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A METHODOLOGY FOR DETERMINING AND CONTROLLING THE BUFFERS BEFORE FLOATING BOTTLENECKS IN HEAVY MACHINERY PRODUCTION

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Heavy machinery industry is characterized by a number of specific features that cause significant variations in the processing time of products in the individual workplaces and frequent occurrence of floating bottlenecks, which change their positions. Depending on the product range being processed, a given workplace is the bottleneck only for some period of time. When the bottleneck moves to another workplace, it leads to unnecessary loss of capacity of the floating bottleneck. To maximize the utilization, it is necessary to protect those bottlenecks by creating special buffers. The objective of this article is to design a methodology used for the determination and control of buffers that are going to protect the floating bottlenecks from operating capacity losses caused by transfer of the constrain to another workplace. These buffers are referred to as „power buffers“. The designed methodology has been verified in the process of forged pieces machining.

Key words: Heavy machinery, Forging, Floating bottleneck, Power buffer, Failure buffer

INTRODUCTION

Heavy-machinery industry is characterized by a number of specific featuresthat make production planning and control significantly more difficult:

- It is mostly unit and small-batch production;
- Both special dedicated devices and universal multipurpose machines are used, while the operating capacities of the devices are highly dependent on the type of product being worked on;
- There are alternative technological processes and production paths, the number and sequence of performed operations frequently change;
- Material flows are multidirectional, with multiple product passages through selected workplace.

Next specifics can be found e.g. in [1,2]. All of these features cause significant fluctuations of the product processing time in each workplace (from minutes to hours) and frequent occurrence of floating bottlenecks. To maximize the capacity utilization, it is necessary to protect those bottlenecks by creating buffers. In manufacturing processes with the presence of stable bottlenecks, the buffers eliminate bottleneck stoppage due to failure in workplaces before the bottleneck (e.g. because of their breakdowns). However, floating bottlenecks are characterized by changing their position. Depending on the product range being processed, a given workplace is the bottleneck only for some period of time. When the bottleneck moves to another workplace, it leads to unnecessary loss of operating capacity at the floating bottleneck (e.g. if a workplace is a bottleneck during 90 % of the production time, the remaining 10 % face an unnecessary operating capacity decrease in other workplaces). The objective of this article is to design a methodology used for the determination and control of buffers that are going to protect the floating bottlenecks from operating capacity losses caused by transfer of the constrain to another workplace. These buffers are referred to as “power buffers”.

THEORETICAL BASIS

The Theory of Constraints (TOC), which was designed by Goldratt [3], deals with the issue of bottlenecks. The basic idea of the TOC is the assumption that no production system will be so well balanced as not to contain a bottleneck [4]. The bottleneck is the weakest element that determines the production system output. A bottleneck usually indicates the available capacity of a resource that limits or confines the outputs of a system or an organization. In a manufacturing system, a bottleneck might be defined as the resource with the longest processing time, or the highest average utilization rate or loading or by reducing processing time of the workstation, it will reduce the entire average flow time of processes [5, 6]. In certain types of productions, we can come across floating bottlenecks that change their position and character over time [7].

One of the main principles of control of bottlenecks is their protection by means of buffers. A buffer is defined as a stock that is created before a bottleneck, thus

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protecting the bottleneck from work starvation, guaranteeing continuous operation of the entire process [8]. The control of bottlenecks searches for optimal buffer size, based on compensations for the losses arising from unused capacities of the production system and the costs of holding inventory used as a buffer.

The basic approaches to setting the buffer size include an expert estimate, analytical calculations using model situations, and computer simulations. Analytical calculations typically focus on stable bottlenecks (see e.g. [5]). Betterton and Cox III [9], Wu et al. [10],Battini et al. [11] or Malindzak et al. [12] deal with the suggestions and verifications of the simulation methods.

DESIGNED METHODOLOGY

The methodology used to determine and control the power buffers includes the following steps (see Figure 1):

1 Identification of critical floating bottlenecks

In the first step, it is necessary to identify the critical floating bottlenecks. A critical floating bottleneck is a workplace with the highest potential occurrence of a bottleneck (most commonly restricting other workplaces). The analysis and identification of floating bottlenecks can take advantage of the procedure designed by Lenort and Samolejova[13].

2 Setting the size of failure buffers

The size of the failure buffer is calculated for critical bottlenecks. Failure buffers protect the bottleneck against downtime of workplaces before the bottleneck. The largest workplace downtimes in heavy machinery production are usually caused by equipment failures. The size of a failure buffer that provides 100% protection of the bottleneck can be determined using the relation:

$$B^{max}_{fail} = T^{max}_{fail} \cdot C^{max}_{b} \qquad (1)$$

B^{max}_{fail} – maximum size of a failure buffer (pcs)

T^{max}_{fail} – maximum time necessary to remove a breakdown before the floating bottleneck (hour)

C^{max}_{b} – maximum operating capacity of a floating bottleneck (pcs·hour^{-1})

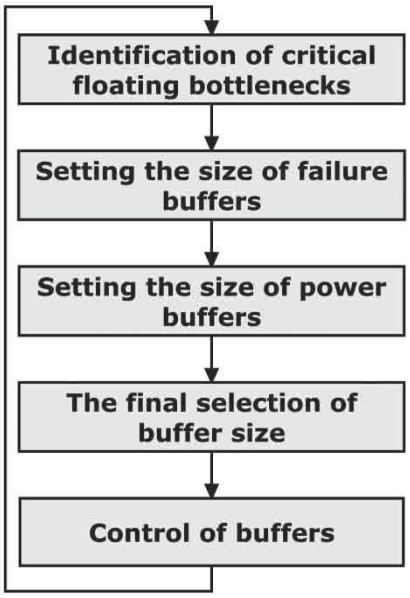

Figure 1 Scheme of the designed methodology

The individual workplaces in heavy machinery production usually include several substitutable devices. In such a case, the maximum operating capacity of a floating bottleneck is determined using the relation:

$$C^{max}_{b} = C^{max}_{b,1} \cdot n^{max}_{b} \qquad (2)$$

C^{max}_{b} – maximum operating capacity of a single device of a floating bottleneck (pcs·hour^{-1})

$C^{max}_{b,1}$ – minimum feasible number of occupied devices in a floating bottleneck

In production practice, however, it is unrealistic to choose the maximum level of bottleneck assurance due to excessive stock buffer and costs associated with its holding. For practical purposes, the following heuristic formula can be recommended:

$$B_{fail} = \overline{T_{fail}} \cdot C^{max}_{b,1} \cdot \overline{n_{b}} \qquad (3)$$

B_{fail} – size of a failure buffer (pcs)

$\overline{T_{fail}}$ – average time necessary to remove a breakdown before the floating bottleneck (hour)

$\overline{n_{b}}$ – average number of occupied devices in a floating bottleneck

3 Setting the size of power buffers

The size of power buffers is also set for critical floating bottlenecks in addition to failure buffers. Power buffers should protect floating bottlenecks during the time when the constraint is transferred to another workplace. The maximum level of assurance is provided by the relation:

$$B^{max}_{c} = T^{max}_{float} \cdot (C^{max}_{b} \cdot C^{min}) \qquad (4)$$

B^{max}_{c} – maximum size of a power buffer (pcs)

T^{max}_{float} – maximum time of transferring the constraint before the floating bottleneck (hour)

C^{max}_{b} – maximum operating capacity of a floating bottleneck (pcs·hour^{-1})

C^{min} – minimum operating capacity of the workplaces before the bottleneck (pcs·hour^{-1})

In the event that the workplaces consist of a higher number of mutually substitutable devices, the maximum operating capacity of a floating bottleneck is determined using the formula (2) and the minimum operating capacity of the workplaces before the bottleneck is determined using the formula:

$$C^{min} = C^{min}_{1} \cdot n^{min} \qquad (5)$$

C^{min}_{1} – minimum operating capacity of a single device before a floating bottleneck (pcs·hour^{-1})

n^{min} – minimum feasible number of occupied devices in a workplace before a floating bottleneck

The following heuristic formula can be recommended for practical use:

$$B_{c} = \overline{T_{float}} \cdot (C^{max}_{b,1} \cdot \overline{n_{b}} - C^{min}_{1} \cdot \overline{n}) \qquad (6)$$

B_c – power buffer size (pcs)

$\overline{T}_{float}$ – average time of transferring the constraint before the floating bottleneck (hour)

$C_{b,1}^{max}$ – maximum operating capacity of a single device of a floating bottleneck (pcs·hour^{-1})

$\overline{n_b}$ – average number of occupied devices in a floating bottleneck

$\overline{n}$ – average number of occupied devices in a workplace before a floating bottleneck

4 The final selection of buffer size

If the failure buffer is larger than the power buffer, the final buffer size equals the failure buffer and vice versa.

5 Control of buffers

In the course of production, the buffers are continuously monitored and controlled before the critical floating bottlenecks in order to prevent their depletion or overflow. The control of buffer repletion is performed by the operational intervention of line management (e.g. change of manning of the individual workplaces or change of the production schedule).

CASE STUDY

The designed methodology used to determine and control power buffers has been verified in the process of forged pieces machining.

The product mix consists of different types of products manufactured in small and medium-sized production batches (from a piece to hundreds of pieces). There are multiple passages of forged pieces through the same workplace in case of complicated products, which causes multidirectional material flows and fluctuations in the workload of the individual workplaces. The processing time of different types of products varies (depending on the complexity of the processing) within the scope of minutes up to hours. All the devices are not occupied continuously, due to fluctuating load of the workplaces.

The manufacturing process includes eight workplaces with twenty six devices (see Figure 2). The original system of production planning and control was based on the creation of buffers before all devices. The size of the buffers were set and controlled intuitively by the production workers.

Once the designed methodology has been applied, their numbers were limited only to the critical floating bottlenecks, which included the workplaces dealing with roughing, face-part machining, finishing lathe work, andgrinding (see Figure 2). Other workplaces (drilling, rolling, non-destructive testing and release of products) do not pose risk of restricting the overall operating capacity of the process.

The work in progress stock of the monitored process and the costs associated with this process have been reduced by almost 15 %, as a result of that.

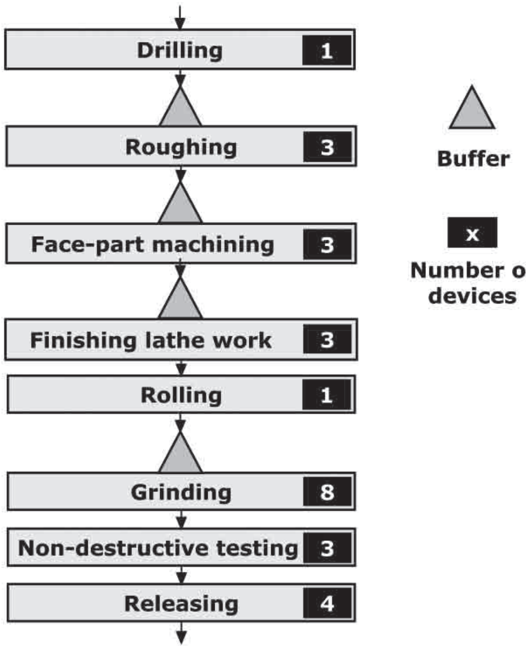

Figure 2 Scheme of the monitored production process

CONCLUSION

Thanks to the case study, the designed methodology for the determination and control of power buffers has been verified. The recommended heuristic formulas used to calculate the failure and power buffers are only the basis for determining their final number. It will always depend on the specific conditions of the manufacturing process. The more complex the processed products and the manufacturing process are, the larger the buffers are and vice versa. Further research work will be devoted to the incorporation of the methodology in the newly developed production planning and control concept based on “production paths” (see more [14]).

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Note: The responsible translator for English language is P. Jaroš (English Language Tutor at the College of Tourism and Foreign Trade, Goodwill - VOŠ, Frýdek-Místek, the Czech Republic)