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# Control of material flow in a metallurgical plant*

by

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The paper concerns a problem of the managing control of mecomplex metallurgical system, that is a problem of material flow in the sector: steel work rolling mill.

A criterion function for the process considered is formulated. This criterion function forms the base for model construction and modelling algorithm of material flow process.

The discussion of the various modelling algorithms of the material flow is given.

The possible actions upon the considered process, that belong to the class of the organization management controls are shown.

The control algorithms of the considered process are given.

## 1. Introduction

The production process in a metallurgical plant in its section between the steel mill and the primary rolling mill is of substantial importance for the quantity and the quality of the products. This process includes some technical and transport operations following one another. Strict technological discipline is a precondition for solving the problem of controlling this process so as to meet the requirements, i.e. to fulfill the goal functions under the existing limitations.

These (often contradictory) requirements make it sometimes necessary to master conflicting situations.

Without discussing the question of controlling separate technological units (subprocesses) let us proceed directly to the optimization for coordinating the particular technological stages of the whole process.

The analysis of the system has discussed the most important criteria, i.e. the purposes of control, on the basis of which a mathematical model has been con-

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structed. If we regulate the process of material flow between the steel mill and the primary rolling mill so as to minimize any standstill in the steel mill that may be due to the lack of hot ingots for rolling and to maximize the temperature for charging the ingots into the heating furnace chambers, we shall obtain the time model of this process. In this model each technological and transport operation is characterized by the time it takes. Because of the great number of technological stages and the diverse operating equipment and because of the many kinds of steel produced an analytical description of this process is not possible. The only effective tool of analysis and synthesis is a digital model.

Such a model makes it possible to follow up the technological sequence by statistical modelling, which in turn permits to detect and investigate the bottlenecks, the effects of breakdowns, the results of planned investments (e.g. building an additional pouring platform or a chamber in the heating furnace). Moreover, in its deterministic version, the digital model may be used for controlling the material flow by means of a computer. This problem is discussed in the present paper.

## 2. The outline of control

The technology analysed here is so complex that even the most experienced dispatchers hardly ever manage to regulate the process so as to prevent a rolling mill from stopping due to the lack of hot metal. Hence the necessity of making decisions by way of modelling.

The controls which belong to the class of organizational and operational procedures are realized on the basis of the knowledge of the actual state of the process and the forecast input stream.

By control decisions we mean operations such as the choice of the moment of stripping each melt, the assignment of the pit furnace chamber into which the melt is to be loaded, decisions concerning the loading of the cold charge or limiting the number of ingots to be charged into the chambers etc.

To make optimum decisions it is necessary to make use of the model of the section between the steel mill and the primary rolling mills.

If we accept their mean values as the operation times, then with the assumed input stream we can obtain a deterministic model of the process for investigating a finite number of control variants choosing the one which is optimum according to the adopted criteria. If the results of analysing the variants are to be used for controlling the technological process, the analysis should be done early enough so as to provide for taking into account the future effect of the decisions on the course of the operation for the current situation in the section.

Thus the a priori analysis should be made at least for such a time $T_m$ (the horizont of the forecast) by which it is possible to have all the melts in the production sequence rolled. The a priori analysis is carried out with periodicity $T_s$ determined by the time necessary to update the model and the time necessary to analyse the control variants for $T_m$. For each cycle of analysis the choice of the optimum variant determines explicitly the control decisions for the entire time of forecast $T_m$.

For controlling the process use is made of those decisions only which occur in $T_s$. In the next cycle of analysis the programme of control actions is determined for the next interval $T_s$. This prevents the accumulation of possible errors of forecast and permits to take into account, with the required accuracy, all actions disturbing the operation in the section, if $T_s \leqslant T_m$. In such a complicated process this condition can only be realized with the use of computer techniques. For this purpose we need the efficient system ODHS, which allows to update the model in time $T_s'$, and a digital computer directly coworking with this system and preparing all possible control variants within the time $T_s''$, at $T_s' + T_s'' < T_s$.

The idea of such a system is shown in Fig. 1.

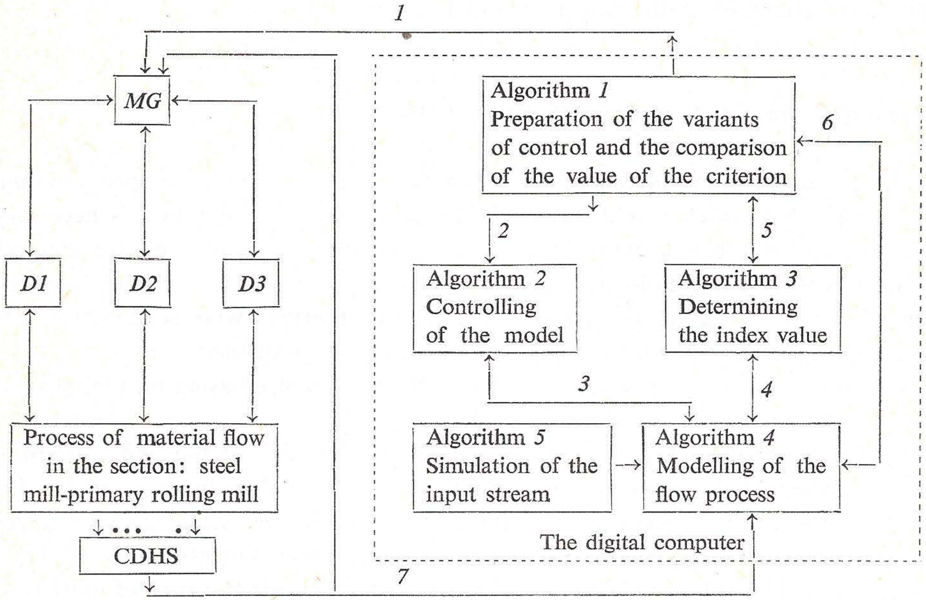


Fig. 1. The scheme of a control system
*1* — optimum variant of controlling the model; *2* — control variant which is being veryfied; *3* — control signals; *4* — informations concerning the dynamics of the process necessary for the determination of the index; *5* — index value for the variant which is being veryfied; *6* — information concerning the actual state of the model; *7* — information concerning the actual state of the process

The process is directed by the main dispatcher to whom the dispatchers of the particular sections of the technological sequence are submitted: $D_1$ — the steel-mill section, $D_2$ — the stripper's section, $D_3$ — the heating furnaces and the rolling mill section. The information concerning the process is sent to the main dispatcher and to the digital computer by means of the system CDHS. The computer's task is to elaborate the optimum control of the model and to pass it on to the main dispatcher, who, having veryfied the proposed control, on the basis of the information obtained from the system CDHS undertakes final control decisions and passes them on to the dispatchers of the particular sections. The working out of the optimum control of the model is realized by the following algorithms:

algorithm 1 — preparing the control variants and comparing the values of the criterion for each variant,
algorithm 2 — controlling the model,
algorithm 3 — defining the value of the quality index for the particular variants,
algorithm 4 — modelling the flow process,
algorithm 5 — simulating the input stream.

After the successive variant of control (algorithm 1) has been determined the controlling of the model is being realized (algorithm 2) and the value of the criterion (algorithm 3) for the time $T_m$ is established. These operations are performed for each possible variant. As a result of their remodelling algorithm 1 works out the optimum variant of controlling the model.

## 3. The modelling of the process of material flow

To realize the above presented idea of control, the working out and programming of an algorithm which would model the process under consideration is necessary. The methods of creating algorithms of this type result from the possible methods of identification a technological sequence. One of them consists in the investigation of the behaviour of the process in time by observers who occupy the same observation points (independently of time) along the sequence.

The other one investigates the bahaviour of the sequence basing on the informations made by observers following each melt [1, 2].

The algorithm which has been worked out on the basis of the first conception may be presented as shown in Fig. 2. It has been thoronghly discussed in [3]. For its elaboration it was necessary to divide the technological sequence into stages, distinguishing the equipment which may execute identical operation in the particular stages. The following stages have been distinguished: the cast of steel from the furnace, standing-by in a ladle, standing-by in the ingot mould at the pouring platform, and next on the storage-tracks, stripping, the charing of the heating furnace, homogenizing treatment and rolling [4].

The algorithm modelling the process reflects the passage of the particular melts through all sections of the production sequence, projecting the succession of the passages and the times spent in the particular stages. The state of equipment in each stage is characterised by the three letters $(T, R, P)$, where: $T$ — time left till operation is finished, with $T>0$, and time of remaining in the stage for $T\leqslant 0$; $R$ — specification of the melt with regard to the kind of steel and the type of the ingot mould; $P$ — additional characteristics of the melt (e.g. its number, time spent in the ingot mould etc.).

The operation times of different melts in the particular stages may differ considerably from each other. On the one hand it follows from different production methods used for the particular kinds of steel (different $R$) and on the other hand from the length of operation times in the preceding stages. This makes the melts get ahead of each other in the sequence.

The passage of the melt from one stage to another is possible only when the two conditions are fulfilled simultaneously: the operation in the stage $j$ ($T^j<0$) being finished and the equipment in $j+1$ ($R^{j+1}=0$) being free.

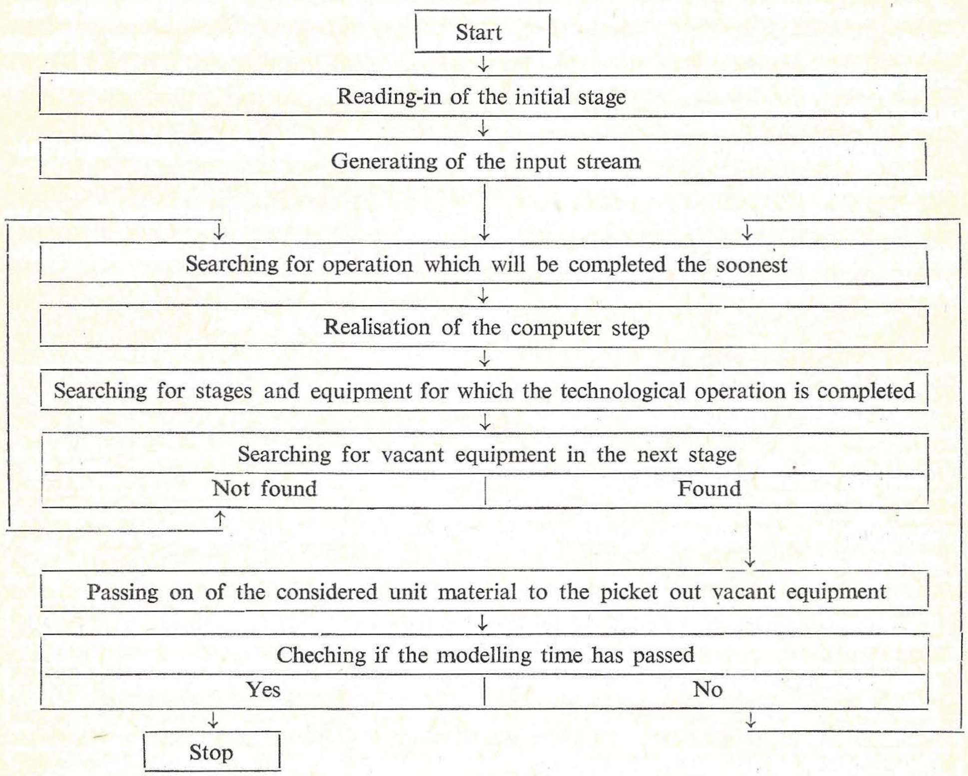


Fig. 2. A block scheme of a control algorithm

The chosen variant of controlling the model for the time $T_m$ realized the decisions concerning the shifting of a material unit from one stage to another in strictly defined moments when the above mentioned condition of passage is fulfilled.

Basing on a detailed algorithm a computer programme called IAIEP has been worked out. This programme has been recorded in the language FORTRAN for the Honeywell H-3200 type computer in the operational system OS-200.

## 4. The description of a control algorithm of charging the furnace with melts

The previously mentioned criterion concerning the quality of the operation of the sequence which is the minimalization of the time of the mill's standstill resulting from the lack of hot ingots for rolling, and the maximalization of the mean temperature of charging the ingots into the heating furnace chambers is most susceptible to the following moments of control: the moments of stripping time of the particular melts, the charging of the unit materials into the proper chambers of the heating furnaces and the charging of cold stock.

We shall present now one of the possible algorithms preparing the ordering of the unit materials to the right chambers and the moments of stripping these materials. The possibility of controlling the assignment of the ingots many different heating furnace chambers results from a great differentiation of the chambers in regard to their thermal efficiency.

It depends, among other factors, on the time which has elapsed suice the particular chamber was last repaired [7].

The block scheme of an algorithm preparing the variants of charging the melts into the heating furnace chambers, as shown in Fig. 3, is one of the control algorithms constituting algorithm 1 (Fig. 1).

↓ From the operational system of algorithm 1

| | |
|---|---|
| Counting of the melts which are past their standing-by time on the crystallization tracks and their arranging in a sequence | A1 |
| ↓ | |
| Counting of the melts being stripped and those after stripping | A2 |
| ↓ | |
| Arranging of the numbers of the heating furnace chambers according to the time of their clearing | A3 |
| ↓ | |
| Choosing the elements from block A3 for charging the melts sorted out in block A1 | A4 |
| ↓ | |
| Preparing of the variants of assignment for the chambers picked out in block A4 to the melts found in A1 | A5 |
| ↓ | |
| Determination of the moments for starting the stripping of the melts for successive variants from block $A_5$ | A6 |

↓ Step towards the operational system

Fig. 3. A block scheme of a control algorithm of charging the melts

The task of this algorithm is to work out the control variants consisting in establishing for a given state of the model the assignment of the melts to the right chambers and calculating the moments of stripping. This algorithm eliminates from further consideration those variants which essentially do not differ from each other (identical specifications $R$), as well as those which do not satisfy the limitations assumed in the model.

After the presented algorithm has been called out there goes on in block A1 the searching for the melts which are past their standing-by time on the crystallization tracks (stage $j=3$), i.e. for those melts which satisfy the condition $T_i^j \leqslant 0$, $i=1, \ldots, n_j$. These melts are reckoned and arranged according to the increasing $T_i^j$; the number of those melts equals $k$.

In block A2 there follows the counting of those melts which are being stripped or have been already stripped and are waiting to be charged into the furnace chambers that have been previously sorted out for them.

Next comes the ordering of the numbers of the furnace chambers according to the time of their clearing. This is done by block A3. Out of the pre-set sequence of chambers in block A4 those are being eliminated to which the melts found out in block A2 have been already assigned.

Further on, all possible, non-recurring and admissible assignments of the melts defined in A1 to the chambers selected in block A4 are established. The working out of all these variants of assignment goes on in block A5.

In block A6 the moments of starting the stripping for each of these variants of assignment are determined.

The stripping of the melt which has been assigned to the i-th chamber should start when the condition:

$T_i^6-(T^4+T^5)\leqslant 0$ is satisfied; where

$T_i^6$ — time left till the heating of the unit material in the i-th chamber is finished;

$T^4$ — stripping time of the melt assigned to the i-th chamber;

$T^5$ — transport time of the melt from the stripping by to the heating furnace aisle.

When all the possible variants have been established, then follows a step towards the operational system.

## 5. Conclusion

The above discussed control algorithm is one of the many algorithms realizing the presented concept of controlling a model. This one as well the other control algorithms have been programmed and veryfied on the digital computer Honeywell H-3200. Actually a research work is being carried out towards the introduction of the presented conception for controlling a real process.

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## Sterowanie przepływem materiałów w kombinacie metalurgicznym

Praca poświęcona jest zagadnieniu sterowania pracą systemu metalurgicznego, a zwłaszcza zagadnieniu przepływu materiałów na odcinku stalownia — walcownia.

Sformułowano wskaźnik jakości dla rozważanego procesu, stanowiący podstawę konstrukcji modelu i algorytmu modelującego proces przepływu materiałów. Rozważono różne algorytmy modelujące.

Pokazano możliwe oddziaływania na rozważany proces, należące do klasy sterowań typu organizacyjnego. Przedstawiono także algorytmy sterowania omawianym procesem.

## Управление потоком материалов на металлургическом комбинате

Работа посвящена вопросам управления действием металлургической системы, а в особенности вопросу потока материалов на участке сталеплавильные цехи — прокатные цехи.

Формулируется показатель качества для рассматриваемого процесса, являющийся основой для разработки модели и алгоритма моделирующего поток материалов. Рассмотрены разные моделирующие алгоритмы.

Указаны возможные воздействия на рассматриваемый процесс, относящиеся к классу управлений организационного типа. Представлены также алгоритмы управления рассматриваемым процессом.