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PLANNING MANUFACTURING VARIANTS OF ROTATIONAL PARTS WITH CNC TURNING-BURNISHING TECHNOLOGIES

W. Przybylski, M. Siemi¹tkowski

Gdansk University of Technology
Department of Manufacturing Engineering and Automation
e-mail: wprzybyl@pg.gda.pl; msiemiat@pg.gda.pl

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Abstract: *The paper deals with issues of cellular process planning in the environment of multi-station production facilities incorporating burnishing technologies. The approach to manufacturing process synthesis assumes multiple choice of process alternatives. It is based on the iterative clustering algorithm ALCA and resource elements REs, meant as basic grouping primitives as well as a unique method for detailed analysis and validation of generated design solutions using fuzzy logic based decision support. Experimental results verifying its usability in industry related to a specific case with burnishing processes are also included.*

INTRODUCTION

In today's competitive markets the success of a manufacturing company depends on its ability to implement flexible automation solutions and production strategies based on it according to dynamic changes in product demand and variety. One way of achieving high manufacturing flexibility and responsiveness in companies is by extending processing capabilities of their existing facilities [3]. Applying burnishing technologies integrated with turning on CNC lathes gives the opportunity for accomplishing the idea since these can be introduced as parts finishing processes (smoothing burnishing-SMB) – replacing grinding as well as surface plastic working, leading to the increase in hardness (up to 45 %) of component surface layer (strengthening burnishing-STB). Surface hardening of 0.8-1 mm in depth gained with STB, comparable with traditional methods of heat treatment by carburising & quenching or by induction surface hardening, is of great value in the view of required operating characteristics of such parts as, e. g.: piston rods, driving shafts and torsion bars [4,5]. The decomposition of production facilities into efficient group technology (GT) based cells, fulfilling the above mentioned requirements is of special value due to significant, well documented performance benefits which cellular manufacturing can offer. The benefits are in particular associated with possible reduction in production lead times, work-in-progress, labour, tooling, set-up – and down-times, the number and costs of transport operations, better machine utilisation, the improvement of the overall productivity of a shop and the simplification of process control algorithms [1,6,7]. Due to the indicated performance benefits offered the concept becomes also an inseparable element of Just-In-Time strategies [5,6]. Many methods have been developed to facilitate the process of cell determination however most of them show unsatisfactory performance [2,3].

1. MACHINING SYSTEM OVERVIEW

The research addresses the issue of cellular manufacturing of mainly shaft-type parts of 20-100 mm in diameter within a facility incorporating burnishing technologies. In the case considered the machining shop comprises 4 CNC machine tools available for selection in the cell determination task. Their processing capabilities are highly differentiated owing to the machining equipment and mainly used with burnishing processes.

2. THE APPROACH TO MODELLING CELLULAR PROCESS LAYOUT

The developed approach to cellular process decomposition assumes multiple choice of processing routings for parts of a definite spectrum in terms of available machine variants. This is proposed instead of the use of pre-determined part-machine assignments, as noted in traditional applications of GT or production flow analysis (PFA) techniques [1,3,7]. The approach utilises a unique method for manufacturing knowledge description and the synthesis of optimised solution is carried out using fuzzy logic based decision support.

2.1. Process knowledge representation

Two interrelated levels of process capability representation are considered: a generic level where processes are described independently from the machines on which they may be executed and a facility level where the capability is described in the context of a definite machining facility. At the generic level the process knowledge is represented by part transformation schemas (TSs) resulting from its shaping abilities on CNC machine tools (MTs), as given in detail in [5,7]. Considering the specific features related to burnishing technologies the transformation schemas TS are defined in broader technological meaning as a combination of tool features, the kind of its contact with part surface worked, part related input conditions (material Rockwell hardness – HRC, part slenderness ratio – L/d, etc.), the objective of the process and technological output factors (tolerance target value, roughness parameter - R_a, the increase in hardness - ΔH). In particular the nominal technological output may be associated with the use of different kinematics form of working method. The objective of the process can be in turn related to the removal of allowance volume (part shaping processes while processes while machining) as well as to smoothing part surface or its strengthening.

The individual TS discerned in the specific process capability description model incorporating burnishing technologies are compiled in Table 1. Part transformation schemas are not referred to a specific machine tool but can be utilised to provide a generalised description of its relevant capabilities and consequently relate them to part processing requirements.

Hence the process capability of a particular machine M_k included in a shop can be therefore represented as the vector:

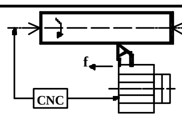
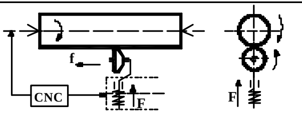
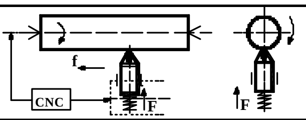
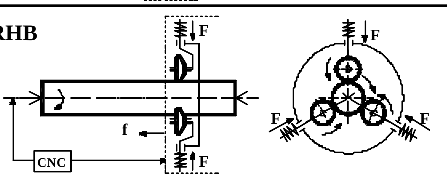
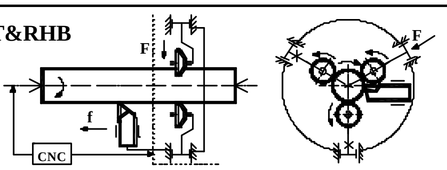
$$M_k = m_{1k}, m_{2k}, ..., m_{hk} \quad , M_k \in M \tag{1}$$

where: m_{ik}=1, if SGPC s_i (i=1,2,...,h) can be performed on the machine k, m_{ik}=0 if otherwise, and h means the total number of distinguished SGPC.

At a machining shop level the process knowledge is represented by the so called resource elements – REs [3,5]. REs are assumed here as sets of TSs that appear jointly in each machine with the same degree of membership. As a result the exclusive machine capability boundaries and the shared boundaries among machines in a specific facility can be uniquely defined. The distribution of REs within a shop is determined by iterative clustering procedure using the frame:

$$\begin{aligned} &IF \ \forall M_k \in M : m_{pk} = m_{qk} \\ &THEN \ \ cluster \ \ s_p s_q \ \ together. \end{aligned} \tag{2}$$

Table 1. *Generic knowledge model of process capability (TS definition)*

Scheme for generating processing characteristics	Workpiece – related input conditions	Code	Objective of the process	Nominal technological output
T 	no special constraints	s_1	Turning preceding the burnishing process (except for the scheme S_{10})	Tol.: IT 7-9 R_a=1.25-2.5
RB 	HRC=20-30, L/d=1-5	s_2	STB	ΔH=30-45%
	HRC=20-45, L/d=1-8	s_3	SMB	R_a=0.32-0.63
SB 	HRC=20-30, L/d=1-9	s_4	STB	ΔH=20-30%
	HRC=30-60, L/d=1-9	s_5		ΔH=2-20%
	HRC=20-30, L/d=1-12	s_6	SMB	R_a=0.08-0.63
	HRC=30-60, L/d=1-12	s_7		R_a=0.16-0.63
RHB 	HRC=20-40, L/d=10-15	s_8	STB	ΔH=35-45%
	HRC=20-45, L/d=10-15	s_9	SMB	R_a=0.16-0.63
T&RHB 	HRC=20-45, L/d=15-20	s_{10}	SMB	R_a=0.16-0.63

Note: T- longitudinal turning, RB- rolling burnishing, SB- sliding burnishing, RHB- rolling head burnishing, T&RHB- simultaneous turning and rolling head burnishing; ΔH- the increase in hardness

Relevant specification of REs within an exemplary shop is shown in Fig. 1.

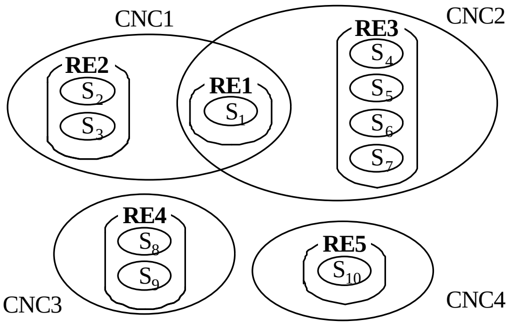


Fig. 1. *Specific facility capability (RE definition)*

2.2. Planning optimised cellular process

Modelling the process capability of a shop in terms of REs accepted further enables in turn the formation of the binary component-REs incidence matrices (Table 2), used by the processing program based on the iterative average-linkage clustering algorithm-ALCA [1].The initial cluster of REs in cell decomposition is formed by calculating a pairwise similarity coefficient for all the REs available in the shop using the formula:

$$L_{ij} = \frac{a}{a+b+c} \tag{3}$$

where: L_{ij} – similarity coefficient between R_i and R_j; a- number of components common to both REs; b and c - number of components that require only R_i or R_j.

The consecutive clusters are obtained calculating average similarity coefficients for groups of REs *i* and *j* defined as:

$$L_{ij} = \frac{S_{ij}}{N_i \times N_j} \tag{4}$$

where: S_{ij} - the sum of pairwise coefficients between all members of the two groups; N_i, N_j - the number of REs in groups *i* and *j* respectively.

This stage of the scheme, associated with iterative clustering of REs, assumed as a basic grouping means and related to individual parts of the spectrum manufactured within a shop, is followed by the the stage of analysis and validation of obtained clustering results where the boundaries of cell units are defined in terms of REs and REs belonging to each cell are translated into physical manufacturing equipment.
The validation criteria of the stage, used in decision making are formally defined as:

- maximum compactness of the formed cell units in terms of capability,
- minimum overlapping of the formed cell units in terms of capability (minimum number of REs shared/number of repeated machines).

The final stage of the scheme is associated with the allocation of part types to determined cells and the selection of routings for a part mix, using decision rules based on fuzzy relations [2,5].
In this context, the following validation criteria, listed in the sequence of their priority, are due to be met:

- minimum part transfers (transport flows) among determined cell units,
- optimum level of concentration of different operations on related work centres [6],
- minimum reversible part transfers within cell units (or their possible elimination to ensure the flow-type process) [7].

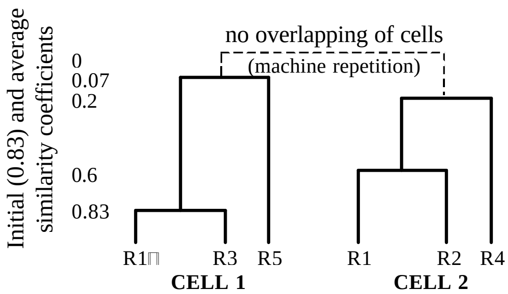
Table 2. *An exemplary part-REs incidence matrix*

		Representative part types											
		A	B	C	D	E	F	G	H	I	J	K	L
Available REs	R1	1	1	1						1	1		
	R1'				1	1	1	1	1			1	
	R2	1	1	1									
	R3				1	1	1	1	1				
	R4									1	1		
	R5											1	1

Note: R1, R1э-RE1 available on CNC1 and CNC2 respectively

3. A CASE STUDY AND RESULTS

The systematic approach with ALCA algorithm has been tested using data from industrial practice. The case illustrated in this research is based as mentioned above on an exemplary machining facility of 4 CNC turning work centres and a representative spectrum of 24 different part types. Applying the algorithm to the case (Fig. 1, Table 2) yields a crisp break-up of individual REs to two cells, without overlapping between them. The machines CNC 2 and CNC 4 are clustered into CELL 1 and the remaining two into CELL 2, with no machine repetition in the cells. The intermediate results of the cellular process decomposition with the ALCA algorithm are shown in the form of dendrogram in Fig. 2. It provides a more descriptive means of their presentation. The similarity coefficient scale has a range of



0 to 1.0 here and is outlined on the ordinate.

Fig. 2. *A dendrogram for clusters obtained with the use of the ALCA algorithm*

The detailed results of cellular process synthesis, including the allocation of part-types to the relevant groupings of REs/machines, accomplished with the use of the clustering method based on REs and fuzzy logic based decision support, are illustrated in Fig. 3. The optimum solution of the related tasks for the illustrative example is decided by the analysis of RE clusters and proposed methodical process planning based on given sets of validation criteria. As seen the design solution gained is characterised by a crisp assignment of individual part types to the determined machining units, with no overlapping between them. This also means the avoidance of the inter-cellular transport flows of parts in the system.
Optimised design solution for cellular process organisation within the machining facility considered is additionally presented in Table 3 in the form of the resultant incidence matrix: part types – related machine tools, with the entries indicating the operation number in relevant process routings.
Additional case studies related to multi-station machining facilities, including the use of burnishing technologies, performed so far with extended spectrum of rotational part types, confirmed the efficacy and practical usability of the methodology under development.

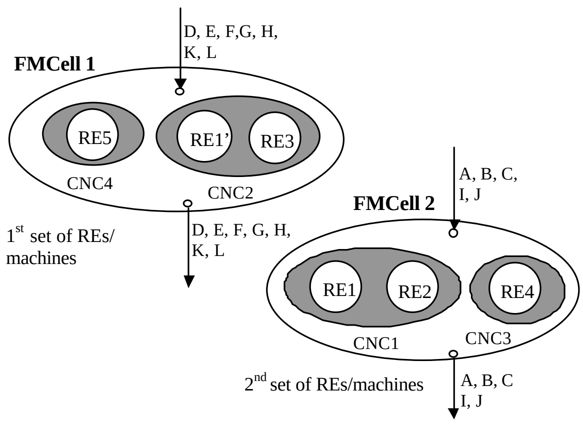


Fig.3. *Cellular process synthesis results with part types mix allocation*

Table 3. *Optimised design solution of cellular process with detailed part types routings*

FMCell No.	**FMC 1**		**FMC 2**	
Part-types/families	Machine tools			
	CNC2	CNC4	CNC1	CNC3
A			1	
B			1	
C			1	
I			1	2
J			1	2
D	1			
E	1			
F	1			
G	1			
H	1			
K	1	2		
L		1		

4. CONCLUDING REMARKS

The proposed methodology enables effective structuring cellular type processes, considering multiple choice of part routings. It gives the possibility for extensive studies of related issues of discrete process planning. Its utilisation yields design solutions that unquestionably outperform the ones produced by human planners and this is of significant value especially in cases, where vast sets of data have to be processed.
Experimental tests carried out so far have shown the industrial adequacy of provided process solutions. In virtue of the analysis of experimental results gained it can be ascertained that incorporating burnishing technologies, extending the process capability of a manufacturing facility and giving the opportunity for concentration of machining operations leads to proper balancing the workload between cell units and ensures better machine utilisation.
The developed models of process knowledge description are of greater flexibility for decision making, corresponding with specific needs of an enterprise. Owing to this the potential benefits resulting from the use of cellular manufacturing concept can be achieved to considerable extent. Further research aims at the development of the proposed framework considering the specification of part related data, such as e.g. machining times and variability of production volumes.

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