The Computer Control of Electric Smelting Furnaces

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SYNOPSIS

Elkem—Spigerverket a/s has constructed electric reduction furnaces for delivery to many countries and owns four ferro-alloy plants in Norway. The company has made an active pioneering effort in the fields of modern instrumentation and control during the last ten years. At present, computer-control systems operate successfully on reduction furnaces producing FeSi, FeMn, and SiMn. Substantial improvement in the operational performance has been a result of this work. The company is today prepared to furnish integrated computer-control systems of a modular concept to furnace customers.

BACKGROUND

Elkem—Spigerverket a/s is a main supplier of electric reduction furnaces on the international market, and also has a considerable interest in ferro-alloy production in Norway. For both reasons, the company has a vital interest in electric reduction furnaces and their operation. Reduction furnaces have grown steadily in size[1]. During the past two decades, the maximum furnace size, expressed in MVA of transformer capacity, has doubled roughly every seven years. This trend cannot, of course, go on for ever, but furnace sizes will probably continue to increase because of the following factors:

(1) lower capital costs per tonne produced for larger furnaces,
(2) increase in the cost of manpower, and
(3) continued increase in annual ferro-alloy production.

The increase in size has three interesting aspects.

Firstly, the production in these units is, of course, very large. In some electric furnaces, the consumption of raw materials is about 1000 tonnes per day. This again means that small improvements in the operation may rapidly turn into a lot of money.

Secondly, with relatively few large units, it is possible to spend more money on instrumentation and control for each furnace, and, as just mentioned, this may be a very profitable investment.

Thirdly, large furnaces behave in a very sluggish way, and slowly developing deviations are not easily detected by furnace operators. Therefore, large furnaces have more need for automatic control than small ones.

This is the general background to the work that we have been doing for the past years on electric smelting furnaces with a computer as the control aid.

WHY COMPUTER?

From a control point of view, the electric smelting furnace is characterized by

long time lags and
problems with measurements.

The time lag is partly due to the time the charge materials take to be transported from the scales and into the furnace. This part of the time lag may be reduced with better-designed charging systems.

Some of the time lag, however, is inherent in the process itself. For instance, some processes have the ability to accumulate coke over time, or to deplete already accumulated coke[2]. We shall have to live with this type of time lag.

These time lags tend to make the process unstable. It takes time from when a control action is executed (for instance, when the amount of carbon in the charge is changed) until the change can be detected in the process itself. One may therefore overshoot the target, and oscillations around the optimum conditions may occur.

The problems on the instrumentation side are very real to all operators. We have no solutions, at least not economic ones, to the problems of measuring continuously the composition of the raw materials being charged to the furnace, the process temperatures, or the immediate production and composition of the products.

How, then, can the computer help us with these problems?

The computer cannot, of course, make up information that is not in some way inherent in the information we receive from the instruments and data. But the computer has a practically unlimited memory and does its job untiringly, so that

(1) we can keep complete track of the raw materials, have different feed mixes in different parts of the furnace, and at all times know the consumption of materials,
(2) the measurements available can be combined in the best possible way to give the data we are interested in, and
(3) all calculations, monitoring, trend evaluation, data logging, and control actions are done consistently and independently of changing operators.

Earlier, the price of the computer itself was an objection to its use in many applications. We have in recent years, however, seen dramatic reductions in computer prices. With increasing furnace sizes, increasing cost of manpower, and decreasing cost of computers, the question today is rather to what extent we can utilize this tool for electric smelting furnaces.

COMPUTER SYSTEMS IN ELKEM—SPIGERVERKET A/S

For the past seven years, our company has worked consistently on the development of computer-control systems for electric reduction furnaces, and also for other metallurgical processes. Altogether, ten process computers are now in operation or under installation in the company's plants in Norway. These are as follows.

(1) 2,7 MVA ferrovanadium arc furnace in Bremanger. One PDP-8S (4K) computer controls the weighing

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and charging of raw materials and the electric conditions (voltage, current, and load), and adjusts the charge recipe according to on-line spectrographic analyses. This computer-control system has been in continuous operation since early 1968. It was the first process computer installed in the company.

(2) 18 MVA ferrosilicon furnace in Bremanger. One Nord-1 (8K) computer controls the carbon addition, the electrode movements, and the electrode slipping. The computer application also includes extensive data logging. This system has been in operation since 1970.

(3) Multi-furnace control system in Bremanger. A computer system comprising a Nord-1 with 32K core memory and a 256 K magnetic-drum storage was installed in 1972. This computer has the capacity for controlling several processes simultaneously. So far it has operated on a 51 MVA ferrosilicon furnace, and the next process to be connected to this computer is a 33 MVA closed furnace for pig iron.

(4) 39 MVA ferromanganese—silicomanganese furnace in Porsgrunn. A Nord-1 (16K) computer has been in operation since 1970. The control system was developed for operation on ferromanganese production[2], with carbon control, electrode regulation, electrode slipping, data logging, and reporting of furnace-operation data as the main functions. Since mid-1972, the furnace has been operating on silicomanganese production, and, except for the carbon control, the computer system has been in continuous operation on mainly the same programmes as for ferromanganese.

(5) 48 MVA ferromanganese furnace in Porsgrunn. One Philips P-860 (12K) computer has been installed to control the batch weighing and charge-transport system for this furnace[3]. The computer weighing system has several advantages of its own, and provides a firm basis for further sophistication of the furnace control. The system has been operating since January 1973.

(6) The control system for the 48 MVA ferromanganese furnace mentioned above is being extended by the installation of a Philips P-855 (16K) computer in addition to the weighing computer. The complete furnace control system is scheduled to be in operation by mid-1974.

(7) 50-tonne UHP arc furnace for melting steel scrap at Christiania Spigerverk, Oslo. A PDP-8S(4K) computer is installed to control the electric input and optimize the melting sequence[4]. The computer system has been in operation since 1968 on this furnace, and the system expertise has been exploited commercially.

(8) A computer system with Nord-10 (32K core and two discs) to be implemented during 1974 at the steelworks of Christiania Spigerverk, Oslo. The computer system will be used for production planning, optimization, and supervisory process control.

(9) At the aluminium melting plant in Mosjoen (50% ALCOA), an IBM 1800 process computer system has been installed. The system has been in operation on pot-line control since early 1972.

(10) A Philips P-855 computer (16K core and disc) is installed at the R&D Centre in Kristiansand for programme-development purposes.

The experience with process-control computers within Elkem—Spigerverket a/s is fairly extensive by now, amounting to a total of approximately 8 million N.Kr. in equipment costs and 30 man years in development effort, with half of this on reduction furnaces. Although some of the projects have been conducted on plants internally, there has been an active cooperation with exchange of experience between the different groups.

The computer-control projects at the manganese-alloy plant PEA in Porsgrunn (items 4, 5, and 6) have been aimed direct at the engineering and marketing activities for the electric reduction furnaces of our Engineering Division. The achievements on computer control of ferrosilicon furnaces at the Bremanger smelting plant (items 2 and 3) have been incorporated in this development scheme, and a computer-control system generally applicable to all types of reduction furnaces has now been designed. This system, which is based on the principle of modularity, is described in the next section.

A MODULAR COMPUTER-CONTROL SYSTEM FOR ELECTRIC REDUCTION FURNACES

A computer-control system can be designed and implemented in a number of different ways, and at many levels of complexity. In fact, because the computer 'can do everything' with regard to data storage, calculations, data handling, and presentation, one of the main problems the system designer must face is that of selection and limitation. This is the paradox of the digital computer, which is also valid for its application on a smelting furnace.

From experience with the computer projects reviewed earlier in this paper, we have been able to specify the applications of a computer for electric reduction furnaces, and, we believe, at the proper complexity level.

Most of the applications in question are generally valid for all types of reduction furnaces, and need only minor adjustments to allow for variations between different plants. A few applications (for instance, carbon control) are strongly process-oriented and require control strategies for the particular process. There may be additional problems to be solved by the computer that are related to one particular furnace installation.

A modular computer system has been designed in such a way that the differentiation required to cover a majority of furnace installations is accounted for by the 'plugging in' of various application modules into a basic structure. This principle of modularity reduces the system development and programming costs for each particular installation. It eases the standardization, which is a necessity for an engineering marketing company, for reasons of step-by-step implementation, service, and system updating. The concept of the modular system is illustrated in Figure 1.

A data base including all available measurements, and calculated and operational data, serves as a common information source for several independent application modules. These are:

- furnace-operation reporting,
- operator communication,
- electric control,
- electrode slipping, and
- carbon control.

These application modules are programme packages that belong to the computer software system, as does their common data base.

The various application modules are associated with their particular peripheral hardware or furnace equipment, as indicated in Figure 1. The weighing and charging

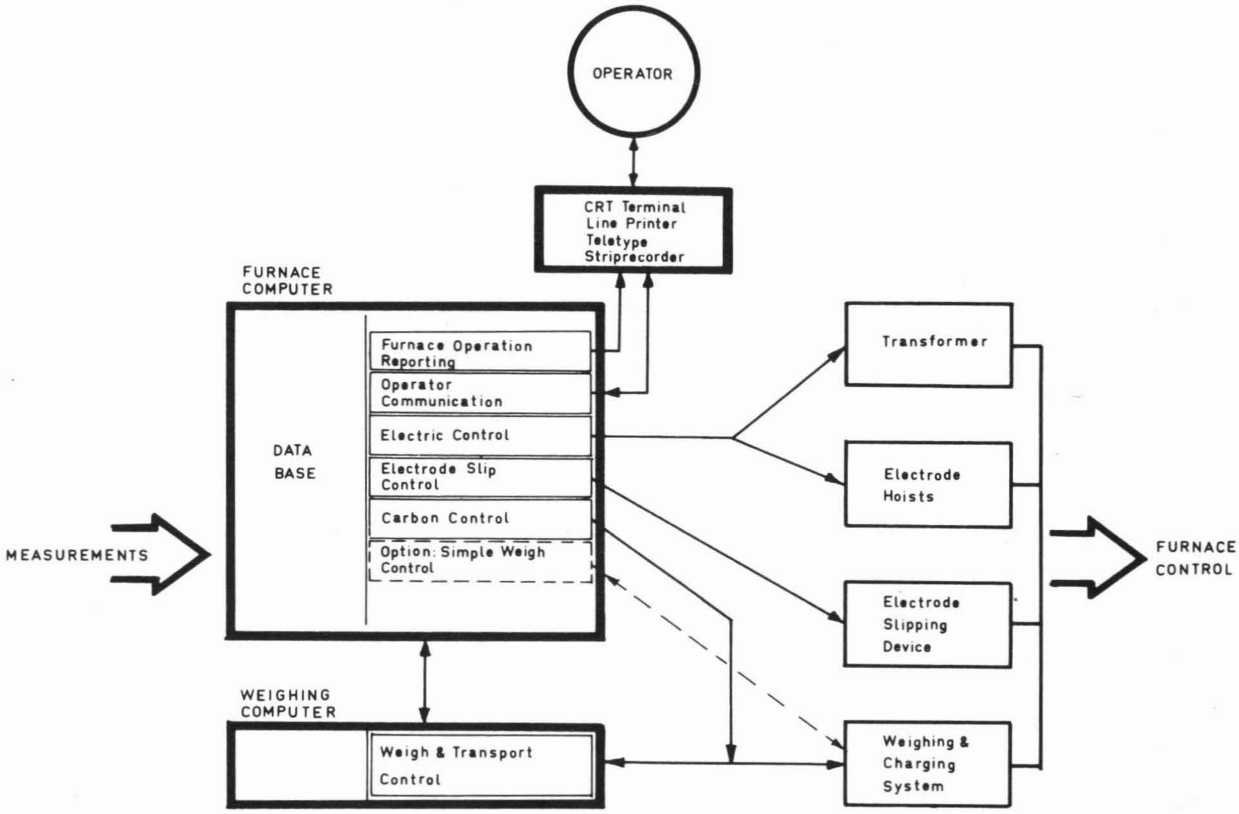

Figure 1

Integrated computer-control system for electric smelting furnaces

system for raw materials is of particular importance, because the carbon-control loop depends fully on this system as the 'final control element', and so does any other control that involves adjustments of the charge composition.

The conventional furnace weighing and transport system does not normally meet the requirements of advanced furnace control as a practical control tool. It may therefore be necessary to improve the accuracy and controllability of the weighing to meet these requirements. It has been found that the computer can be utilized favourably for this purpose.

A computer batch-weighing and transport-control system has been developed as a separate module[3], which can be installed and utilized separately on a permanent basis. It can also be considered a first step towards an extended system for integrated control, thus offering plant management the possibility of entering the computer field in a modest and non-committal way.

The main functions of the computer weighing module and the previously mentioned application modules are described in more detail in the following.

Computer Weighing System

This is a computer control system adapted to the batch-weighing equipment normally delivered with modern Elkem furnaces to achieve

(1) improved accuracy with automatic taring and overshoot compensation,
(2) individual charge corrections and feed-mix control for different furnace hoppers or groups of hoppers (furnace zones),
(3) optimum transport control, and
(4) complete reporting on raw-material consumption.

Furnace-operation Reporting

Reports are printed out at regular time intervals to give essential operational data. These data depend partly on process on-line measurements, and partly on manual inputs. Except for a few particular measurements, only well-known measuring techniques are applied. The main difference between the various reduction-furnace processes is the difference in gas measurements between open and closed types of furnaces.

The furnace-operation reports for a closed type of furnace (e.g., ferromanganese) will typically include

- all relevant electrical variables for each electrode,
- electrode holder positions and slipping data,
- gas flowrate,
- gas temperatures,
- gas analysis (CO, CO_2,H_2,O_2),
- raw-material consumption,
- calculated metal production,
- calculated specific-energy consumption, and
- calculated electrode-penetration estimates.

Operator Communication

Besides the report printouts at regular time intervals, the communication between the operator and the computer system is aided by a TV display unit (c.r.t. terminal) with an adjacent keyboard, a teletype terminal, a line printer, and a multichannel strip-recorder.

The TV screen can display on-request information on single variables or prespecified groups of variables that naturally belong together.

Operational changes to control parameters are introduced from the keyboard while displayed on the screen. In this way, manual inputs can conveniently be verified before they are entered into the computer.

The teletype terminal covers the same functions as the TV display for back-up purpose, and is also used to print alarm messages. It can be used further as a data logger for specially designed experiments. The line-printer writes the operational reports. The multichannel strip-recorder is used to display the long-term trend of selected variables. The paper is fed at a low rate so that a record of several days is visible to the operator.

Electric Control

The computer is used to control the electrical conditions by electrode movements and voltage changes. Alternative strategies can be applied according to the power-supply constraints for the installation in question, to achieve maximum load within the plant's safety limits.

The control of the three electrodes can be intercoupled to give a symmetrical load distribution.

The computer control can work on the setpoints of the conventional electrode regulators, or act direct on the electrode hoist actuators, thus completely replacing the functions of the regulator.

Electrode Slipping

Computer control of the electrode slipping helps to ensure optimum operation with respect to baking conditions when Söderberg electrodes are used, by even distribution of the slipping. At the same time, it tries to maintain a constant length of the electrode tips, and to keep the electrode holders within their best operating range.

With prebaked electrodes, the computer's slipping system can be utilized to control the electrode-joint position relative to the current clamps.

Carbon Control

An effective feed-back control strategy for the carbon balance has been developed for the ferromanganese process. This strategy is based mainly on gas analysis and gas-temperature data.

Also for ferrosilicon smelting, a carbon-control system has been established, which is based on information deduced from the electrical measurements, together with a fume-density measurement and electrode-holder positions.

The improved accuracy offered by computer weighing tends to reduce the primary disturbances in the carbon balance. Although on-line coke-moisture measurement is expensive, this may be recommended for the processes for which feed-back control strategies have not yet been established.

DOES COMPUTER CONTROL PAY?

A general answer to this question cannot, of course, be given. Let us, instead, start pointing out some of the obvious areas for improvements in furnace operation with computer control.

(1) Improved weighing accuracy by computer control reduces the variations in the established charge composition. Thus, one of the primary causes of process disturbances can be minimized.
(2) A carbon-control strategy, using feed-back signals from the process itself, can be applied more consistently with a computer, and the corrections to the coke addition can be effected earlier and more accurately than with manual control. This will most likely give more constant operation, closer to the optimum conditions.
(3) With computer control of the slipping of the electrodes, the element of human error has been removed, and a safer, more consistent electrode operation results. We can expect this to lead to fewer electrode difficulties and a possible increase in operating time.
(4) Computer control of the electric conditions should allow us to utilize the electrical system in a more efficient way, resulting in a possible increase in the furnace load and the product.
(5) A closer control of the process with fewer variations around the desired point of operation could lead to reduced maintenance work and down-time on the furnace.

The improvement that can be achieved in different plants depends strongly on the quality of the operation. But the experience with existing computer-control systems in our own company may give an indication; so let us take some examples.

(1) We know[3] that, even in a modern weighing plant, there may be long-term errors in the proportion between ore and coke of up to 5 per cent. With computer control, this has been reduced to below 1 per cent.
(2) On a ferromanganese furnace[2], there was strong improvement after the introduction of computer control. The spread of the weekly results was strongly reduced, as shown in Figure 2, resulting in a reduction in the average power consumption of 12 per cent. The operating time increased from 93,8 to 96,2 per cent, and the furnace load increased by 6 per cent. This improvement can be attributed partly to the automatic control introduced, partly to the extended data presentation as an operator's aid, and partly to the increased process knowledge resulting from the computer project.

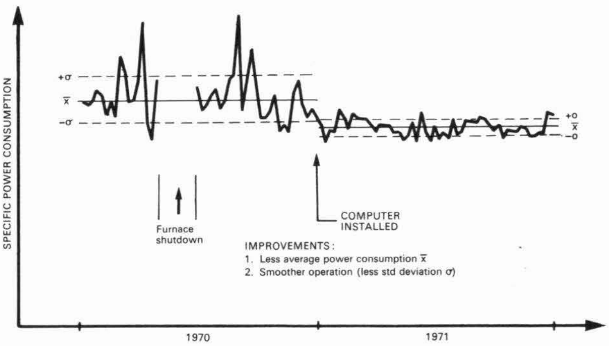

Figure 2
Improvement with computer control
(specific power consumption for a ferromanganese furnace, weekly average values before and after computer control)

(3) On an 18 MVA ferrosilicon furnace, we obtained promising results with computer control, even if some unrelated changes in the furnace operation make a direct comparison between results before and after the introduction of the computer more difficult. For comparable periods, we have, however, increased the furnace load by 11 per cent and decreased the power consumption by 7 to 8 per cent, resulting in an increase in production of 20 per cent.

So, even if it is difficult to make a fair comparison between operating results before and after computer control, and even if conditions vary greatly from plant to plant, there are indications that considerable gains are within reach when this new aid is introduced to furnace operation.

SUMMARY AND CONCLUSION

With the increasing size of electric furnaces and decreasing cost of computers, the important question today is: To what extent can we utilize the computer in the control of electric smelting furnaces? Elkem—Spigerverket a/s has developed a system in which the computer handles the weighing and transport system, the control of the electric parameters, the slipping of electrodes, and data logging and monitoring. This system is independent of the product made in the furnace. In addition, strategies for the control of the carbon in the charge for the ferromanganese and ferrosilicon processes have been developed.

We have found that the use of computers for control has been very profitable in our own plants, and we believe that it will also be profitable in other places. We are therefore ready to deliver computerized control systems with future furnaces.

Our experience so far with compatibility between computer and furnace equipment is incorporated in the equipment we shall deliver from now on. Our furnace equipment therefore lends itself readily to what has already been developed and what may be developed in the future on the computer-control side.

Elkem—Spigerverket a/s has invested several years and a considerable amount of money and manpower to arrive at its present status. In return, we have solved a number of problems on the way. We do not think that the control systems we have already developed are the final ones, but we know that further improvement can be accomplished in the future. We think that what has been developed so far is a good basis for further work, and we believe that future improvements can be incorporated readily in the design concept of a modular system.

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In his presentation, **Mr Arnesen** explained why computer control could have advantages, especially with large production furnaces. He pointed out that most hardware and software were usable on most ferro-alloy processes. For instance, the raw-material control equipment was not process-dependent and could therefore be used wherever material control was envisaged.

Unfortunately, no more technical details, other than the ones presented in the paper, were given, although there was an impression that the audience would have liked to hear more information. Nevertheless, Mr Arnesen stressed that Elkem was now prepared to install such systems outside their own ferro-alloy plants. He also believed that, with the introduction of a computer, the monitoring of the process became easier and better understood, thus setting off the effort of getting used to a process controller.

DISCUSSION

Dr D. Slatter:*

When will the control of ferrochromium and ferrochromium-silicon furnaces be investigated?

Mr Arnesen:

All our control modules, with one exception, are process independent and can be used also for chromium-alloy furnaces. The carbon control module is the exception and is also very important. As Elkem has no chromium-alloy furnaces, we shall have to work on the carbon control module for chromium-alloy furnaces in collaboration with an interested customer.

Mr A.L. Melvill†:

Mr Arnesen has indicated the advantages of computer control in areas such as the weighing of raw materials, power efficiencies, and operating time. To assist in the evaluation of those benefits, will Mr Arnesen indicate the additional outlay necessary to incorporate the various computer systems on a furnace installation, where the outlay is expressed as a percentage of the basic furnace cost? Secondly, will he give the operating cost as a percentage of the overall production cost on a furnace producing standard ferromanganese or ferrosilicomanganese?

Mr Arnesen:

The cost for computer control of our weighing system is approximately R80 000 and about three times that for the total system. This figure includes everything except modifications to buildings and cables between process and computer. The operating costs are very low because no extra manpower is needed, although, if there were no reasonably efficient instrument maintenance in the plant, an instrument technician would have to be employed to maintain and check instruments.

Dr R.A. Person‡:

Will Mr Arnesen please comment on the bases for the carbon control system for ferrosilicon smelting?

Mr Arnesen:

Elkem are not willing to disclose all the details of carbon control for the ferrosilicon process. In general, it is based on a combination of information from an estimate of the position of the electrode tips in the furnace, a special electrical signal, and a measurement of dust concentration in the stack.

Mr A.H. Mokken§:

What sampling and analytical techniques are used for monitoring the variations in the quality of the raw materials and the final products?

Mr Arnesen:

Although sampling in analytical practice varies at different plants, nowhere has it been necessary for the sampling practice to be changed or new analytical equipment to be installed because of the computer. On only one of our computer-controlled furnaces – a ferrosilicon furnace – has a nuclear instrument been installed for coke-moisture measurement.

Mr G. Sommer◊:

Will Mr Arnesen supply some information on the slip-

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§Union Carbide Corporation Ltd, South Africa.

◊National Institute for Metallurgy, South Africa.

ping indicators on computer-controlled furnaces. I should also like some information on the price of computer-compatible instrumentation compared with the price of standard instrumentation.

Mr Arnesen:

Specially designed slipping indicators have been used with computer installations. A number of alternative designs have been used because the reliability varies between furnaces, depending on the equipment, mantle-welding practice, etc. Magnetic coupling between the indicator wheel and the electrode mantle has been used successfully, as well as pulse switches and high-resolution potentiometers. 'Computer compatibility' means standardized d.c. signal levels for all analogue signals, e.g., 0 to 20 or 4 to 20 mA. This is now becoming standard, and the additional instrument costs caused by installation of the computer are therefore insignificant for new furnaces. For older furnaces, the degree of required modification will vary, and the additional cost involved will have to be evaluated in each case.