PRODUCTION CONTROL OF CONTINUOUS STEEL FOUNDRIES BY COMPUTERIZED MODELLING

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Introduction

Production in the actually modern continuous casting plants is highly suited — thanks to its technology — for being planned. But this same technology implies also the necessity of a well developed (possibly computerized) control system ensuring fast adaptation to the situations arising in the course of the production, as a preliminary condition of the optimum exploitation of these foundries.

The main requirements of controllability are

- the exploitation of the high capacities of the production units,
- the timely co-ordination of the successive work phases,
- co-ordination between the casting area and the supplying plants (core production, sand works),
- low waste value,
- the possibly greatest homogeneous product series,
- mechanized certification and registration.

For a given enterprise, where the foundry is one of the plant units, the complex task described above may be solved by a three-level computerized system, of the following hierarchy:

A. The level of general data processing.

B. The level of the direct, or on-lone production control.

C. The level of process control.

The flow scheme of the individual levels is shown in Fig. 1.

This paper is concerned with tasks arising at level B. The technological process is outlined below.

1. The technological process

Steel is produced from pig iron, scrap iron and slag formers, melted in shaft furnaces. The liquid pig iron is disharged into ladles, desulphurized on shaking frames, then poured into converters for burning the carbon content

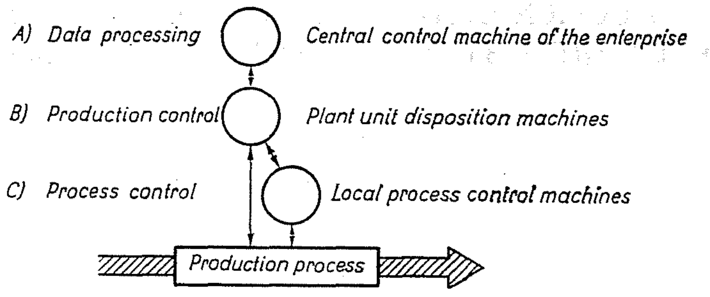

Fig. 1

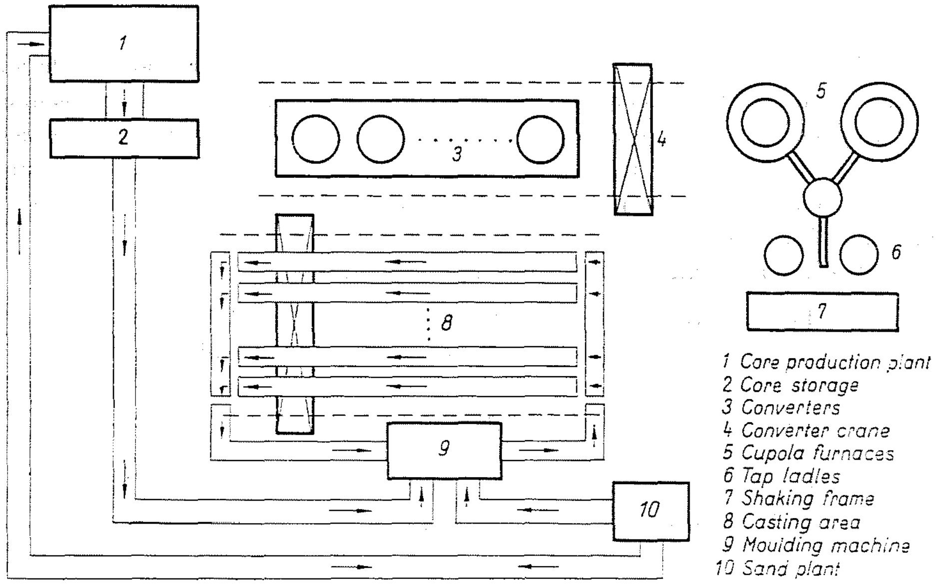

Fig. 2

according to the Bessemer-process by blasting air through it. In this way the pig iron is converted to steel. Also alloying is performed here. The contents of the converters are poured into casting ladles carried by a crane to the casting area, where the casts are prepared. The casting area consists of a number of MS uniform casting lines, receiving the mould boxes from roller tables arranged perpendicularly to one end of the casting lines, from which they are removed by roller tables arranged perpendicularly to the casting lines at their far end.

The new mould is pushed by hydraulic force on the casting line, stepping the column of the mould boxes by one mould box further. If the casting line was full, then the last mould box is stepped onto the far end roller table, to be removed.

The moulding is mechanized. The moulding machine accommodates two lower and two upper pattern plates, which are sufficient for preparing two complete moulds. The cores are injected by two core injection machines containing two work stations each, which may be operated practically independently of each other, each at its own rate.

Sand is prepared in a separate technological unit. The moulds removed from the casting area are cleaned, heat-treated, then submittde to quality control. The lay-out of the individual technological units is shown in Fig. 2.

2. The reference signals of the production process

- Charge period — time period between the appearance of two charges,
- time moment of the appearance of the first charge,
- moulding task for which the individual lines are laid,
- casting sequence of the mould boxes laid on the individual lines,
- core delivery sequence,
- metal quality of the successive charges.

3. Known initial data

- the quantity of the casts to be produced by types,
- relationship between the cast types and the metal qualities,
- relationship between the cast types and the moulds,
- number of casts possible in one mould box,
- casting period of the individual moulds,
- cooling period of the individual moulds,
- expected waste ratio,
- liquid metal requirement of the individual moulds,
- assignation of the cores to the moulds,
- assignation of the press plates to the moulds,
- sand requirement of the mould types,
- safety period — time between laying out a given line and the start of casting,
- moulding time-standard,
- sand plant capacity,
- melting plant capacity limits,
- number of mould boxes placed on one line,
- maximum permissible time demand of casting one charge,
- metal content of the casting ladle,
- number of the operating lines,

— condition of the core storage at the start of the core production,
— core production time-standards,
— permissible overtime hours in core production,
— total number of moulds between the moulding machine and the mould charging station.

4. Restrictions imposed by the technology

— The cupola furnace must operate during the whole cycle (one day) with constant capacity.
— Casting is performed by casting lines.
— The mould boxes must be ready for casting on the actual lines by the starting moment of the safety period before casting begins.
— The cores of the casts to be produced during the cycle must be available in the core storage by the start of the cycle.
— The mould boxes are removed and placed on by casting lines.
— The sand necessary for the moulds of one line must be available by the start of moulding.

The algorithm determining the reference signals aims at optimum exploitation of the production equipment under the restrictions listed above in a way that the partial processes of the whole production are accurately co-ordinated.

5. The description of the algorithm determining the decade reference signals

Several methods lend themselves for solving the task, out of which the one offering the possible best solution and acceptable also with a view to the machine time must be selected. For simplicity's sake, set out from the production task foreseen for one decade; this circumstance is irrelevant to the general validity of the method. The determination of the decade reference signals contains two major tasks:

1 — decomposing the decade casting plan to cycles (days),
2 — studying the realizability of the resulting cycle tasks, with respect to the core production plant.

5.1. Determination of the decade reference signals by homogenizing the task of casting

The sequence of casting must be determined in a way that the successive casts are possibly homogeneous, because by their inhomogeneity the production is slowed down, the material storage capacity of the casting area is considerably reduced, due to the necessity of replacing the pattern and pressplates during moulding and placing the mould boxes.

The whole range of the decade plan is easier homogenized than are the tasks in a single production cycle, as the quantities to be produced of each type is increased by an order of magnitude, i.e. the percentage of the casts permitting no homogeneous serial casting is much lower in relation to the decade plan than in the program of a single cycle.

The basic idea of the method is to form only homogeneous and serial casting vectors, in order to minimize the number of the required pattern plate replacements for the moulding, at the same time simplifying the mathematical treatment and reasonably restricting the required machine time.

(The casting vector is the number of moulds cast from one charge. The serial casting vector is formed by several casting vectors. A serial casting vector means the number of the mould boxes to be placed on one line.) The homogenization of the task implies certain roundings off (only whole serial casting vectors are taken into account), negligible related to the total volume to be produced during the decade, and lower than the waste percentage.

The algorithm follows up the movement of the mould boxes over the casting area and examines the realizability of the casting task at the given production rate (charge period). (The charge period is the time between the appearance of two successive charges.) The basic criterion in this examination is that loading the casting line must be finished sooner by at least the safety period than the casting starts, on any line, with due consideration to the cooling conditions of the preceding — not yet removed — mould boxes standing on the line and the possible pattern plate replacement in course of placing the new mould boxes.

One of the most important problems in solving the task was the arrangement of the various shaped moulds in one line, i.e. finding the optimum criterion of the line arrangement.

The optimum casting sequence of the various forms in the lines could be found by dynamic programming, but this method is rather time-consuming and actually its application could not be justified by advantages significantly over those from other methods supplying quasi-optimum solutions.

In the following two arrangement methods are described.

5.1.1. *The method of the principial charge periods*

With regard to the rather great serials implied by the decade tasks it seemed advisable to study the possible production rates of the casts of given forms in the casting area.

For the purposes of this study we introduced the concept of the theoretical chargeperiod, during which the criteria of continuous castability era satisfied within an assumed continuous production cycle producing exlusively casts of the involved form.

By ordering the forms in a sequence of increasing theoretical charge periods, the types of similar charge periods can follow consecutively and so the inclusion of a type of new form in the daily production program will not much increase the charge period (the theoretical charge period of a given production cycle is the maximum of the theoretical charge periods within the cycle).

5.1.2. *The method of theoretical discharge periods*

A time moment can be established for each form relating the time moment of placing the mould boxes on an emply line to the moment when the removal of the line of mould boxes can be started at a maximum placing-removal rate. This relative time moment is called the discharge period of the given form.

By ordering the forms in a line of increasing discharge periods it can be ensured that the forms, which may be discharged most favourably, should be cast the first always.

By comparing both arrangement methods it may be established, that

1 — although the two methods result in quite different sequences of the forms, for the same task, yet the study of the criteria of continuous castability gives approximately identical charge periods for both sequences;

2 — both methods may be regarded as quasi-optimum, but in the case of a given task it may be advised to examine, which of both sequences will give a result closer to the optimum (shorter charge period);

3 — in applying the first method considerable time intervals arise between the moulding of the individual lines, so the casting rate is little affected by changes in the time duration of placing the individual mould boxes, or by the inclusion of pattern plate replacements;

4 — with the second method the operation of the moulding machine is nearly uniform, so the daily charge period is sensitively influenced by every variation in placing the mould boxes;

5 — on applying the first arrangement method the sand plant imposes probably no restrictions whatever, due to the time intervals in moulding, while with the second method, where the moulding is nearly continuous the predicted casting rate might prove impossible due to the insufficiency of the sand plant capacity.

As a conclusion it may be stated that both arrangement principles approximate the possible optimum in the sequence of the lines of various forms from two different sides, and the selection between the arrangement principles, supplying a quasi-optimum solution each, depends on the given task, the results obtained by both methods for the given task and the actual technological conditions.

The daily assignations are obtained from the decade task by the following main decomposition steps:

1. Forming the serial casting vectors by cast forms.
2. Determining the charge periods of the individual cycles; determining the possibility of the continuous implementation of the task (by lines) with the shortest possible charge period (maximum melting plant yield).
3. Determining the number and the types of the casts to be produced on each day, in the knowledge of the minimum charge periods, obtained for the individual cycles.

5.2. *Control of the realizability of the casting task with a view to core production*

The algorithm decomposing the decade task to cycles supplies the types and the number of the casts to be produced on each day of the decade. The sequence of the days may be chosen arbitrarily, as for the castings, while the final sequence is obtained by the control of the core production.

Examining the possibility of supplying the core requirements of the casts it is attempted to find a sequence of the continuous production cycles derived from the decade task, for which the cores required in each cycle can be produced during the preceding cycle, i.e. one cycle period earlier.

Such a sequence is likely to be found, as the core requirements of each cycle may be very different, so during certain cycles more cores than needed for the next cycle, — i.e. some for the subfrequent cycles, — may be produced in advance.

The algorithm to be described gives the types and the number of the cores to be produced in each cycle, distributes the production task among the workplaces and determines the time schedule and the rate of the production.

Notice that the problem of core (ageing is ignored a finished casting core "ages", i.e. it comes useless beyond a certain time).

The algorithm assigning the core production is constructed — as already mentioned above — in a way that the cores for each cycle are produced at least one cycle earlier. The production of the cores for a certain cycle several days earlier occurs only in rather extraordinary cases (when e.g. several cycles in the decade require no core).

The present algorithm takes an arbitrary number of core injection sets into account (one set is only used for producing a definite core type).

A case to be treated specifically — namely when only one set is available, giving use to a very critical situation — due to the far reaching homogenization —, as a certain type can be produced with the only set at one workplace at a time, although there are several workplaces, operable independently of each other. The obtained core production assignation plan may be regarded as quasioptimum. For attaining the optimum solution a computer apparatus of too much running time (e.g. for dynamic programming) would be needed, where as application of this time-consuming method could not be justified by any jumplike improvement in optimality.

The sequence of the continuous production cycles obtained in the above manner forms an indissoluble unity, i.e. the sequence of the days cannot be interchanged, no one production cycle can be abandoned, as on each day not only the cores for the next cycle are produced, but prefabrication is also carried out. An additional day can only be included in the sequence of the cycles, if its core requirement can be satisfied from the stock of the actual initial store and this same core requirement can be produced within a core production cycle to make up the initial level of the core storage again (production cycles requiring no cores may be included naturally in any arbitrary number in the sequence of the cycles).

On the basis of certain considerations (e.g. breakdown algorithm) making one casting cycle to correspond one core production cycle may be of advantage.

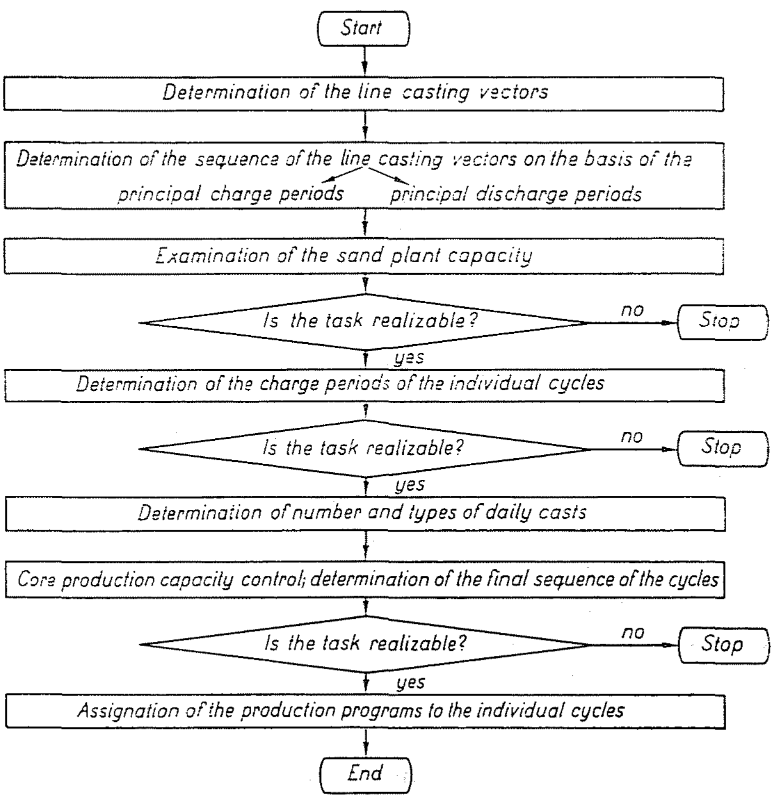

Fig. 3

Therefore we have included in the program prepared on the basis of the algorithm an additional parameter indicating the mode of operation, to enable the planner of the core production to work — depending on the value of this parameter according to routine, or in the manner described above, or to try to accomplish the production of the cores for the individual continuous production cycles in separate core production cycles (i.e. by starting a new core production cycle for each new casting cycle). In this latter case — if the task of the core production proved realizable — the sequence of the cycles may be arbitrary and the cycles are independent of each other with respect to the core production too.

6. The structural scheme of the algorithm

The structure of the production control algorithm is illustrated in Fig. 3.

Summary

An algorithm modelling the casting process is presented permitting to elaborate the daily production tasks derived from the production data foreseen for a longer period and the optimum production rates during each workday.

The described algorithm supplies the reference signals of the foundry control system ensuring the co-ordination of the partial processes and the optimum realization of the production task of the foundry.

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