ARTIFICIAL INTELLIGENCE TECHNOLOGY: VALUE-ADDING TO THE CONTROL OF A PYROMETALLURGICAL PROCESS

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ABSTRACT

The operational state of pyrometallurgical processes can normally only be inferred from process parameters that are removed from the process and variables that can be continuously measured. Submerged arc furnaces are presently the most cost effective production methods for ferroalloys but there is scope for optimization. This is the subject of this study where it is envisaged to use artificial intelligence methods to add value to the process by optimizing the control which will in turn increase the overall process efficiency. Specifically an expert system will be used to optimize the technical aspects of the process and a neural network will be used to build a model of the encompassing ferroalloy production scenario. The neural network model will be used to institute feed forward control.

PURPOSE OF THE RESEARCH

Pyrometallurgical processes are by nature aggressive as a result of the high temperatures and the direct measurement of operating conditions is difficult. This and the fact that the reaction takes place in a closed environment that does not lend itself to direct study makes control and modeling a challenge. The interpretation of conditions leading to explanation of process variables can only effectively be achieved by inferring conditions from process variables that lend themselves to continual measurement. Aldrich (1999) concurs with this by stating that "... the majority of chemical and metallurgical processes are ill-defined...". As is the case with most industrial processes unplanned breakdowns are and extended maintenance is expensive and suboptimal operational efficiency is costly. This study has the objective of making use of artificial intelligence technology, specifically an expert system and a neural network to add value to a process producing high carbon ferromanganese.

Introduction

Manganese is, as an element, indispensable in the production of the so-called carbon steels. It fulfils two functions in the process, the first being as a strong desulphurizing agent it cleans the steel, and the second more important function is as an alloying element. Although the use of manganese in the steel production process is indispensable, the specific consumption has been declining steadily

13th Annual Conference of the
Southern African Institute
For Management Scientists
- Stellenbosch University
9-11 Sept 2001

and with the total steel production in a zero growth situation the use of manganese alloys has been declining. The manifestation of this is in a real decline of manganese alloy prices that places the producers, such as Samancor, under cost pressure.

The production of manganese containing ferroalloys in submerged arc furnaces is presently the most efficient and cost effective method available. Submerged arc furnaces steadily increased in capacity from about the 1940s to the late 1970s. Samancor was in the forefront of these developments and ceased capacity expansion with the commissioning of an 81MVA submerged arc furnace for the production of high carbon ferromanganese. Whereas it was originally believed that larger furnaces provided economies of scale the truth is that larger furnaces are exponentially more difficult to control and manage, both operationally and metallurgically. This negated any advantages as a result of the economy of scale.

As a result of the ferroalloy industry being linked to steel, a smokestack industry, it was stigmatized as being very rough, and labour intensive and it did not receive the 'hi-tech' treatment that was necessary to maintain it near the forefront of technological development. In the 1980s there was a significant allocation of resources in trying to develop alternative methods of production, for example plasma (or DC) technology, but to no avail. The realization that submerged arc furnace technology was here to stay for the foreseeable future eventually took root and the identification of areas of optimisation to increase efficiency occurred in earnest.

The late 1980s then heralded the start of attempts to optimize the process of submerged arc furnace production methods. The first aspect of the process at the Meyerton Plant of Samancor that came under the spotlight was the control systems and the requirement for an integrated control system that would be instrumental in the optimization of the process.

Background

Prior to discussing the progress on the study and the results achieved thusfar it is pertinent to take note of a two cardinal issues in respect of the process and the developments. The first issue is the production of high carbon ferromanganese has two significant cost components in the raw materials, specifically manganese ores, and electric power. Inefficiencies in the process immediately manifest themselves in significant cost excursions that prevent the maintenance of competitiveness in these two areas. The second issue, which is a hotly debated one in the South African context, is labour complement. Although locally operational organizations have a moral obligation to provide employment it should be not be achieved by creating or maintaining inefficiencies in the processes. The objective should be to achieve competitiveness on a global scale by maintaining world-class operational complement levels and creating additional employment by expansion of facilities. Within the operational environment prevailing in the early 1990s it was felt that the improvement of the control systems of the large submerged arc furnaces was where the most impact could be achieved.

The diversity of systems and the number of individual components present dictated that a common control system be instituted on each of the furnaces together with the energy recovery unit that was being installed at the time. The most expedient, but not the only, way of achieving the objective was a Distributed Control System (DCS) for each of the production units.

Although the DCS would provide the control integration and stability required it would not be able to move to the following level up of providing a method of optimization. To this end it was decided to institute Advanced Process Control (APC) on the 81MVA submerged arc furnace. The APC consists of an Expert System (ES) and a Neural Network (NN) using the DCS and an external database as platform.

Progress of Study

General

The widespread use of computing power and the relatively inexpensive mass data storage has allowed collection and manipulation of large amounts of data that has, in the opinion of the author, resulted in a "shotgun" approach to deciding on the data to collect. The syndrome of "collect the data and maybe it will be useful later" has resulted in the unnecessary complication of systems. The approach being followed in the development of the Advanced Process Control, specifically the expert system, is the use of the minimum number of parameters to define the system together with the maintenance of modularity so that further rules can be added as process knowledge expands.

There are three issues of importance when consideration is given to developing advanced process control. They are as quoted in the references

- "... artificial intelligence methods compliment classical process control theory" (Aldrich 2000). If a process or sections of a process can be well defined in terms of inputs and outputs classical process control has no substitute and APC is the sweetener.
- "The basic philosophy within Elkem was not to replace operators but to develop systems that support and involve them" (Holmelid 1995). The APC must act as a tool that expands the sphere of influence of the operator. To place the issue of the Elkem philosophy in perspective, Elkem was a

respected supplier of submerged arc furnace technology and also a renowned supplier of ferroalloys.

- A modular system (Arneson and Asphaug 1974).

These three issues encompass the philosophy followed by Samancor at the time of starting to consider the advanced control philosophy.

The control of the process is performed by the DCS that controls on the basis of operator-defined setpoints. Any deviation from a setpoint results in a variation that has a predefined action associated with it in order to return the process back into the defined operating region or it triggers an alarm condition upon which certain external interventions are required. The limitation is that it is binary in the sense that there is, in the event of a deviation from the setpoint, a single action is required. The action required could be a system intervention or an external operator intervention. This type of intervention is adequate for a well-defined process and where all possible eventualities can be defined up front. This is not the case in this particular pyrometallurgical process and a great reliance is placed on the experience and knowledge of so-called experts.

There is a database, Infoplus21, which acts as data storage for the DCS and a data repository for a real-time process interrogation tool. This database is common for all the plants making use of the same DCS platform. Certain information required by the Advanced Process Control will be sourced from the Infoplus21 database.

Expert System

The DCS monitors 390 functions in this plant of which approximately 29 are actively controlled in algorithms in the control system. The remainder are either monitoring functions which have use in a better understanding of the process or alarm conditions which if allowed to persist would damage the process to the extent that a breakdown will be the result. The capital investment in such a plant is high and this makes the repair of breakdowns an expensive exercise.

Analysis of the furnace process indicates three well-defined subsystems that interact but are very different in their function definition requirements. The systems are a) the electrical subsystem where the time constants can be extremely short and actions dictated within fractions of a second, b) the metallurgical subsystem where the time constants are long and where results of actions take multiples of hours to manifest themselves, and c) the protection subsystem where the deviations from setpoint alarm values can be instantaneous. The outputs from the protection system are very often as a result of uncorrected deviations in the other two subsystems.

The control functions referred to above are almost exclusively in the electrical subsystem where the time constants involved lend themselves to active control. The control algorithms are also very easily defined in terms of classical control theory.

The objective of the expert system is to consider the 360 remaining non-control functions, which are in the metallurgical subsystem and the protection subsystem, and link their outputs and trends to predict operating conditions that have sub-optimal operating results as their consequence. There is also a certain amount of interaction with the electrical subsystem.

The development of an expert system revolves around two issues, the first of which is the selection of the variable which will be the primary parameter, and the second of which is what is to be done with the parameter. The first issue is one where the implementation of many expert systems is doomed to fail as a result of the developer attempting to consider too many variables which results in the system providing contradictory results. Very often the functions that are being considered are interrelated to such an extent that the identification of the cause and effect relationships is a major stumbling block in the successful development. Reducing the number of parameters facilitates the definition of the cause and effect relationships thereby simplifying the development.

There are two ways in which primary parameters can be identified and applying them in a complimentary way will ensure that at least the majority of the predicted process conditions will have been addressed. This is encompassed in the objective of this part of the study. By applying the identification of catastrophic process conditions on the one hand and identification of critical operating parameters on the other will, in the opinion of the author, ensure that at least 95% of the possible operating conditions will be addressed by the expert system. In this study application of this method yielded 38 of the 360 non-controlled parameters that would fulfil the requirement and will thus form the basis for the expert system.

Whereas the natural mode of control is by feedback loop where the results of an action have to be observed prior to deciding whether further action is necessary, the 38 parameters will enable operators to act proactively on the basis of trends in the individual parameters or combinations of parameters. This feed forward mode of control is one that will go a long way in negating the effects of the long time constants of the metallurgical subsystem. The feed forward mode of control will be instituted via intelligent alarming which will interpret the trends in and combinations of the parameters.

This mode of operation will add significant value to the pyrometallurgical operation by addressing and optimizing the technical parameters of the process on the one hand and by providing support in the decision-making process on the other.

Neural Network

The optimization of the encompassing process, which has a number of external influences, will be expediently accomplished by means of an Artificial Neural Network. The neural network is a numerical process that must taught to recognize patterns of outputs based on a set of input data. The detail of the neural network will not be considered further suffice to say that the technology is well developed and the objective of this section of the research is to model the global process that can be used for feed forward control of the overall process.

The modeling of the process using a neural network is not outside the realm of reality as the submerged arc furnace process is

- non-linear,
- multidimensional, and
- one having long time constants

for which the neural network technology is ideal and where there is no definition of the underlying mathematical model of the process required.

Whereas the expert system relies on the micro aspects of the process that, when optimized, will eventually optimize the total process in terms of the control variables, the neural network will optimize the encompassing process within the limits of the parameters of the expert system. In line with commercial norms the ferroalloy production is governed by costs of production. The most important drivers of the cost of production are the costs of raw materials and the cost of electricity. These are the two global parameters that will have the most influence on the neural network and they will be used to define the operating regimes.

The neural network model of the process will be used for "what-if" analysis without having to resort to pure theory or plant trial and error. In the performance of the optimization "what-if" studies there are constraints that will determine the existence of a global or local extreme. These constraints will be defined by the input variables as the neural network results cannot be extrapolated outside the experience region of the model. The important aspect of building a robust neural network model is the amount of data that is required. This will not be a limiting factor bearing the data collection capacity of the DCS and the data storage capacity of the Infoplus21 database in mind.

Conclusion

This study was prompted by a need for integrating the control of the various subsystems in order to improve the functionality of the ferroalloy production process. It rapidly became evident that significant value adding could be obtained by using artificial intelligence techniques.

The expert system will cater for the optimization of the micro subsystems of the process while acting as an operator advisory system. By being able to predict occurrences in the process feed forward control will be the controlling mode.

The neural network will model the encompassing process system that will take external factors into consideration. The neural network model will be used to perform "what-if" analyses in order to model different operating regimes which will be used to institute feed forward control thereby reducing the negative effects of the long time constants of the process.

Achieving the goals of the study as laid out will result in informed management decision-making in the process that is a prerequisite for a world-class operation.

Acknowledgement

This paper represents ongoing research being undertaken for a PhD to be submitted to the University of Stellenbosch.

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