgical guidance includes aspects such as (i) relating feed compositions to given products and (ii) fault diagnosis i.e. suggesting changes to feed or operation as a function of product quality, specific energy input, metal recovery/losses to slag, materials input, type of reductant, etc.

In summary, metallurgists benefit from knowledge gained by relating electrical and metallurgical parameters to optimize the energy input to the furnace, as well as to maximize recovery. This is the sort of tool that is needed to control the furnace operation by ensuring quality inputs to guarantee quality output.

CONCLUSION

FurnStar provides a system by which an optimal furnace operating point can be defined as a function of metallurgical as well as electrical parameters. Where as the Minstral furnace controller balances and optimizes the electrical operation of a submerged-arc furnace, the aim of the FurnStar system is to provide the user with metallurgical and operational guidance to allow for better overall furnace management, as well optimal controller set-points.

This system makes it possible to extend the proven economic benefits of the Minstral [5] by incorporating metallurgical and other non-electrical aspects into the overall control strategy.

ACKNOWLEDGEMENT

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