CNC MACHINE GROUP SCHEDULING METHODS IN A MULTITASKING SYSTEM

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Abstract
A proper production plan for bottlenecks is the key to productivity and cost-effectiveness in the machining industry. The paper describes specific aspects of the production planning and shop floor scheduling in the CNC machine groups system. Important factors in scheduling in these systems - on the example of cutting CNC machines which are split into groups with a limited number of operators - are listed. The idea of a machine operator operating more than one workstation at the same time is presented. The scheduling methods, their pros & cons, and limitations concerning practical side of planning process and the introduction to a workshop are explained and evaluated.

Keywords: Planning methods, scheduling machine cell, multitasking system, heuristic algorithm, multi-workstation

1. INTRODUCTION
In a production system where the bottleneck capacity is a constraint, the bottleneck's efficiency is the key to the system productivity [1]. The idea of cost-effective dealing with the constraint - when it is a CNC machine group - is shown in this paper. The cost-effectiveness can be achieved by limiting worker-numbers without limiting machines capacity substantially. It is possible when appropriate scheduling methods are used. The methods and techniques were tested or developed by ANGA Mechanical Seals Ltd and AVIOmechanika Ltd. The companies have the multitasking and undirected production flow system on their shop floor. The whole idea was developed in lathe and milling machine cells, but shown solutions are believed to suit the majority of production departments where CNC machine groups are their constraints. The aim of the article is to present methods of scheduling multi-workstation CNC machine cells.

2. PLANNING IN THE MULTITASKING AND MULTI-WORKSTATION SYSTEM

2.1 Multitasking system
The multitasking system is a system in which a wide number of different parts are machined on the same machine or machine group. The parts have different routings, machining parameters, tools and equipment requirements. The quantity of components are related with a company's product portfolio and may constitute 1000 different part-types machined in each machine group. The other characteristic for such a system is generally small lots [2] – from 1 to 10 pieces per lot on average. The system that has this characteristic and is not a Flexible Manufacturing System (FMS) requires an appropriate machinery. Some say [3] that the appropriate machinery is CNC flexible multitasking machines which are e.g. both milling and turning machines. They differ from the milling machines with a turning option and lathes with a milling option from a decade ago. Although they might be right for the job, these machines are very expensive and this investment in a medium and small-size company is risky when the cash-flow is considered. Therefore the latter machines are often favoured.
2.2 Multi-workstation cells organisation

With a constantly varying demand it is very difficult to construct a proper production system. The capacity depends highly on a workforce. It is said that in make-to-order systems the workforce should be kept on 80-90% of average demand to lessen negative effects during time periods with the lower demand level. When the demand is higher than the capacity – doing overtime is advised [2]. It sounds reasonable, but there is a solution that in connection to a proper scheduling gives more flexibility to the changing demand and reduces labour cost. When the CNC machines are used, and the principal time of an operation is longer than a specific for every machine type minimal time – it is possible to operate $m$ machines with $n$ operators when $m > n$ at the same time. To make it possible, the workplace must be as ergonomic as possible. It is essential to limit the movement between workstations which are operated together. The example of such a group is presented in Fig. 1.

![Double lathe group with an operator](image)

Although it is not a necessity that machines in the cell are similar, it is recommended due to the increase of a human error probability in a non-homogenous machines group. This may result in an increased number of waste. Operations that flow through workstations with a limited operators number are divided into:

- non multi-workstation operations – they need the whole operator’s attention during the principal processing: 1) Operations where the principal time is shorter than a specific minimal time or 2) when it is longer but the processing is complex and demands an operators attention, and 3) operations which are processed for the first time;
- multi-workstation operations – all that are not non multi-workstation operations.

There are some requirements that need to be fulfilled to allow the presented way of organising workstations: 1) The work flowing through a production system needs to have appropriate proportion of non and multi-workstation operation for considered workstation type, 2) the operators need to be high-skilled.

2.3 Planning in the system

Effective planning in a multitasking system is difficult as the variety of units that goes up always decreases the performance of the production system. As the result, the system is buffered by the combination of an inventory, time and capacity [4]. In a multitasking system with a diversified product range and small production lots the capacity and time are its main buffers. The capacity buffer is more substantial when machines work in a multi-workstation way, as presented in Fig. 1, because it prompts more potential overtime machining hours per operator. The basic data for a production planner are following times [5] [6] [7]:

- Setup time $t_{pz}$ – consists of a) preparations, post-process adjustment, parts and tools checking 30% b) tools and parts mounting/dismounting 5% c) measurement, adjustment, calibration 15% d) trials and corrections 50%. During setup time the machine operator cannot conduct any other operation that involves manual work;
- Principal time $t_1$ – it is carried out for each item of a lot, during it the shape or characteristics of an item are changed. When the machining is carried on CNC machines, the operators’ attention is theoretically not needed until an item is finished;
- Storage time – spent on material and work-in-progress storing,
- Transportation time – an item or a lot is transported between workstations, and storage, etc.
• Inspection time – the dimensions or characteristics are checked for accuracy.

In the scheduling process, the listed times, operation sequence and raw material per part standards are used as basic data and constraints. The dynamically changing demand is compared with workstation capacities using the data. The result of the planning is an operational production schedule which workshop has to keep to. Its targets are: keep on schedule, limit tardiness, maximise effectiveness with the minimum of resources involved. There are numerous methods of production planning and scheduling [8] [9] [10] [11] [12] [13] but not all them suit the multitasking system that has multi-workstations machining groups.

3. SCHEDULING METHODS

Methods and techniques that can be used to tackle the particular scheduling problem are 1) Gantt charts limited to bottlenecks and combined with micro-planning by an operator and 2) Heuristic algorithm created by the author in ANGA Mechanical Seals Ltd.

3.1 Gantt charts combined with Micro-Planning

Scheduling all workstations in the described system using Gantt charts is not easy as there are numerous operations. It is simply too complicated to deal with the whole scheduling problem using the charts without a computer system. The created plan would be prepared too long and any change that happens frequently on the shop floor level would prompt the plan updates. Because of this, the scheduling can be narrowed to bottlenecks, priority jobs and work in progress that accumulates next to the bottleneck. This approach is right as throughput of the production system depends on its constraints/bottlenecks [1], so their proper scheduling improves the whole system performance.

The first thing a planner has to do is to split all operations-to-be-placed to non multi-workstation and multi-workstation. Then they have to schedule all operations with consideration of job time limits and trying to maximise the effectiveness of multi-workstation work – both targets are closely related. Two different schedules with different results for a multi-workstation from Fig. 1 are presented in Fig. 2.

These schedules show how scheduling has an impact on the cell efficiency. When operations are queued properly the aggregated time when nothing is happening on the machines is reduced. While such a machine group is a bottleneck, time with no action is perceived as waste.

It was mentioned before that multi-workstation operators need to be high-skilled. Additionally, people are said to be self-optimising [4]. If their self-optimising is proportional to their work efficiency we can use their creativity and their solutions according to the scheduling. An effective way of achieving a relation between the self and schedule optimisation is implementation of a premium system that cements high efficiency with high wages. In the case a worker makes an effort to maximise efficiency which means minimum waste
caused by no action time on the machine in a multi-workstation group. It is known that operator’s ideas are useful, therefore not taking them into account is a mistake [14].

Gantt charts and micro-planning combined together proved to be surprisingly efficient in ANGA’s and AVIOmechanika’s production system. The priority jobs and some machines in a multi-workstation group are planned using the charts, and the rest is left to be planned by an operator on their own. If this method of planning is chosen, it provides the easy-to-operate scheduling system that is able to provide acceptable results, and do not require a computer system. Depending on a situation, Gantt charts can be used with or without micro-planning. The drawbacks of the methods are often lack of control of the production flow, and sometimes not useful plans. It has its roots in simplifying the complexity of the scheduling problem. The other problem is that using micro-planning dispels operators responsibility for keeping to the plan, and that its quality depend on the operator’s scheduling skills.

3.2 Heuristic Algorithm

Heuristic algorithm that is used in described multi-tasking system was invented by the author when the computer-aided scheduling system was being developed. The developed scheduling system is hierarchical and of great complexity which exceeds this paper, but the method can be employed wherever a number of operations are to be scheduled in a multi-tasking CNC machine cell. The data for the algorithm is obtained after the first level of roughly scheduling, which distributes sets of operations in time increments to all workstations and cells. The operations planned for machining in multi-tasking groups for incremented time periods belong to specified operation sets. The sets are as follows: $I$ – operations to be scheduled in the machine group in the particular time period, and that belongs to the considered machine; $R$ – operations already scheduled. $R \cap I = \emptyset$; $K$ – non multi-workstation operations; $N$ – multi-workstations operations.

The other data which is needed for the algorithm are operators number on the shift $k$, machines number in the group $m$ and the penalty time for multi-workstation working $T_k$ set by the planner. The penalty time is added to the setup time of an operation. The $e$ parameter equals 0 when the sum of operations $\in I \cap K$ and operations $\in R \cap K \geq k$. Otherwise $e$ equals the sum of operations $\in I \cap K$ and operations $\in R \cap K$ minus $k$ parameter. The algorithm activates for a machine every time set $I \neq \emptyset$ and it is possible to schedule an operation when moving on in time. The algorithm can be used to schedule many parallel machine groups simultaneously using the sum of $I$ sets. It requires some certain and proper data stored in the computer system. The Fig. 3 presents the algorithm. When the number $f$ of operations $\in R \cap K$ is bigger than $k$ on the next shift, then $f - k$ operations $\in R \cap K$ are frozen until $f = k$. The freezing starts from the operation with the longest machining time when $k$ parameter changes.

Fig. 3 The multi-workstation scheduling algorithm.
The scheduling method using the algorithm is believed to give a good and quasi-optimal solution in numerous production systems, where CNC machines are combined into functional groups, and where multi-workstation work organisation is used. Although, it is important that individual boundary conditions for a production system have to be identified and taken into consideration while using the algorithm. The method can be applied with or without computer system, but it gives much better solution with it, and the scheduling is faster. The main advantage of the algorithm is that it is flexible. It can be used to schedule a wide range of machine groups – different machine types, machines quantity, varying from one to the other shift - operators number. The presented heuristic algorithm has been tested in 3 and 5 axes CNC milling machines and CNC lathes so far. The most significant drawback of the method is its requirements - if it is to be used, without simplifying the production system. In this case, the algorithm needs a lot of data and at minimum MRP II computer system. Introducing such a system to the shop floor is always a challenge.

4. SUMMARY
Summing up, there is a clear need for improved scheduling methods for multi-workstation groups, dealing with a wide range of parts that involve many setups and small lots. The two methods of tackling a multi-workstation problem need the basic planning data shown in the paper. In the future, a further research concerning efficiency of schedules obtained through the heuristic algorithm will be conducted. Additionally, multi-workstation cells organisation will be analysed to achieve higher cell efficiency.

The heuristic algorithm and narrowed Gantt charts combined with micro-planning have been successfully tested and can be introduced to other production systems which face similar problems to these of ANGA Mechanical Seals Ltd and AVIOmechanika Ltd.

LITERATURE