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CONTROL OF FERROALLOY FURNACES - EXPERIENCES AND CHALLENGES

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ABSTRACT

Within Elkem the development of control systems for ferroalloy furnaces started 25 years ago. This paper shows that we can draw a continuos line of development throughout these 25 years. From the very beginning metallurgical experience and process knowledge were combined with a control engineering approach. Unlike many other systems developed at that time, Elkem focused on developing a hierarchical system with well-defined functional modules. Today's trends both in control theory and system engineering support this approach.

The basic philosophy within Elkem was not to replace operators and metallurgists, but to develop systems that support and involve them. More than computer systems and closed loops is needed to bring the process under control. Raw materials, operating time and operator training are also critical factors. To control a furnace is a totality and the result is not better than the weakest link in the chain.

INTRODUCTION

The development of computer control systems for ferroalloy furnaces within Elkem started in the late sixties. Approximately at the same time development work started within Union Carbide and Christiania Spigerverk. When Elkem merged with Christiania Spigerverk and later the Metal Division of Union Carbide, the total knowledge was pooled and does now cover a wide range of processes and functions [1]. In 1973 Elkem decided to market process control systems to users outside the company. This external sale through Engineering Division (now Elkem Technology) contributed considerably to further development and broader experience. Presently, control systems are installed on more than 30 furnaces and refining processes within Elkem. Control systems from Elkem have also been installed on a variety of furnaces outside the company.

During this period of nearly three decades there has been a tremendous development in computer hardware and software. Hence a variety of computers and software systems have been taken into use. As a curiosity we can mention that the first installation was a Nord-1 computer with 32 kilobytes of memory, and the assembly language was used for application programming. But in spite of this dramatic change in available hardware and software, the most important basic principles have survived. Modularity, operator involvement and improved process knowledge have been building bricks from the very beginning, and today these principles are focused more than ever.

THE MODULAR APPROACH TO CONTROL

The "black box" or the "skilled operator" approach to furnace control was discussed in the very beginning. One approach was to look at all available measurements and indicators and try to make rules for manipulating the available actuators based on experience. Elkem chose, however, at an early stage to develop a modular system, and to divide the system into functional modules based on process knowledge [2,3,4,14]. Attention was paid to choosing modules with limited and well defined interactions [5]. The furnace process consists of three subsystems: the electrical system, the metallurgical system and the electrode system. In addition, we have the auxiliary systems such as filters, and weighing and transport. The electrode system may also be looked upon as an auxiliary system.

The interactions between the electrical and the metallurgical systems are in principle very few and simple as shown in Fig 2. The electrical system supplies energy to the metallurgical system, and the metallurgical system gives a conductivity back to the electrical system. It is important to remember that power and resistivity are distributed quantities [17]. Lumped parameters are used as an approximation in most calculations. One has, however, to be careful not to draw false conclusions using lumped parameter models [17].

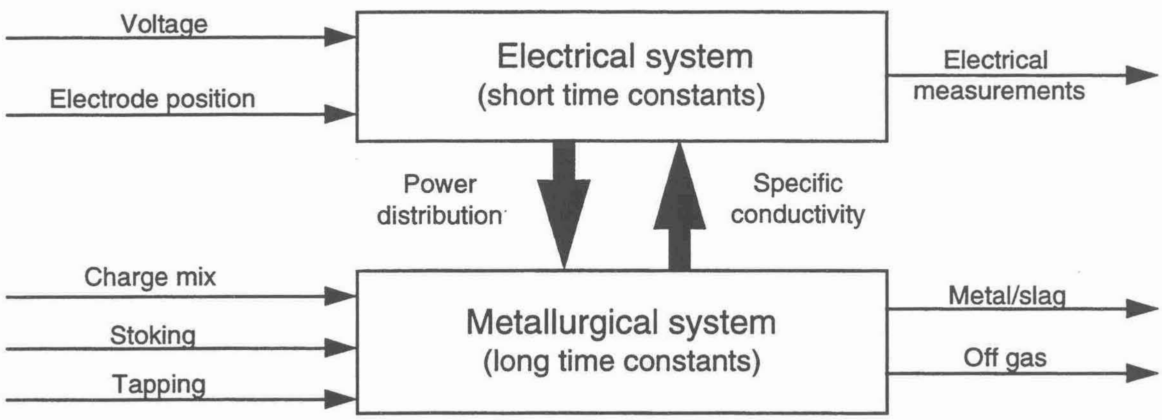

FIG. 1. Interaction between electrical and metallurgical subsystem.

The electrical subsystem is described by Maxwell's equations, or by equations from electrical engineering if lumped parameters are used. The metallurgical subsystem is very different, as it involves gas and particle flow, reaction kinetics etc.[10]. Here it is more difficult to establish a set of equations that describe the process to the relevant level of accuracy. To be successful in furnace modelling and control, it is important to be aware of the modularity showed in Fig.1, and to understand the difference in nature between the two subsystems.

One of the most important challenges in furnace control today is the interaction between the metallurgical and the electrical system. As we have managed to control the electrical system as such, we have gradually focused more on the interaction between the two systems. For the FeSi- and the Si-process Westly's C3-factor offers a solution to this problem, partly based on experience and partly on process understanding. However, further work is required to explore the interaction between electrical and metallurgical conditions [6,7,8]. The electrical system can be divided further into subsystems. These subsystems and the interactions between them are rather well analysed and understood [7,8], but there are still room for improvements in the control algorithms.

Unlike the electrical system, the metallurgical system differs rather much from process to process. However, the reduction process and the material transport are always dominating factors. The main actuator to control the reduction is the charge mix, especially the carbon balance. In open furnaces the material transport is influenced by the operator through the stoking. Model work has given us increased insight into the metallurgical system the latest years, especially for the Si- and the FeSi-process [9,10]. The challenge now is to transfer this knowledge into the control system e.g. by using model based estimation [8].

With the introduction of expert systems we are in some respect back to the concept of making the computer a "clever operator". Since the reduction process in a smelting furnace can not be classified as well defined and fully understood, expert systems will have a place in furnace control. But it is very important to use the expert systems as supplement to and not instead of process control based on physical understanding of the process. It is also important to bear in mind the modularity of the process when using expert systems. Expert systems should be used in a way that helps to improve process understanding and operator involvement, and not to introduce a greater distance between process and operators [12]. The expert system can for instance help to distinguish between process conditions that show rather similar symptoms. It can also be used to give a warning if certain measurements are unreliable and should not be used for control actions, or wen the furnace approaches undesirable conditions.

DECISION SUPPORT AND OPERATOR INVOLVEMENT

From the first computer control project Elkem focused on the presentation of process information[2]. In addition to stabilising the furnace by means of simple closed loops, an aim was to give the metallurgists and the operators a proper tool for manual optimisation. When developing operator interface it was focused on a design that was easy to understand and that helped the users to an improved process understanding. The importance of information presentation can not be overestimated. When information is selected, combined, and presented in the right way, the user gets the right process understanding that leads him to good conclusions [11]. On the other hand, badly presented information will confuse and irritate.

As the possibilities for data communication, data storage and data analysis have improved, we have seen an increased interest in decision support for metallurgists [11,12]. For the moment the most beneficial decision support is the simplest one: having available relevant data in a relevant form for manual evaluation. It is important to have easy access to a complete set of data including raw materials, metal analyses and slag analyses. We all know that the furnaces now end then have their "bad periods". By analysing selected data as a matter of routine in stead of waiting until the problems are obvious, the metallurgists can take corrective actions in time to avoid running into problems. It is also important for the metallurgists to have reliable historical data available when evaluating furnace operation in order to choose proper raw materials etc.

Today's development in communication networks, PC-hardware and Windows-based software has lead to a revolution in decision support. Now the metallurgist easily can get information into his personal computer for handling in spread sheets, statistical packages etc. But new possibilities lead to new challenges. One must be careful so that the new flexibility does not lead to chaos and individualism. If every metallurgist ends up with his own "self designed and perfect" decision support system on his personal computer, one easily loses the ability to pull together for better furnace operation and a commonly accepted process understanding. Therefore, standard application modules must be available, and they must be consistent with the common accepted process knowledge. To take advantage of the new flexibility without running into problems, Elkem has developed recommendations and standards for the plants [13]. Fig.2 shows the functional modules of a typical system including process control and decision support both for operators and metallurgists.

Education has proved to be one of the key factors to obtain user involvement and to get benefit from the control and information systems installed. Earlier, it was focused on computers and control theory, and separate courses in this area were arranged. Now the process itself rather than the computer is put in the centre, and hence the training in computer control is incorporated in the general process education for operators. In this way the control and information systems have become a natural part of the process equipment and the operators working situation.

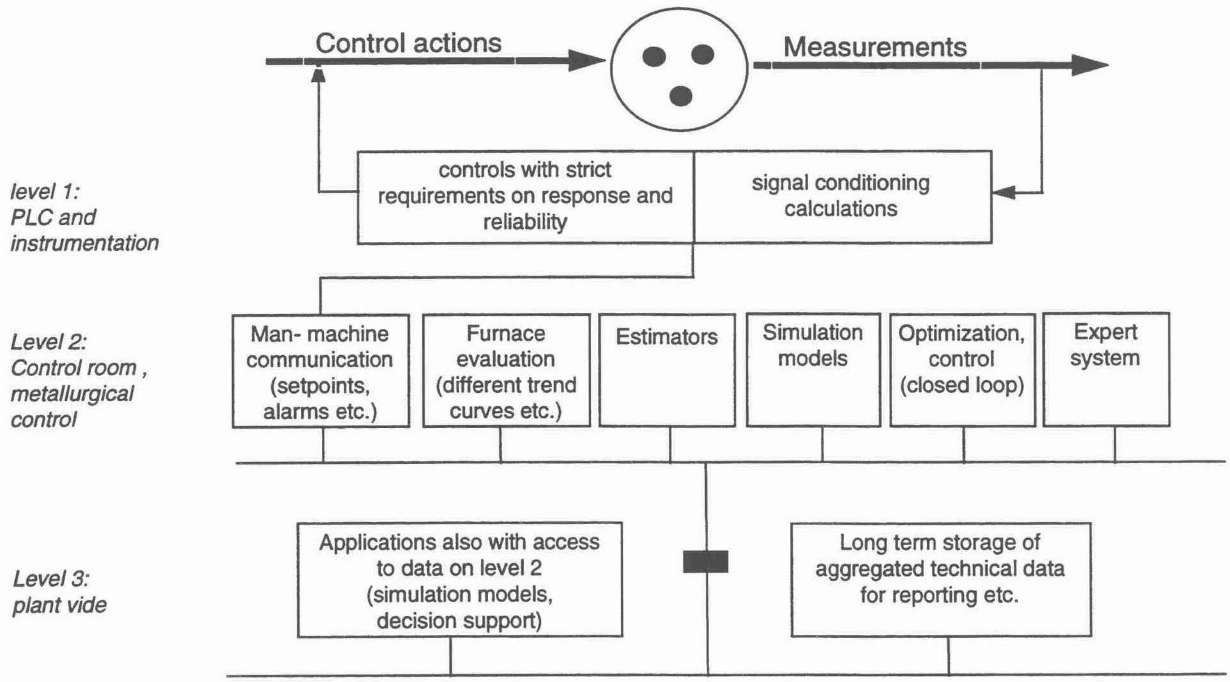

FIG. 2. Functional structure for furnace control and information system.

FROM STABILISATION TO OPTIMISATION

From the beginning of the control system development the goal was to stabilise the process. The stabilisation is beneficial in itself, because reduced variations allow us to use setpoints closer to the equipment limits [14,15]. Gradually the systems have become a tool also for optimisation. Less process variation combined with more reliable data gives the metallurgists better opportunities for optimising important parameters like carbon balance and furnace resistance.

Improved and well structured process knowledge is the main key to process optimisation. Take for instance the carbon balance in the Si/FeSi-process. Traditionally we have used variables such as overharmonics, electrode tip position and metal analyses to indicate change in the carbon balance. But these measurements do not tell us if the carbon balance is close to the optimum ore not. Ten to fifteen years ago we started to focus on the fact that increased carbon level increases the Si-recovery until a certain point where the Si-recovery starts to decrease. Hence we had a tool for optimisation. Through work with mathematical models [9,10], this relation is visualised. Model simulations also have shown how other parameters influence the optimum carbon balance and Si-recovery. This improved process knowledge combined with a more stable process and more reliable data gives the metallurgists better opportunities to find the optimum carbon balance, and the best raw material.

Si-recovery based on metal weight was of limited value for on line optimisation due to the time delay. The introduction of new instrumentation to measure the amount of silica in the off gas has considerably decreased this time delay and hence improved the possibilities for optimisation. This illustrates that improved process knowledge and improved instrumentation are like twins in the work for furnace optimisation. The improved process knowledge indicates what new measurements we should develop, and the new instrumentation helps us to verify our process understanding and to bring the furnace under control. In the future the work with improved instrumentation will be given increased attention [13].

Even with improved instrumentation the information from the reaction zone and the heart of the furnace will be limited. Therefore, model based measuring techniques will become an important part of the future development within furnace control. Estimators for metallurgical variables will become an important tool for controlling the furnace either manually by operators and metallurgists or directly by automatic controllers [13].

TO BRING A FURNACE UNDER CONTROL IS A TOTALITY

To bring the furnaces under control is a totality that includes more than closed loops and information systems. The main disturbances to the furnace process are:

- variation in raw materials
- downtime
- variation in stoking and tapping practice

Raw Materials

The right choice of raw materials is perhaps the most important factor for obtaining good furnace operation. The first step towards improvements is to reduce the variations. Frequent changes in the mix order make it difficult for the metallurgists to interpret measurements and observations from the furnace. We also know that choice of electrical setpoint and carbon balance may depend on the type of raw materials used. Frequent changes in the mix order therefore reduce the possibility for furnace optimisation. Over and over again we have experienced considerable drops in furnace performance when more frequent changes in the mix order have occurred for one reason ore another. This may happen even if the raw materials used are of good quality. The next step is to choose the best raw material for the actual process, taking both technical parameters and price into account. Earlier, we have focused on collecting historical data and handling them statistically. The latest years we also have worked on developing methods for proper characterisation of the reduction materials. Relevant characterising methods very often are specific for a process or a group of processes. Example of this is the SiO-reactivity for carbon materials used in the FeSi- and Si-process.

Downtime

Experience has shown that it is very difficult to obtain good furnace operation if the downtime is too high. If we do not have an acceptable operating time, an advanced control system is of limited value. One of the reasons for this is that the dominating time constants for typical furnaces are from two to four hours and upwards. Another reason is that unplanned shutdowns of a furnace may lead to electrode problems and hence to new shutdowns and cutback on load. With the introduction of preventive maintenance the operating time has increased the latest years. Now it is important to find the cost effective level of preventive maintenance. To do this one needs more specific knowledge about the cost of the poor operations that comes in addition to the production loss during downtime. It is important to learn more about what downtime that can be tolerated without destroying the furnace operation.

Stoking and tapping

Control engineers sometimes forget the importance of the operators' influence on the furnace. If the furnace is not properly drained, we can not expect good furnace operation. For some processes too much metal or slag in the furnace may also lead to misinterpretation of important measurements and observations. The latest years we have seen increased focus on the tapping area. Mechanical equipment is improved, education is carried out, and information systems are taken into use to give the operators feedback on their job. This has shown very promising results. For the FeSi- and the Si-furnaces the stoking is also very important. Metallurgists have always paid attention to stoking practice. Nevertheless, considerable improvements in furnace operation due to improved stoking have been experienced the latest ten to fifteen years. Improved theoretical insight has given a better basis for specifying stoking routines to the operators. But perhaps the most important factor is the silica measurements that give the operator immediate feedback on his job.

Control and information systems may be of limited value if we do not take care of the three factors discussed in this chapter. On the other hand instrumentation and information presentation can give very valuable contributions to improvements in these fields. It is not a question of either - ore. It is a question of both - and.

PROCESS CONTROL SYSTEMS IN THE PLANT WIDE AND THE COMPANY WIDE NETWORK

Fig. 3 shows in principle how the process control and information systems are linked up to other systems within the plant and the company. The first integrated systems were installed more than ten years ago [11], and the basic structure is very much the same today. Integration becomes now more and more important due to increased focus on cost reduction, minimum stock, product differentiation and product quality. Without going into any detail on the different systems, it can be pointed out that considerable benefit from the integration has been experienced, both for the process control systems and for the other systems shown in Fig. 3.

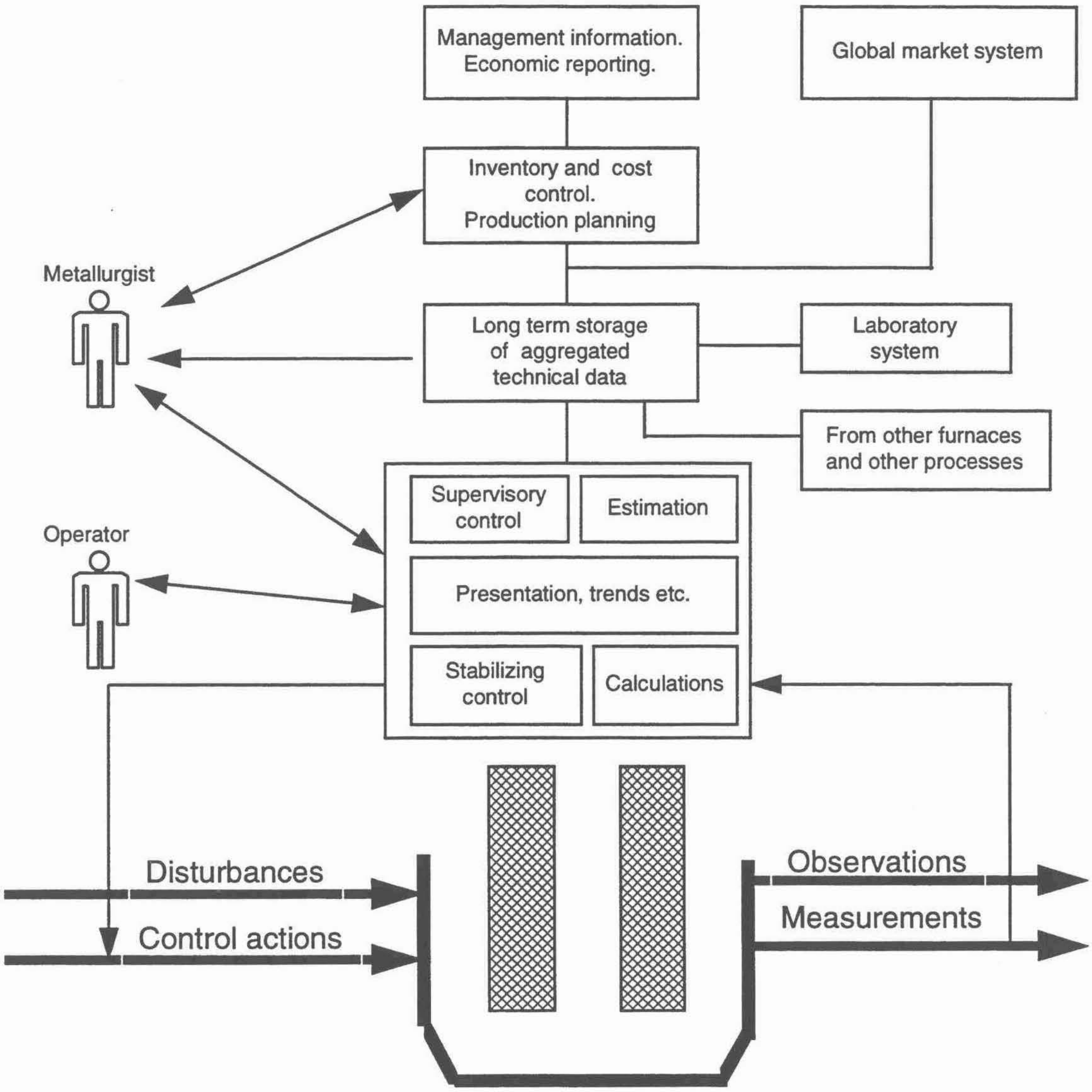

FIG. 3. The process control system integrated in the plant wide network.

However, the integration introduces new challenges. The process control systems take care of an important part of the data capture for the other systems, and one must be careful not to spread incorrect or questionable data. It is therefore important with well defined standards and check routines. One must also design the systems so that problems within the plantwide network du not lead to downtime for the process computers, and so that data can be temporarily stored in the process control systems until the plantwide network is restored. On the other hand, we must take precautions to avoid that comprehensive communication between process computers overloads the plantwide network.

Focus on communication and data structure has shown to be very important. Mistakes here may lead to considerable extra costs and time delay during implementation. Recommendations for communication and data storage are developed within Elkem. But this is not enough. The plants have to make their own plans to adapt the recommendations to the local needs in the best possible way. In this planning process it is important to use highly qualified expertise, and to focus on modularity and simplicity.

SUMMARY

- The modular approach to furnace computer control applied since this development first started in Elkem has shown to be successful. Resent trends in software, hardware and control theory support this approach. One of the challenges now is to maintain modular and well structured systems when we take into use new tools like expert system shells.

- The goal for the control and information systems has not been to replace the operators and/or the metallurgists. The systems are developed to support and to involve the personnel running the furnace. Hence the operator interface and the information presentation are very important.

- The control systems are based both on process knowledge and experience. Mathematical models have been very helpful in the work with process understanding and control strategies. One of the main challenges now is to achieve a better understanding of electrical and the metallurgical system interaction.

- With a few exceptions too little attention has been paid to the development of furnace instrumentation the latest years. This is now about to change, but still we will have very limited information from the heart of the furnace. This points towards use of model based estimators that can be used in control loops, either directly or indirectly by an operator.

- The process control systems are now integrated in plantwide and companywide networks. This has increased the usefulness of both the process control systems and the administrative systems. To achieve a good result it is important to focus on data integrity, modularity and proper choice of network solutions.

- One of the most important experiences throughout all these years is that the implementation has to be carefully planned. When systems and standards are developed, they have to be adapted to local needs. It is important to use highly qualified expertise wen making implementation plans for the plants.

- To bring a furnace under control is a totality that involves education, raw materials, operating time and stoking and tapping practice in addition to control systems. To get a good result one has to pay proper attention to all these factors.

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