AUTOMATION AND CONTROL IN IRON AND STEEL INDUSTRIES

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Summary

Processes in iron and steel industries are either metallurgical or rolling and refining processes. In metallurgical processes (sintering, pig iron production, steel production, continuous casting, electric arc furnaces, secondary metallurgy) the liquid phase of the metal is predominant while in forging, rolling and refining processes the metal is in the solid phase.

Production control (scheduling and set-up) in the metallurgical parts of an iron and steelworks is mainly done in a feed-forward manner by engineers and technicians. Automatic feedback control is restricted to PID controllers for flows, pressures, temperatures, and so on, of some essential process variables.

In rolling processes and processing lines, automatic feedback control strategies are more sophisticated: there are for instance advanced and complex schemes for controlling the thickness and flatness of strip in hot and cold rolling mills. There is not room here to describe them in detail.

In overall automation systems, computers, programmable controllers, and micro controllers are connected in the form of a local area network to perform all communications from the enterprise level down into the plant and vice versa in an optimal way.

Recent development trends such as net shape casting, the application of CI methods, and the need to replace first-generation automation equipment are described.

1. Introduction

Though iron is one of the oldest materials used in the history of humankind (nearly 3000 years), iron and steel products are essential parts of life today:

- Railways, cars and ships are unimaginable without steel;
- In modern buildings and bridges it is applied to an essential extent;
- Platforms for drilling oil in the sea are constructed in steel;
- Essential parts of refrigerators, washing machines and kitchen stoves are made of it;
- Motor blocks are made of cast iron;
- No plant producing any thing you can think of can be constructed and built without steel.

Iron and steel products are therefore produced worldwide. As an indicator of the production intensity, the amount of crude steel produced worldwide during the year 2000 was more than 830million t. The distribution of this production worldwide is shown in Figure 1. Whilst the tonnage of steel produced in Europe and the United States remains constant, it is still expanding in Asia and the rest of the world.

A small part of the crude steel produced is used for casting only and for forging, but the overwhelming part of it is further treated by rolling processes. There are two classes of rolled steel products:

- long products as rails, beams, and wire; and
- flat products as plates and strips.

Nearly two-thirds of the total weight of rolled products consists of flat, and only one-third of long, products.

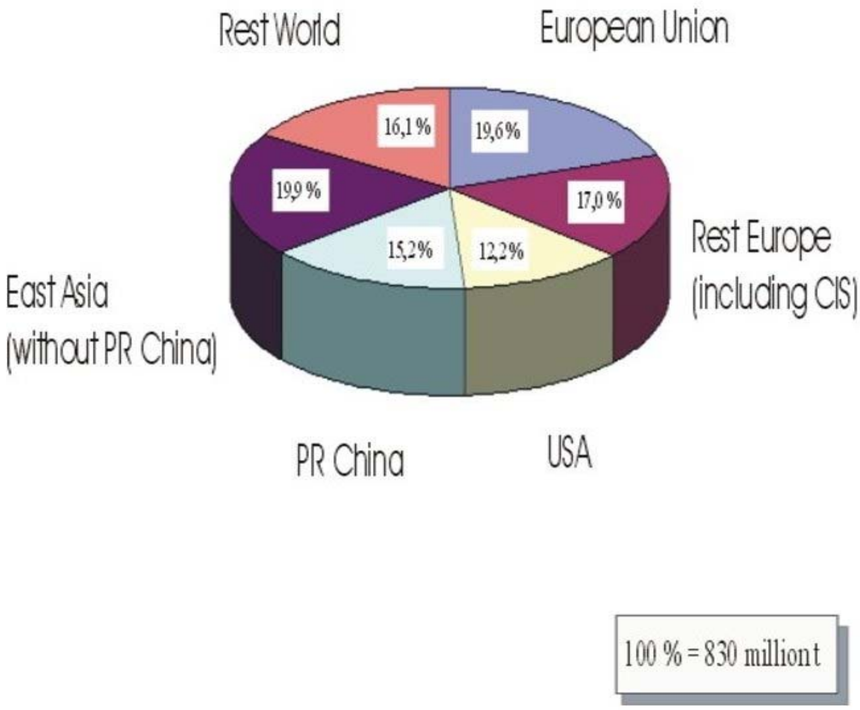

Figure 1. Crude steel production worldwide

From the point of view of ecology and environmental protection, steel is one of the best materials to use. A considerable part of equipment made of steel (such as cars, refrigerators, and industrial reactors) can be reused as scrap for new steel products. The steel equipment or components that are not reused corrode (rust) quickly and do not leave backrest products that are toxic or otherwise harmful to the environment.

It is not correct to speak of "steel" as a single entity. It is possible, by alloying exact mixtures of Mn, Cr, Ni, Mo, V, Si, P, and S, to give a particular sort of steel very dedicated properties of use. There are for instance structural, rustless, high-temperature resistant, and many other kinds of steel. The German national standards distinguish about 7000 kinds of steel. So a particular kind of steel is like an "inorganic plastic".

The ever-growing demands of users and manufacturers for the quality of steel products cannot be fulfilled without automation. From the point of view of modern control theory, iron and steel works contain highly complex multivariable processes.

The automation problems to be dealt with range from problems of classical control theory of linear and nonlinear, single, and multivariable systems in process control, to questions of operational research in production control. In terms of computer science, complex operating systems have to be applied for process control purposes.

They have to start and stop special program modules ("tasks") automatically, without the operator, to fulfill the so-called "real-time condition": the computer must have reacted completely in a clearly defined maximum time (deadline) to an event in the process. The deadlines range from some minutes in the case of a blast furnace to a few milliseconds in a cold rolling mill, and for some special drive controls, microseconds.

2. Overview of Processes in Integrated Steelworks

This section mentions only the mainstream processes. A huge variety of variants exist. But independent of the particular plant configuration, there are two groups of processes in an integrated steelwork:

2.1. Metallurgical Processes

The first group contains metallurgical processes. This group of processes starts with burden preparation for the blast furnace: coke production, pelletizing, or sintering. The blast furnace process itself follows, for the generation of pig iron. Since pig iron is not forgeable and not rollable, the too-high content of carbon and of other undesired companion elements has to be removed in the succeeding steel production process. This is done in most cases by blowing oxygen into a bath of iron, scrap, and some fluxing agents, which is located in a converter. In most applied versions of this process, oxygen is blown on one hand through a lance onto the top of the bath, and on the other hand through holes in the bottom of the converter into its lower parts. This creates a lively stirring of the bath.

Once all undesired elements (C, Mn, P, and so on) have been burnt away from the bath by this process, the converter is tilted, the content is poured out into a ladle, then exact amounts of wanted alloys are added into the bath, which is kept at the correct temperature in ladle furnaces. This is called “secondary metallurgy” and is a very important step for producing steel with clearly defined properties.
The contents of these ladles are then poured out into a continuous casting machine, and the outputs are billets (for long products) or slabs (for flat products). In the continuous casting machine the transition from the liquid to the solid phase of steel products is achieved.

An important alternative to the process sequence, burden preparation → blast furnace → oxygen blowing converter → secondary metallurgy, is steel production in an electric arc furnace. Input materials of this process are in nearly all cases scrap, partially combined with pig iron. Scrap is molten by the heat of electric arcs, which are ignited between the material in the furnace and anodes of sintered carbon fed with electric current by transformers. In many cases the melting process is assisted by also blowing oxygen into the furnace.

2.2. Rolling Processes and Processing Lines

Nearly all pieces leaving a continuous caster are rolled. For flat products there is usually a chain of first hot and then cold rolling processes. An exception is plates that are only hot rolled, usually on a reversing plate mill. Heavy plates with thicknesses greater than 3 mm are the most frequently produced.

In a strip production line, the first step after flame descaling is to reheat the slab in a pusher-type or walking-beam reheating furnace. The slab with a thickness of about 250 to 300 mm is then rolled in a hot strip mill (consisting of 1–4 rougher type stands and a 6- to 7-stand finishing mill) down to thicknesses usually 8 mm to 2 mm. Afterwards it is cooled down intensively by water sprays to temperatures of about 550 °C to 700 °C and winded up in a coiler.

Nowadays an alternative to the production line, continuous casting → reheating furnace → hot strip mill, is direct hot rolling (net shape casting), described in Section 6.1.

After natural cooling down to ambient temperature the coil is transported into the cold rolling mill, with the stages: pickling line, 4- to 6-stand tandem mill, annealing line, and temper rolling mill. The final reduction of thickness is done in the tandem mill, down to 0.8 mm–0.1 mm. The final elongation of the strip in the temper mill of about 1%–2 % is to get the desired surface quality and tensile strength of the material.

A growing part of the cold rolled strip produced is further treated in processing lines by galvanizing, tinning, or coating.

2.3. Principles of Control Tasks

In connection with all the processes mentioned above the following tasks have to be treated:

- *Scheduling*. The planning of the sequence of production steps (for instance the sequence of coils to be rolled in a cold rolling mill).
- *Set-up*. The initial positioning of actuators before starting the process itself (according to the decisions of the scheduling process).
- *Control*. This (which today is nearly always carried out automatically by dedicated electronic equipment or by computers) is the bundle of tasks to maintain during the process the desired values of the process variables of interest (for instance the desired thickness of a rolled strip). Automatic control involves measuring the actual value of the process variable, comparing it with the desired value, evaluating the difference between both by a control algorithm, then influencing a dedicated actuator.

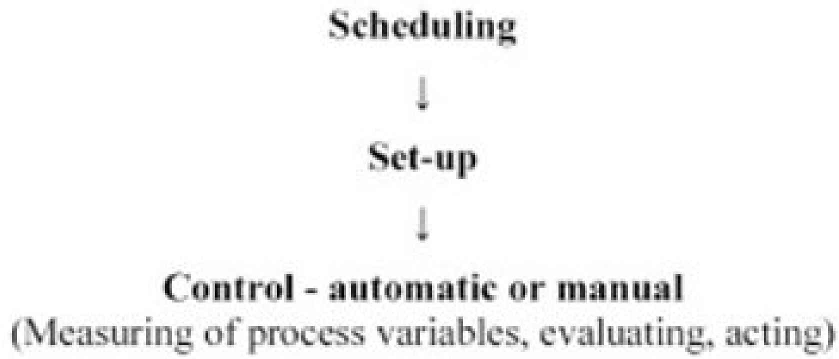

Figure 2. Functions to be solved in process control

These tasks have a hierarchical order in time (Figure 2). For the production steps mentioned above they have a different significance in an integrated steelwork: while scheduling for a blast furnace is rather simple, it is a very sophisticated problem for a hot strip mill.

3. Control of Metallurgical Processes

The main goal of the metallurgical processes is to maintain constant properties of the intermediate products (sinter, pig iron, and steel immediately after blowing). This is done mainly by human decisions during planning the course of production (scheduling), which means that it is done primarily by feed-forward control with a human as the controller. Automatic feedback control, mostly by means of PID controllers, is used only for clearly defined process variables like pressures, temperatures, and material flows.

Human planning needs exact and actual information about the production goals reached in the time since the last meeting of the responsible engineers, which in the sintering plant and at the blast furnace normally take place every morning. So reports about production issues within the last 24 hours have a very high importance. From the viewpoint of control theory, these reports have the character of a vector $\boldsymbol{y}(t)$ of measured values in the production control circuit.

From the viewpoint of system theory, the dominating attributes of the metallurgical processes (with exception of the oxygen steel blowing process) are extremely large time constants (in the order of hours) and very high dead times by transportation lags (in the order of several or many minutes).

3.1. Sintering Process

Of the set of burden preparation processes only the sintering process of iron ore is discussed here.

In the case of the sintering process one has to produce a sinter of sufficient mechanical resistance to abrasion and of optimal reducibility in the blast furnace. For the latter the FeO content in the sinter is an important characteristic. Sinter attributes can be influenced by proper mixing of the raw components (iron ore from the blending yards, coke, return fines, and water) in the mixing drum. These actions are currently undertaken by engineers and operators based on their experience and process knowledge, not by mathematical models within a computer.

In addition, sinter attributes can be influenced by the proper sintering process, which takes place on a sinter belt. The belt moves with a speed of 2–4 m min^{-1}. Its total length in modern plants is about 120 m, so a sinter particle remains on the belt for about 40 minutes. The mixture is fired in the ignition hood at the beginning of the belt. The sintering front moves down from the top of the bulk to its bottom, driven by air that is vertically sucked through the mixture by wind boxes with negative pressure. When the sintering front reaches the bulk bottom ("burn through point" BTP), the sintering of the mixture is finished.

To optimize the sintering process the BTP should coincide with the end of the belt. If the BTP lies before it, energy is wasted, and if it lies behind it, the sinter quality is bad (abrasion is too high because there are not yet sintered parts in the mixture).

The position of the BTP cannot be measured directly, so one takes $y(t)$, the position of the maximum temperature in the wind boxes, as an alternative process variable. These temperatures are measured by thermocouples. In the past the position of the maximum was calculated by regression analysis of the temperatures in the last wind boxes. Recently finite element models have been used for the calculation of the total thermal state of the mixture on the sinter belt and especially for the position of the BTP.

The short-term manipulating variable $u(t)$ for the position of the BTP is the belt speed. Automatic feedback control of the drives is mostly used to deliver the coincidence required.

Long-term variables $u(t)$ are the components of the mixture, and today, this superposed control (it has the character of a set-up) is done by the operators or the responsible engineers. In the future, algorithms of computational intelligence may be useful in this context, as initial researches at a German sinter plant have shown.

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Biographical Sketch

Professor Jürgen Heidepriem was born in 1935 in Berlin, Germany. He received the degrees of M.Sc. in Electrical Engineering in 1959 and of Ph.D. in 1965 from the Technical University of Berlin. From 1962 to 1974 he worked in the Institute of Applied Research for the German Steel Industry (Betriebsforschungsinstitut BFI) in Düsseldorf, Germany. There he was first the team leader of one of the first three projects concerned with the application of computers for the control of rolling mills in Germany. Later he became head of the Plant Engineering Division of the BFI with about 35 collaborators, half of those being scientific.

From 1969 to 1974 he was an external lecturer on automation techniques in the Department of Mechanical Engineering of the Technical University of Clausthal, Germany, and at this university he got in 1974 the venia legendi (the right of giving lectures as an associate professor) for “Mechanization and Automation in the Steel Industry.”

From 1974 to 2000 he was Professor for Automation Techniques and head of the Institute of Automation in the Department of Electrical Engineering of the University of Wuppertal, Germany. In 1983 and 1988 he was a guest professor at the University of Science and Technology in Beijing, China.

His scientific interests are centered on process modeling, model adaptation, process visualization, and communication in multicomputer automation systems, and since 1985 he has focused on applying methods of knowledge-based systems (artificial intelligence), fuzzy logic, artificial neural networks, pattern recognition, and wavelet transformation in process control.

He has also been involved in about 25 commercial projects, mostly in the steel industry, including the modeling of dynamic phases in the gap of rolling mills, the interactive visualization of the process in a reversing hot rolling mill, a complete universal profile control concept for reversing cold rolling mills, roll eccentricity control, the modeling of hydrodynamics and chemical processes in a newly developed pickling line, and an operators’ guide system for the set-up of 20-high cold rolling mill. He also worked on developing a visualization system (electronics and software) for a car simulator, for Volkswagen from 1982 to 1987.

More then 90 published papers and reports and some 20 Ph.D. theses have been completed under his guidance. He is and active member of the Working Group of Automation in Mining, Mineral and Metal Processing (MMM) of the International Federation of Automatic Control (IFAC) and was scientific organizer of the ninth MMM-Symposium held in 1998 in Cologne, Germany. In 2000 and 2001 he wrote two monographs on automation systems with computers.