COMPUTERIZED PRODUCTION CONTROL OF PROCESSES IN MACHINE INDUSTRY

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Introduction

Production processes in the modern continuous production plants require to be planned. The technology implies the necessity of well developed (possibly computerized) control systems for fast adaptation to the situations arising in the course of production, as a preliminary condition of the optimum exploitation of the production plants.

The main requirements of controllability of the production plants are

- the exploitation of the high capacities of the production units,
- the timely co-ordination of the successive work phases,
- low waste values,
- co-ordination between the manufacturing and the supplying units
- the possibly greatest uniform product series,
- computer-aided certification and registration.

For a given enterprise in the machine industry, where a production line is one of the plant units, the complex task described above may be solved by a three-level computerized system, of the following hierarchy (Fig. 1):

A — the level of general data processing,
B — the level of the direct or on-line, production control,
C — the level of process control.

The separation of these three levels is motivated by the tasks to be solved and by the applied different methods.

On the highest level of an integrated computer-aided production control system, the economic considerations are the most important factors, but on the lower levels of control — approaching the production process — the technological aspects of the process to be controlled have to be taken even more into consideration.

The staff of the Department of Automation has been dealt with the problems arising in control of large industrial processes for many years. In the following some examples will be presented to illustrate the possible ways of approach to this task. But a short description will be given of each problem, but stress is laid upon the solution methods. Finally, relevant experiences will be recapitulated and conclusions drawn therefrom.

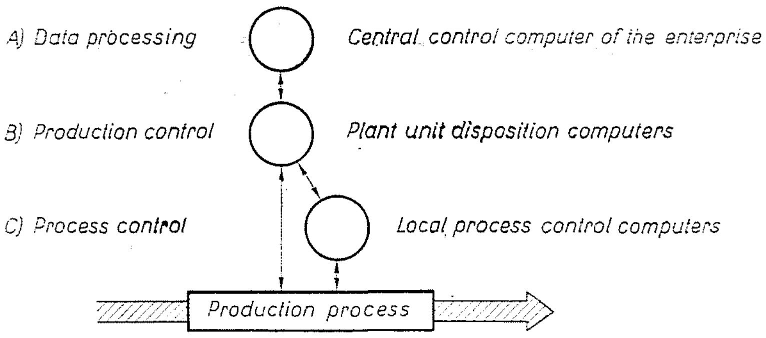

Fig. 1

1. Computer control of complex production lines based on algorithmic models

1.1. *A short description of the technological process*

The plant consists of three parts:

- production lines,
- store of semi-products (service parts),
- assembly line.

Each production line consists of cutting machines and cold-working machines, 20 to 30 in total.

1.2. *Functions of the control algorithm* are:

- decomposing the monthly production plan to decades (10 days),
- calculating the beginning and the ending time of a production sequence,
- determination of the optimum production sequence,
- controlling the process and signaling the occasional break-downs,
- ensuring the maximal use of manufacturing capacity or minimizing the production time.

1.3. *Production models of the production line*

In establishing a mathematical model of a production line, supposed to consist of g working places (homogeneous machine groups) served by a conveyor, where w product sorts are produced and there are $n_j\,(j = 1, 2, \ldots, w)$ pieces in each product sort.

The available data are: preparation periods **E**, operation periods **A**, the matrix **T** of transportation periods and the assignment matrix **M** describing the technological sequence (see definitions below).

Let us investigate first the case, where the speed of the conveyor is infinitely high. The production model will be formulated by introducing some notations. Be $n = \{n_j\}$ the (w by 1) vector containing the piece numbers of the product; $\mathbf{A} = \{a_{i,j}\}$ the (g by w) matrix of the operational periods; $\mathbf{E} = \{e_{i,j}\}$ the matrix of the same dimension of the preparation periods. Subscripts i and j denote the serial numbers of the involved machine and of the product, respectively.

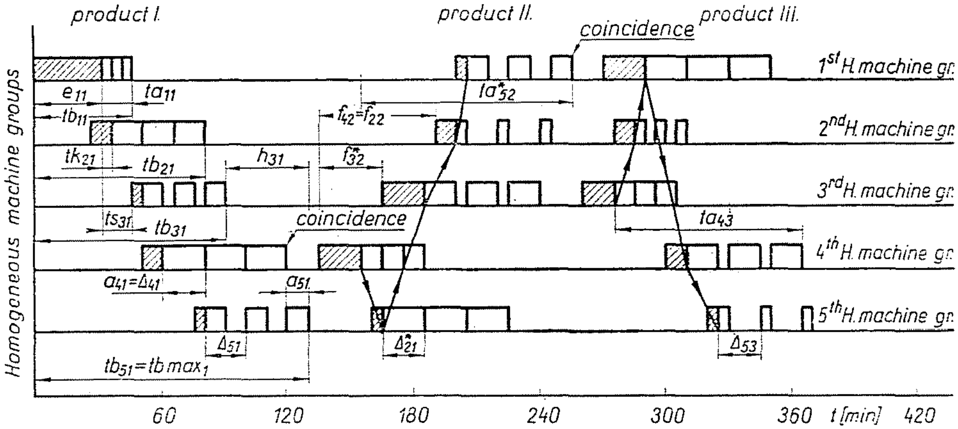

Fig. 2

Let us define an assignment $\mathbf{M} = \{m_{i,j}\}$, or operational sequence matrix of dimension (g by w) of elements $m_{i,j}$ denoting the serial number of the i-th machine in the technological sequence of the j-th product; where $m_{i,j} = 0$ means standstill of the involved machine, or that it is not producing the j-th product. Matrix $\mathbf{M}$ permits to obtain matrices of operational sequence elements from the matrices of machine sequence elements (see further the matrices marked by *).

The algorithm for simulating the production line can be constructed on the basis of Fig. 2.

In simulating intermittent production with infinite conveyor speed, it was also presupposed that the product did not return to one and the same homogeneous machine group. But one or more uniform machine groups may not take part in the production of some product. This is denoted by the corresponding zero-value elements of matrix $\mathbf{M}$.

For the sake of simulating continuous production, the corresponding algorithms can be constructed according to Fig. 3.

Concerning the evaluation of the developed algorithms it must be said that even the last two cases represent a rather high degree of abstraction as compared to the operation of the real production line.

Those among the presented models simulating the intermittent operation involving the assumption of infinite conveyor speed were seen to be the most for useful. Namely, in this case the characteristic times of the theoretically possible (fastest) ideal production are obtained. Comparing them with the real times results in the relation between theoretical and real preparations, and particularly, operational periods. After a few corrections, and using the algorithm, the corresponding standard periods (operational periods, piece-time) can be determined.

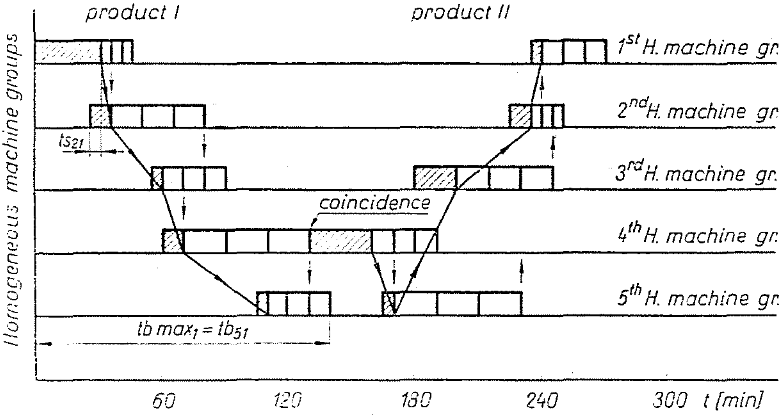

Fig. 3

Thereafter, the initial matrices can be refined on the basis of site measurements.

For instance, modifying the matrices of the preparation and the operational periods are modified after a q-th series of measurements:

$$\mathbf{E}(q) = \mathbf{E}(q-1) + \frac{1}{q}\big(\mathbf{E}(q) - \mathbf{E}(q-1)\big) \tag{1}$$

$$\mathbf{A}(q) = \mathbf{A}(q-1) + \frac{1}{q}\big(\mathbf{A}(q) - \mathbf{A}(q-1)\big). \tag{2}$$

These relationships may be regarded as a sequential averaging (stochastic approximation) method.

1.3.1. *Determination of the optimum product sequence*

As optimum will be regarded the sequence implying minimum total throughput time $tb^*_{g,w}$. (See Figs 2 and 3.) This can be calculated and for low product numbers ($w < 6$) its minimum is found by counting the possible w!

permutations of the products. Naturally this way is not viable in the case of high product numbers.

In manufacturing products consecutively, a time-saving $p_{j-1,j}$ is obtained by creating the phenomenon of "junction" when going over from the $(j-1)$-th to the j-th product, against the case of waiting until the last piece of the $(j-1)$-th product comes out of conveyor. The value of $p_{j-1,j}$ can be expressed as

$$p_{j-1,j} = \min_{(i=1,\ldots,g)} \{d_{i,j}\} = du_{j,j}. \tag{3}$$

Be the (w by w) matrix **P** composed of elements $p_{j-1,j}$, i.e. of elements $p_{r,s}$ representing the time saving at finishing the r-th beginning the s-th product.

The diagonal elements of **P** are indifferent by definition. In optimization, one has to select from among the sequential vectors

$$S_{s1} = [s_1, s_2, \ldots, s_w]^T \qquad s_i \neq s_j \tag{4}$$

the one, for which the quantity

$$Q_{s1} = p_{s1,s2} + p_{s2,s3} + \cdots + p_{sw-1}, s_w \tag{5}$$

is a maximum, that is the problem is to determine the optimum permutation

$$S^* = \max_{S_1} \{Q_{s1}\}. \tag{6}$$

This problem is a well-known fundamental type of discrete programming which can be handled in various ways. It can be investigated as a travelling salesman problem and solved as Hamiltonian ways of the maximum length. Various solution methods are known, but most of them are very complex and become especially cumbersome, when combined with the degeneration problem.

An algorithm supplying a simplified, suboptimum solution will be presented. Accordingly, the value of (5) will be calculated with the initial values of $s_1 = 1, 2, \ldots, w$ for the permutations generated in the following way:

$$p_{s_{k-1}, s_k} = \max_{j} \{p_{s_{k-1}, j}\} \tag{7}$$

$$j = s_1, s_2, \ldots, s_{k-1}$$

Then s^* will be selected according to (6). The algorithm gives no global optimum, but it is easily programmable and the solution gives usually a rather convenient result [3], [4].

2. Production control in a continuous steel foundry by computer modelling

2.1. *The technological process*

The lay-out of the individual technological units is shown in Fig. 4. The Bessemer process of steel production is supposed to be known. Only the main features, important from the point of view of modelling, will be outlined.

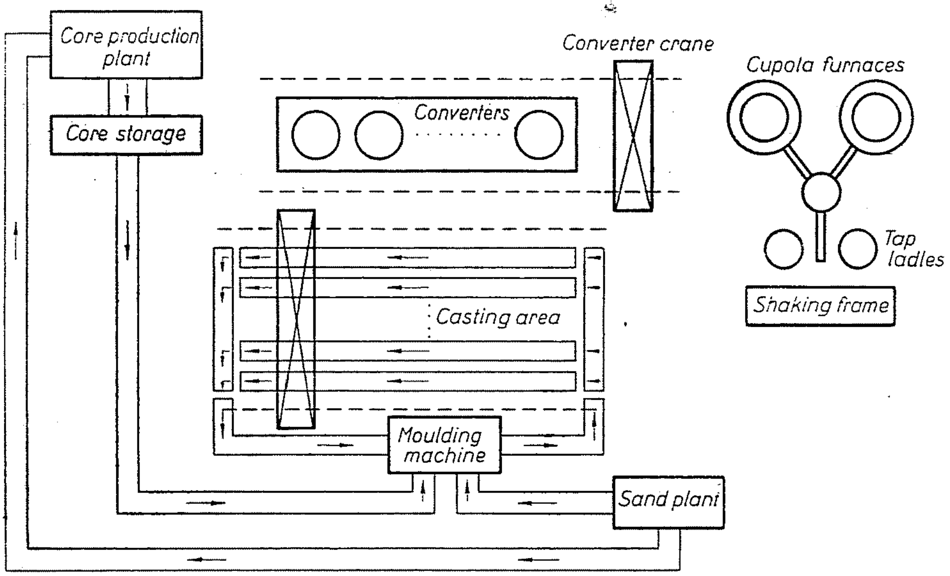

Fig. 4

2.2. *Restriction imposed by the technology*

— The cupola furnace must operate during the whole cycle (one day) at a constant capacity.

— Casting is performed by casting lines.

— The mould boxes must be ready for casting on the actual lines at 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 at the start of the cycle.

— The mould boxes are removed and placed by casting lines.

— The sand necessary for the moulds of one line must be available at the start of moulding.

2.3. *The tasks of control algorithm*

The reference signals of production process:

- charge periods (time periods between 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.

According to the above, the aim of the modelling algorithm can be stated as follows:

> in knowledge of the long-term production tasks, and the production capacity limits of the manufacturing unit, the reference signals are to be determined with regard to the optimal use of production plant and in a way that the partial processes of the whole production are accurately co-ordinated.

Thus the demands upon the modelling algorithms are seen to be variegated.

2.4. *The algorithm determining the decade reference signals*

Several methods lend themselves for solving the task, out of which the one offering the best possible solution that is acceptable also with a view on the machine time must be selected.

For simplicity's sake, let us 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 involves two major tasks:

1 — decomposing the whole decade casting plan to cycles (days)

2 — studying the feasibility of the resulting cycle tasks, with respect to the core production plant.

2.4.1. *Determination of the decade reference signals by unifying the task of casting*

The sequence of casting must be determined in a way that the successive casts are possibly uniform, because their inhomogeneity slows down, the production considerably reduces the material storage capacity of the casting area, because of the necessity of replacing the pattern and press plates during moulding and placing the mould boxes.

Accordingly, homogeneous serial casting vectors are introduced. (The casting vector is the number of mould casts from one charge. The serial casting vector is formed from several casting vectors. A serial casting vector means the number of the mould boxes to be placed on one line.)

The fact should be stressed that the unification of the task implies certain roundings off (only whole serial casting vectors are taken into account), although negligible related to the total volume to be produced during the decade, and lower than the waste percentage.

The developed algorithm follows up the movement of the mould boxes over the casting area and examines the feasibility of the casting task at the given production rate (charge period). (The charge period is the time between two successive charges.)

The basic criterion in this examination is that loading the casting line must be finished sooner at least by the safety period than the casting starts, on any line, with due consideration to the cooling conditions of the previous — not yet removed — mould boxes standing on the line and the possible pattern plate replacements 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 sequence (finding the maximum casting rate) was determined by dynamic programming not to be described here in details.

Further investigations showed that two algorithms supplying quasi-optimum solutions could also give a method very accessible for operative production control. In the following these two suboptimal algorithms — based on simple physical considerations — will be described.

2.4.2. *The method of the principal charge periods*

With due 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.

Within the scope of this study the concept of the theoretical charge periods has been introduced, which the criteria of continuous castability are satisfied within an assumed continuous production cycle, producing exclusively casts of the involved form.

The forms can be ordered in a sequence of increasing theoretical charge periods, where similar charge periods 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).

2.4.3. *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 empty 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 always the forms, which may be discharged most favourably, should be cast the first.

By comparing both arrangement methods it may be established, that

— the two methods result different sequences of the form,

— the two different sequences ensure approximately identical charge periods,

— when applying the first method considerable time intervals arise between the moulding of the individual lines, the sand plant imposes no restrictions,

— with the second method the operation of the moulding machine is uniform, so the daily charge period is sensitively influenced by every variation in placing the mould boxes, that is from the point of view of controllability — by using this method — one must be careful,

— the second method seems better from the point of view of cooling.

It may be concluded that both arrangement principles approximate the optimum in the sequence of the lines of various forms but from two different sides, and the selection between them, each supplying a quasi-optimum solution, depends on the given task, the results obtained by either method and the actual technological conditions. The structure of the production control algorithm is illustrated in Fig. 5.

The checking investigations, however important from the point of view of core production, are not detailed here, but have been described in [5].

A FORTRAN program based on this algorithm proved to be very efficient, its running time never exceeded 5 minutes in the investigated cases.

Therefore, the algorithm can be applied for continuous production control: in the case of occasional break-downs the effect of parameter changes can also be taken into consideration, by rerunning the program.

The running time remains always beyond the time constants of the casting plant.

Investment planning may also be an important field of application of this algorithm. Namely, the program involves the available capacities as variables, so the number of the necessary casting equipment and of the objects, as well as the required capacity can be determined.

The previous exposition of the two case-studies refers to the task — already mentioned in the introduction — affecting on the B-level of the hierarchical production control system.

The relation between the lower and to the upper level is very clear: both algorithms get the basic dates from the A-level and provide information for the C-level.

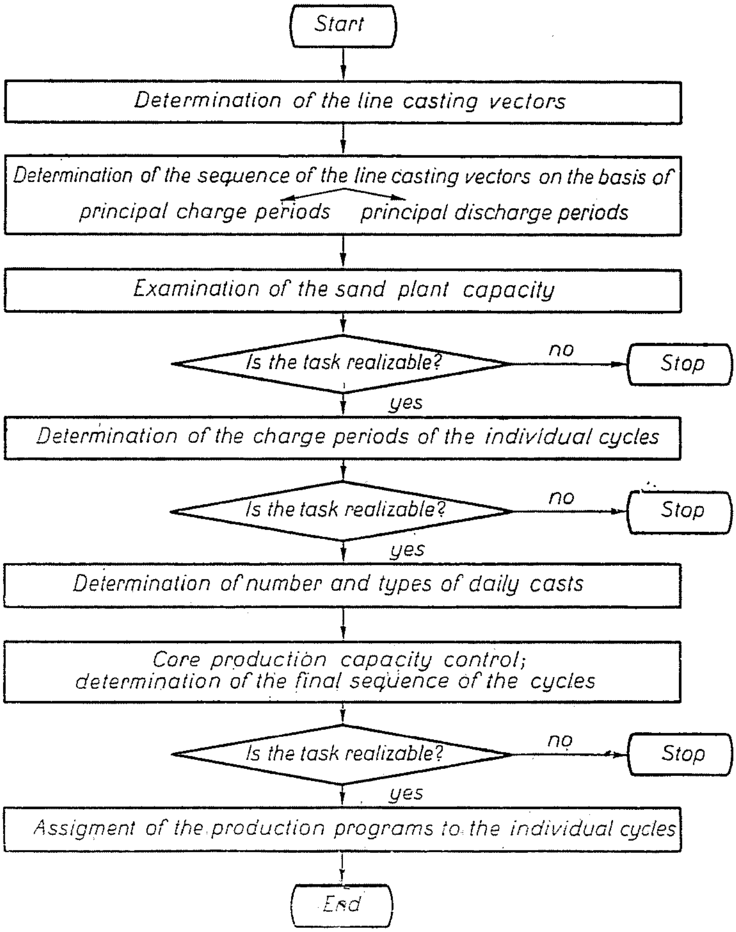

Fig. 5

In the third part some approximative methods, typical for the A-level related to inventory control elaborated at the Department of Automation will be discussed.

3. Investigation of inventory systems

The aim of storing (stock building) is:

— stability and continuity of the production in a plant and

— readiness for continuous delivery toward the customer with minimum prime costs.

There is ample literature on the inventory control technique. Unfortunately, in most cases the presented methods are rather difficult to adapt in it because of the deviations in the control effects of the regulating mechanisms of different national economies.

There are two essential points in this problematic: one is reliable forecasting of several characteristics mobilizing the stock (i.e. demands) and the second one is the development of an optimum inventory model.

Both of these questions have been considered in detail. The methods applied and conclusions drawn therefrom will be outlined.

3.1. *Forecasting the customer's demand*

In developing computer controlled inventory systems one basic task is to forecast the characteristics affecting the store state, i.e. the expected demands. (The applied methods are independent of the investigated characteristics.)

The forecasting block of the computer-controlled inventory system has to give a reliable forecast of the expected future value of the tested magnitude on the basis of its past progression.

The following estimation methods have been examined:

- direct investigation by means of a standard distribution function;
- exponential smoothing algorithms;
- stochastic approximation algorithms.

The methods are known from the literature except some adaptive algorithms recently developed at the Department of Automation [8], [9].

Having studied and compared the results of these methods, they were found to show great deviations in the required number of starting data, computation time and expected estimation error.

The choice of the procedure for a given case is always a compromise. The choice must be very circumspect:

- the class of importance of the given item must be determined (ABC analysis [9]),
- an appropriate, economic algorithm of satisfactory accuracy must be applied.

Concerning the effectiveness, the exponential smoothing algorithms give the optimum results, whereas from the viewpoint of accuracy the successive approximation algorithms seem to be the best. The usefulness of these latter ones is strongly limited by the great number of basic data needed for them to be efficient.

Considering the economic operation, their utilization is recommended only for products or product groups judged to be important by the ABC-analysis — if other conditions for their operation are satisfied.

A very effective program library have been prepared for these three main groups of algorithms utilized in forecasting.

3.2. *Inventory models*

The inventory control system has three important tasks:

— to determine the minimum stock-level likely to satisfy the demands of statistical character at a certain predicted safety,

— to determine the time of filling up the store, the time of purchase order,

— to establish the optimum quantity for an item to be ordered.

Our investigations concerned several models.

Most publications refer to cost type models, but in the socialist sector the costs appearing in these models are rather tedious to determine. Hence our investigations mostly concerned reliability models, involving formulation of algorithms and computer programs.

Although costs are generally ignored by reliability models, their application essentially reduced the previous average store level in every case.

Beside the application of the deterministic and stochastic models found in the literature, several new models have been developed. The optimal parameter values were set e.g. by dynamic programming or by simplex method.

Summary

The organization work prior to introducing a computer control and information system is a contribution to optimum operation.

In introducing a new computer control system it is just the organization work, the generation of basic data necessary for the control that meets difficulties.

Parts of program-packages developed by the great computer manufacturing companies are utilized successfully in practice also in this country, but because of their striving for generality some modules need modifications to be applied in an actual control problem.

In such cases the described rather particular solutions may be applied.

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