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HEURISTIC ALGORITHM FOR PLANNING AND SCHEDULING OF FORGED PIECES HEAT TREATMENT

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Preliminary Note – Prethodno priopćenje

The paper presents a heuristic algorithm for planning and scheduling of forged pieces heat treatment which allows maximizing the capacity exploitation of the heat treatment process and the entire forging process. Five Focusing Steps continuous improvement process was selected as a methodological basis for the algorithm design. Its application was supported by simulation experiments performed on a dynamic computer model of the researched process. The experimental work has made it possible to elicit the general rules for planning and scheduling of the heat treatment process of forged pieces which reduce losses caused by equipment conversion and setup times, and which increase the throughput of this process. The HIPO diagram was used to design the algorithm.

Key words: forged pieces, heat treatment, planning and scheduling, 5FS continuous improvement process, dynamic simulation

Heuristički algoritam za planiranje i terminiranje toplinske obrade otkivaka. U radu je predstavljen heuristički algoritam za planiranje i terminiranje toplinske obrade otkivaka i koja omogućava maksimalno iskorištavanje kapaciteta procesa toplinske obrade i cijelog proizvodnog procesa kovanja. Metoda Pet koraka fokusiranja za kontinuirano poboljšanje procesa je odabrana kao metodološka osnova za kreiranje algoritma. Njegova primjena je podržana simulacijom eksperimenata koja se izvodi na dinamičkom računalnom modelu za istraživanje procesa. Simulacija eksperimenta je omogućila da se mogu izvesti opća pravila za planiranje i terminiranje procesa toplinske obrade otkivaka koji smanjuju gubitke uzrokovane opremom i vremenskim planiranjem, a povećavaju propusnost tog procesa. Hijerarhijski dijagram planiranja i terminiranja procesa je korišten za izradu algoritma.

Ključne riječi: otkivci, toplinska obrada, planiranje i terminiranje, 5FS kontinuirano poboljšanje procesa, dinamička simulacija

INTRODUCTION

The current competitive and globalized market environment is characterized by strong pressure of the customers to supply wide range of products (often of special construction) in smaller quantities and to manufacturing products with high added value and quality [1]. This naturally leads to frequent conversion of the production facilities and reduction of capacity exploitation.

The objective of this article is to design a heuristic algorithm for planning and scheduling of forged pieces heat treatment which allows maximizing the capacity exploitation of the heat treatment process by minimizing the conversions and setup times.

METHODOLOGICAL BASIS

The Goldratt's Theory of Constraints (TOC) [2] has been selected as the main methodological basis. Applying TOC in production planning and control starts from an assumption that no production system will be so well balanced as not to contain a bottleneck. Floating capacity bottlenecks - the workplaces or devices that tend to become bottlenecks depending on the portfolio of products processed - are regarded as the basic constraints in metallurgical processes [3].

The bottlenecks are the starting point of the Five Focusing Steps (5FS) continuous improvement process [4]: (1) Identify the constraint (capacity bottleneck); (2) Decide how to exploit the constraint; (3) Subordinate everything else to the decision in step 2; (4) Elevate the constraint; (5) Go back to step 1, but avoid inertia.

Step 2 is considered to be the key one - searching actions for better capacity exploitation of bottleneck. Effective production planning and scheduling is one of the ways that can be used for that purpose.

EXPERIMENTAL WORK

The forged pieces heat treatment process has been assessed in a metallurgical company situated in the Czech Republic. The studied process was originally designed for processing of large production batches of

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forged pieces of a relatively narrow range using simple types of heat treatment techniques. Increasing demand for complex products with high added value leads to continuous expansion of product range (in terms of shape, sizes and heat treatment) and reduction of delivery quantity (volume of work orders). That is why heat treatment was becoming a critical area, limiting the entire forging production.

Material flow diagram with basic production equipment of researched heat treatment process is illustrated in Figure 1. Forged pieces coming out of the forging process represent the input. Heat treatment is carried out in two continuous furnaces, straightening of forged pieces in one straightening presses. This is followed by cooling in the cooling bed or bath hardening. Forged pieces prepared for machining are the output of this process. Passage of forged pieces through the process and their order in each device is given by the technological prescripts.

Dynamic simulation was chosen to analyze the capacity of the heat treatment process and the possibility of increasing it [5]. Basic principles of dynamic simulation and the methodologies of its application are described, for example by [6], [7]. The created simulation model enabled the identification of two floating bottlenecks (the first step of 5FS improvement process):

1. Heat treatment furnaces - the main factors that influence the degree of capacity exploitation of both furnaces are the transitions between different heat treatment techniques and time-temperature regimes. The furnaces become a bottleneck if the forged pieces are processed in furnaces in sequence which requires frequent furnace conversions for another heat treatment technique or temperature-time regime.
2. Straightening press - the key factor here lies in adjusting the press to a different range of forged pieces in terms of shape and dimensions. The press becomes a bottleneck in case the forged pieces are straightened in sequence that requires frequent adjustments.

In compliance with the second step of 5FS improvement process, rules for planning and scheduling of heat treatment have been searched that will maximize the exploitation of the two bottlenecks.

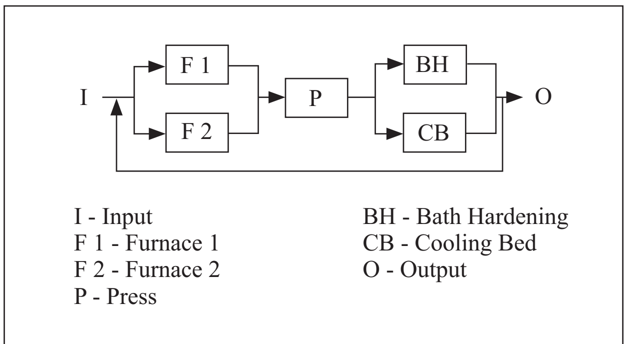

Figure 1 Diagram of material flow of the heat treatment process

The accumulation of work orders into batches which eliminate conversions of furnaces and adjustment of the press forms the basis for planning and scheduling of the heat treatment process. Work order for the heat treatment process is represented by the forging order (FO) which clearly identifies the shape and size (S&S), the heat treatment technique (HTT) and temperature-time regime (TTR) of the forged piece. Based on experiments conducted on a simulation model, the following (compromise) rules for accumulation of FOs into batches and their sequencing have been proposed:

Rule 1: The accumulation of the same FOs into production batches (PB).

Rule 2: The accumulation of PBs with the same TTR into regime batches (RB) and their order – it is beneficial to accumulate PBs and sort them according to TTR in order to eliminate or at least shorten the furnace conversions between processing of the individual PBs. The reason is that time of conversion from one PB to another depends on the type of TTR in both PBs. For ex., conversions of TTR within the scope of one HTT are shorter than conversions between TTR of different HTT. This rule expresses the priority of furnace conversion shortening before elimination of press adjustment. The reason is disproportionately longer conversion time compared with the setup time. Rule 2 can be applied only if permitted by the technological prescripts. By default, the rule is applied for normalization.

Rule 3: Modification of the sequence of processing PBs in RB – it is beneficial to put PBs in RB in such order, so that PBs with the same S&S of a forged piece follows each other. Rule 3 is again applicable only if permitted by the technological prescripts.

Given that the PBs are processed in two furnaces, but straightened on a single common press, they can be processed in the furnaces using two methods:

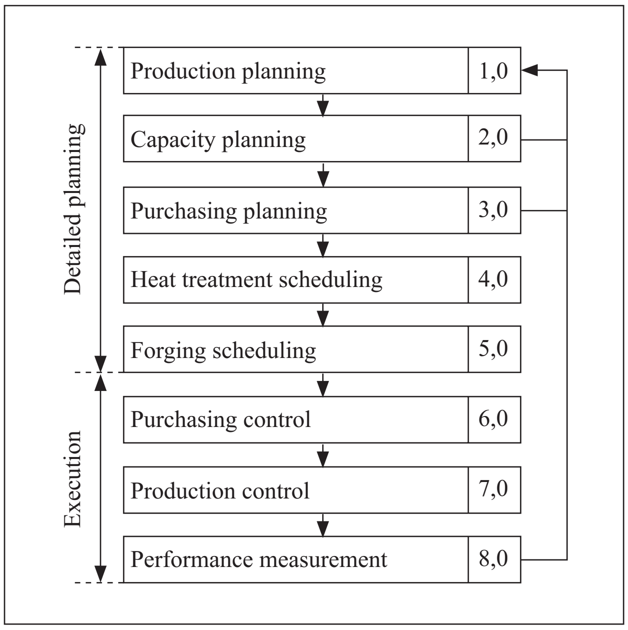

Figure 2 Hierarchy diagram of the planning and scheduling process for the entire forging process

1. Separately - PBs are processed in turns in both furnaces with such a time shift that guarantees minimum setup times of the press. Parallel processing of different PBs would lead to necessary adjustments of the press after each forged piece.
2. Simultaneously - PB is divided in half and processed in both furnaces simultaneously.

The choice of processing method depends mainly on their size. In case of large PBs, it is more suitable to process them using simultaneous way, small PBs in separate way. Due to the extensive range of heat treated forged pieces, the simultaneous processing applies only to a very limited number of PBs with the same HTT. For this reason, the decision to use simultaneous processing method is subjected to a determined uniform batch size limit (PBlim). It was determined experimentally using a simulation model. In order to select a processing method, the following rule can be used:

Rule 4: Selection of PB processing method – in case a PB is bigger than PBlim, the PB will be divided in half and processed simultaneously in both furnaces.

RESULTS

The outcomes of the performed simulation experiments led to the development of the algorithm used for planning and scheduling of heat treatment of forged pieces, which allows maximizing the capacity exploitation of the entire forging process. During the development of this algorithm, the procedure was in line with the third step of 5FS improvement process. The algorithm was recorded using modified HIPO (Hierarchy plus Input Process Output) diagram – a diagramming technique developed by IBM that uses a set of diagrams to show the input, output, and functions of a system or program [8].

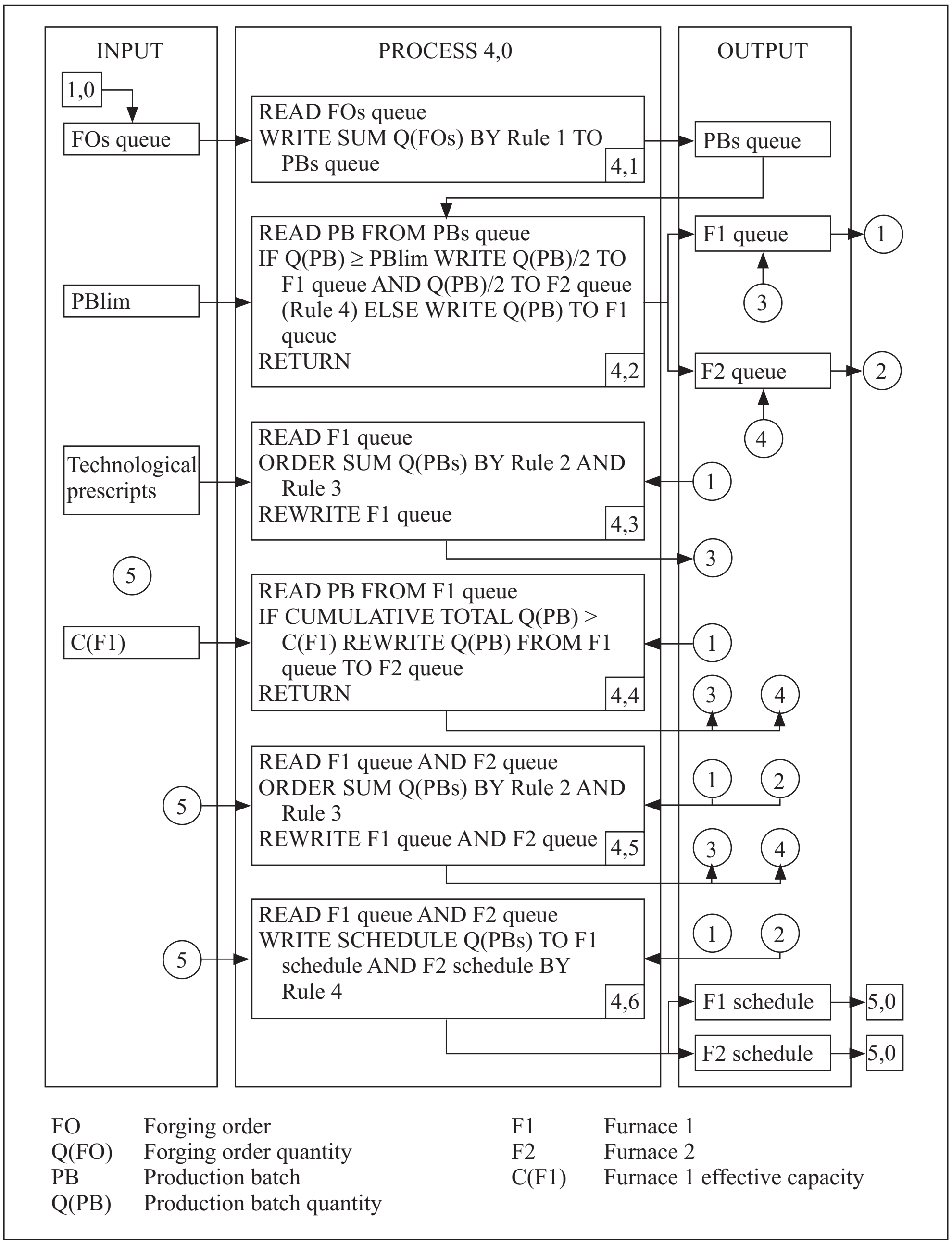

Figure 3 IPO diagram of the heat treatment scheduling process (4,0)

The hierarchy diagram is shown in Figure 2. According to the supply dates of work orders, a production plan is drawn in 1,0 process (the planning period is one month). The production plan is corrected on the basis of static capacity balancing (2,0) and the material availability check at suppliers (3,0). The production scheduling (the scheduling period is usually one week) is performed firstly for the constraint - the process of heat treatment (4,0). Based on that, the forging process schedule is created (5,0). In the execution stage (6,0, 7,0), the actual supplier and production performances are measured and compared with the plan (8,0). This feedback enables constant updating of the production plan and schedules.

The IPO diagram of the key process of the heat treatment scheduling (4.0) is shown in Figure 3. Its design fully respects the rules acquired during the experimental work. The main input of the algorithm is the FOs queue obtained from the production planning process (1,0). In sub-process 4,1, the PBs queue is created following Rule 1. Application of Rule 4 decides which PBs will be processed in simultaneously and which separately (4,2**).** PBs designated for simultaneous processing are divided in half and assigned to both furnaces (to F1 and F2 queue). The remaining orders are assigned to furnace 1 (to F1 queue). PBs in F1 queue are, when the technological prescripts are observed (mainly the technological sequences), arranged according to Rule 2 and 3 (4,3).

In sub-process 4,4, the PBs from F1 queue exceeding the effective capacity of furnace 1 (C (F1)) are transferred to furnace 2 (to F2 queue). C (F1) was determined experimentally using a dynamic model of the heat treatment process. After the orders are allocated to furnace 2, it is again necessary to verify the technological prescripts are respected, and the PBs in F1 queue and F2 queue are arranged according to Rule 2 and 3 (4,5). In the last sub-process (4,6), a schedule for each furnace is created (F1 and F2 schedule). It is based on the technological prescripts (especially treatment, setup and conversion times) and Rule 4. F1 and F2 schedules form the basis of the forging scheduling process (5,0).

CONCLUSION

The implementation of the designed algorithm in the researched process of heat treatment brought app. 25 % increase in capacity exploitation and throughput of the entire forging process. Because customer's demand keeps growing and this step did not move the constraint to the forging process, the fourth step of the 5 FS improvement process - an investment in the heat treatment technology – has been taken.

The general rules for planning and scheduling of the heat treatment process of forged pieces, which are applicable in similar processes in metallurgical companies, were deduced based on experimental work. From the methodological point of view, combination of Goldratt´s 5FS continuous improvement process and dynamic simulation can be recommended in order to eliminate the bottlenecks in the complex metallurgical processes. Experiments on a simulation model can clearly identify the floating bottlenecks, identify and verify the suitable rules for planning and scheduling of the identified bottlenecks (or other ways increasing their exploitation and not requiring high investments), design a new system of planning and scheduling of the entire manufacturing process and verify its benefits, decide about elimination of bottlenecks by higher investments and regularly check the implemented solutions when changes in the market or in the manufacturing process occur.

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Note: The responsible translator for English language is Petr Jaroš (English Language Tutor at the College of Tourism and Foreign Trade, Goodwill - VOŠ, Frýdek-Místek, the Czech Republic). Revised by John Vlcek (Literacy Tutor at West Suffolk College, Bury St Edmunds, England).