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50. Internationales Wissenschaftliches Kolloquium
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Process Capability Modelling for Costs Minimization in Global Manufacturing Environment

ABSTRACT

This article deals with the intelligent model of a process capability for costs minimization. The paper considers the contradictions both in product design procedure when seeking its best performance so many problems arise in production stage. The proposed model is being implemented in industry and for study processes in universities and colleges.

INTRODUCTION

Stiff competition in Global Manufacturing (GM) environment demands to minimize the product and process development costs and delivery time to customer in all stages of a product life cycle. The key part of a product development cycle is the conceptual design phase that greatly influences the resulting cost, quality, product manufacturability and its life cycle parameters [1, 2]. The inter–enterprise integration, where enterprises can be combined together to develop, design, produce and distribute their common product, enables engineers to use models more effectively. Models help saving the costs and time of the product and process development.

This paper is devoted to the development of an intelligent functional model for minimization of mechanical product process costs. It is focused on the capability of various processes and suppliers located in different countries and companies to combine the product design and manufacturing.

REQUIREMENTS OF A GOOD PRODUCT DESIGN

Requirements of a good product design are defined by its performance and manufacturability. Our paper is related with manufacturability problems and appropriate processes capability. A good design can only be made under consideration of the manufacturing processes [3]. One point, which makes a lot of problems in practice, is tolerance allocation. In general the designer is interested to have only small deviations from the dimensions because this eases his or her work and saves time. But the small tolerances are expensive or often not possible to produce. So the designer is only able to define a suitable product if he or she is familiar with the process capabilities of producer production plants. Well designed tolerances enable to minimize manufacturing costs and hold place in the market. This tolerance optimisation seams to be easy on the first view but it is not. If there are, for example, three parts between gaps in general the design should be made according worst case tolerances. In Fig. 1 the dimension of the surrounding part has to be $18^{+0.8}_{+0.4}$ mm otherwise the mounting is not possible without force. If the dimension of the outside part is fixed because it is a standard part, the other parts tolerances have to be optimised to meet requirements. To allocate the tolerances here is much more complicated and consumes more time. This becomes more complex if some of the inner parts are standard parts with fixed tolerances. If there is a two or three-dimensional task it is much more complicated especially if you take care about parts which are not parallel or if you have to fix the shape of parts. If it is complicated the time consumption will increase, the quantity of mistakes during allocation of tolerances will increase also and consequently will increase the manufacturing the costs.

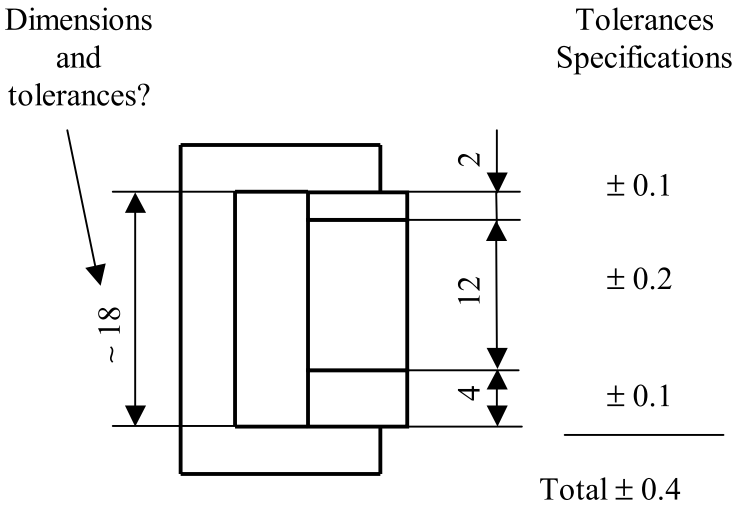

Fig. 1: Example for a tolerance optimisation

That means this situation needs improvement. There are some possibilities: first possibility is to use this optimisation of tolerances by simulation tools such as Computer Aided Tolerance (CAT); second possibility is when designer can re-allocate tolerances in a chain dimension combining the value of tolerances for standard and original parts. In this case designer should keep only in mind the standard parts' tolerances and suggest which tolerances of original parts are fixed, and which have to be defined by the any well known tolerances re-allocation method. It is necessary to take into account other restrictions like manufacturing costs, quality requirements or product delivery time to the customer. CAT is a tool that simulates the effects of dimensional variation of the manufacturing of original parts and their assembly as completed products. CAT models often consider the parts ideally rigid cinematically, with no elasticity or friction to compute the mutual position change between interacting parts and their clearances. The rigid and cinematic model is a strong idealisation and more realistic models such as Multi-Body Systems simulations are necessary to use. Tolerance analysis consists of tolerance specification, variation modelling, and sensitivity analysis. The allowed variation on tolerance specification in shapes and configurations are defined for the parts of the systems.
It is important for designer to have an appropriate technique, which could help him to vary the characteristics of product alternatives and their manufacturing costs. Our work is emphasized with second approach, i.e. with a tolerances re-allocation methodology and appropriate software. Various CAD systems widely used for product design have not such technique. For the early design stage the technical – economic models and for the batch production stage the specialised software are used [4, 5]. A lot of various models are created to help engineer to make this job. The models are based on product requirements and manufacturing restrictions. Rational tolerance design is analytical model, which calculates the accumulation of tolerance in assemblies. All models could be divided in three groups: 1) Worst Case; 2) Statistical; 3) Sampled [6-8]. The product part tolerances could be allocated using 3 methods: 1) distributed equally among all parts; 2) allocated by proportional scaling; 3) allocated using weighted methods. Unfortunately, reviewed methods cannot relate the tolerances, indices of process capability and costs.
When designer has selected a best product's alternative with minimum manufacturing costs, this decision is a risky. It is necessary to verify a process capability achieving the high quality of product with less manufacturing costs. The modelling of process capability for costs minimization is a

technique of above-mentioned task. The developed model structure of process capability modelling for costs minimization and its mathematical formalization in the next chapter of paper is described.

PROCESS CAPABILITY MODELLING FOR COSTS MINIMIZATION

In GM environment companies are facing strong competition and have to make many efforts for their survival. Attractive products and services proposed to the marketplaces are one form achieving these aims. New product design is a creative effort attempting to turn customer wishes into an economically producible product to be useful all over its life cycle. In most design situations, compromises among performance, cost and delivery time cannot be avoided. Therefore a lot of product design alternatives are necessary. Production processes do not make perfect products and, eventually, they introduce more variation and product defects. The capability of a process refers to its ability to meet the implementation needs of a product. Process capability is measured by its indices. Capability is not inherent to a process, but rather it depends on the designer's expectations [9]. In most cases, product implementation costs are directly related to process capabilities. Our research is devoted to consideration of process capability aiming at minimization of both product costs and delivery time. The most popular process capability indices are C_p and C_{pk} [9, 10]. A process capability index is a measure relating the actual performance of a process to its specified performance which depends on the traditions of plant and environment, peculiarities of equipment, operation, materials and people. Any process P of product G is expressed as a set of operations R:

$$P = \bigcup_{i=1}^{n} R_i = \{R_1, R_2, ..., R_i\}. \tag{1}$$

The means of process capability indices are to be calculated for each operation R_{i}, and hereby a lot of C_p for whole process P could be expressed as follows:

$$C_p = \{C_p(1), C_p(2), ..., C_p(i)\} \tag{2}$$

The critical operation in set P defined by expression (1) is the one having the minimum value of C_p index. Manufacturing engineering efforts have to be excited for improving the C_p value which at the current moment is not enough. The co–operation among product designer and production engineer has often to be used improving C_p and seeking minimum manufacturing costs C. A parametric function for Cdefinition has been created.

We have developed a specialized model for solving this problem (Fig. 2). It is based on the systematic approach implementing the methods of Design for Manufacture (DFM), Design for Assembly (DFA) and Design for Costs (DFC) during the integrated product and process development. Computer Aided Process Planning (CAPP) system develops the manufacturing process P for each product G alternative, and Material Resources Planning (MRP) and Enterprise Resources Planning (ERP) systems calculate appropriate manufacturing resources. The intelligent mathematical tool and software for developed model have been proposed:

$$\begin{cases} 0 < C \le C_{\max}, & C \to \min, \\ C_p^{\min} \le Cp \le C_p^{\max}, & Cp \to \max \end{cases}; \tag{3}$$

Where C is relative cost of operation; $C_{\max}$ is the biggest acceptable operation costs; Cp is the operation (process) capability index; $C_p^{\min}$, $C_p^{\max}$ are maximal and minimal acceptable index mean.

There is possibility to use *make or buy* approach searching variant of a product design and manufacturing when process capability index is low or production costs are high in appropriate plant. The customers-suppliers-producers data base (DB) has to be created for various products and components.

The proposed model is programmed using dBase and Visual Basic 6.0 objective programming language tested and validated both in KTU, Laboratory of integrated manufacturing engineering and in Lithuanian Company X. A number of process plan alternatives *P* with different *Cp* and manufacturing costs *C* have been generated for various products or components *G*.

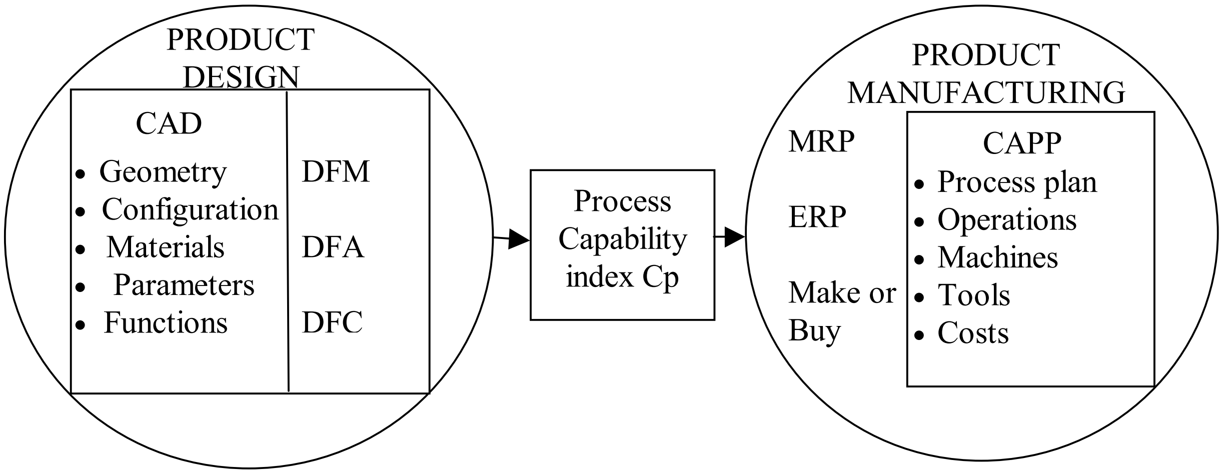

Fig. 2 The structure of process capability model for product design and manufacturing

There are published a lot of papers concerned with tolerance re-allocation, process capability and costs. For some researches the manufacturing cost is the main parameter for the tolerance allocation [11-13]. Other group of scientists name the process quality (i.e. process capability) as main criteria [14]. These publications show the urgency of this problem in new manufacturing environment. The method that is described in this paper differs from any others that are currently available and has some advantages. It is an integrated system that relates CAD and CAPP developments for simultaneously design of products and processes taking into account their qualitative and quantitative parameters and customer requirements. The next sections illustrate how the developed model works and some available results from its activity are presented.

CASE STUDY 1

The created software enables to check capability indices of new product manufacturing process in the early design stage. The experimental investigation of process capability by the created model was carried out with the gear pump (Fig. 3). It is classified into seven (1,…,7) design features (DF). The study of the gear pump housing manufacturing process capability for two manufacturing systems A and B was carried out. The process capability indices and relative manufacturing costs according to the developed processes by CAPP system and DF qualitative-quantitative parameters were calculated [16] and results presented in the Table 1. This table shows that results in manufacturing system *B* have been got better than in manufacturing system *A* both for process capability index and manufacturing costs. The approach *make or buy* can be used according to the results defined by developed model. The *case study 2* is devoted for consideration and implementation of tolerances re-allocation by developed model in whole complicated product or assembly unit.

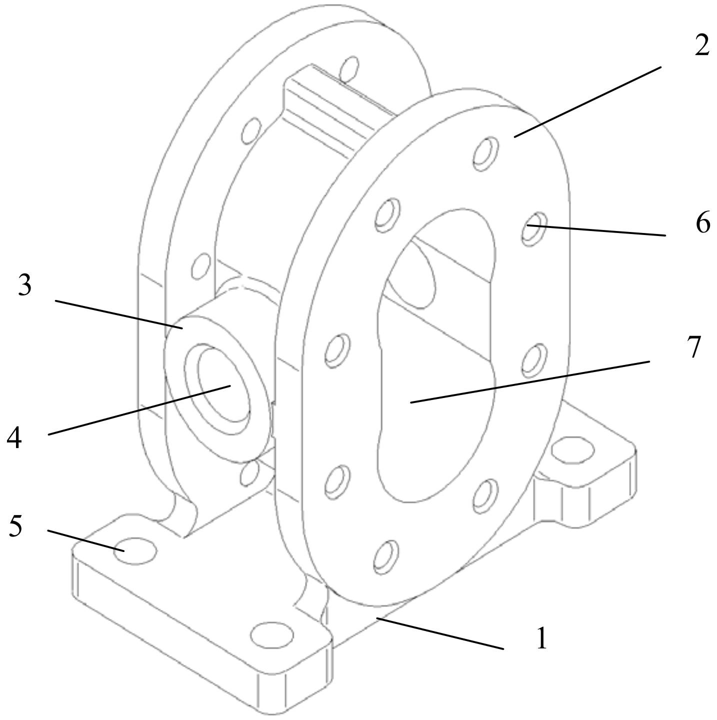

Fig. 3 Gear pump housing

Table 1

Process capability indices and relative manufacturing costs

Feature No.	Dimension	Process	MS A		MS B	
			Cp	Cost, MU	*Cp*	Cost, MU
1	136x76	Rough milling	1.15	1,55	1,25	1,44
		Smooth milling	1.15		1,37	
2	135x92	Rough milling	1.16	1,63	1,27	1,48
		Smooth milling	1.19		1,36	
		Rough grinding	1.27	1,04	1,28	1,03
		Smooth grinding	1.04		1,11	
3	∅40	Countersinking	3.03	0,34	3,7	0,33
4	∅22	Countersinking Threading	1.67	0,66	1,66	0,61
5	∅10	Drilling	1.92	0,51	2,27	0,48
6	∅8	Drilling Threading	1.79	0,87	2,33	0,81
7	∅36	Rough turning	1.39	2,76	1,57	2,7
		Smooth turning	1.48		1,8	
		Rough grinding	1.79	6,75	1,94	6,73
		Smooth grinding	1.32		1,47	
		Precise grinding	1.02		1,08	
			Σ	16,11		15,61

MU – relative money units

MS A – Manufacturing system A

MS B – Manufacturing system B

CASE STUDY 2

The tolerance allocation is an essential factor to the manufacturing cost and product quality. In the created software, the tolerances are re-allocated according to the process capability indices and manufacturing cost for the whole product but not for a separate part.

Tolerances are allocated in three steps:

1. The initial tolerances are determined using desired maximum process capability index;
2. The weight factors are calculated for each member of dimension. The weight factor evaluates the changing gauge of the dimension chain member tolerance [15]. A larger weight factor for a given component means a larger fraction of the tolerance pool will be allocated to it.
3. Re-allocation of the chain members' tolerance.

The Worst Case and Root Sum Square methods were used. Dimensions are shown in the Table 2. The calculation results for the dimension chain shown in Fig. 4 follows. Fixing ring (A) and bearings (C, G) dimensions and tolerances are standard. The obtained tolerances are compared with the tolerances which are obtained using trivial proportional factor method in Fig. 5.

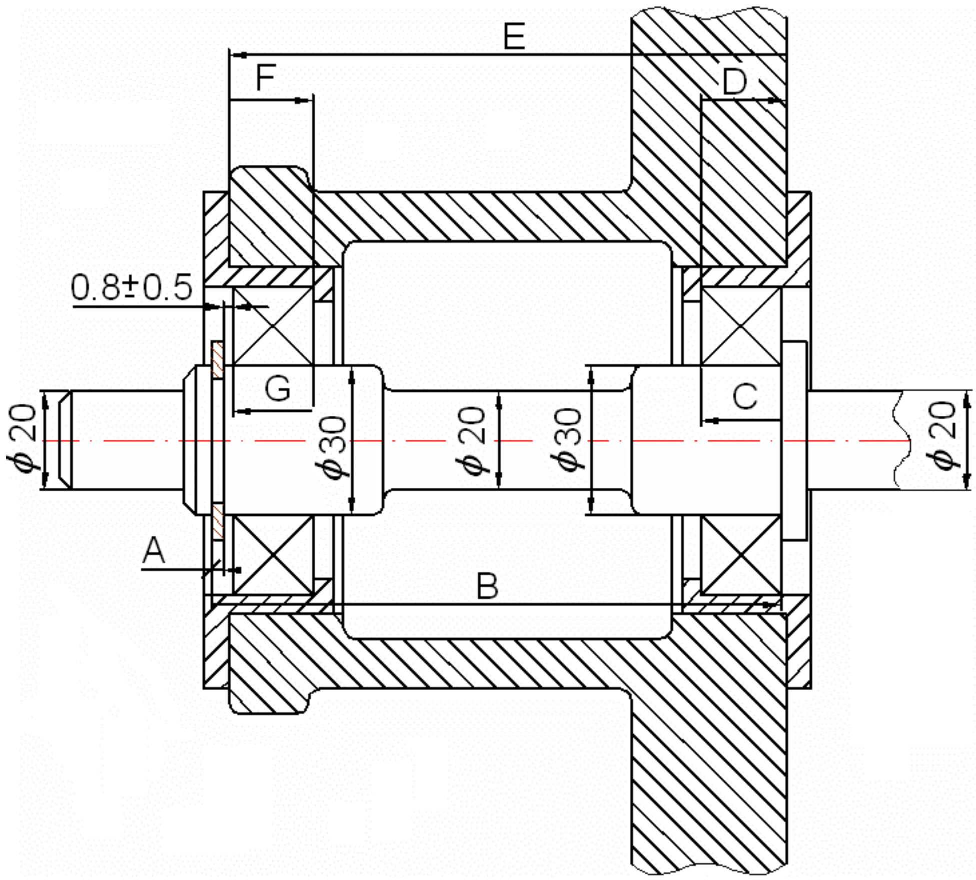

Fig. 4 Dimension chain in assembly unit

Table 2

Dimension chain members

Dimension	A	B	C	D	E	F	G
Value	1,2	117,7	16	18	120	18	16
Type	standard		standard				standard

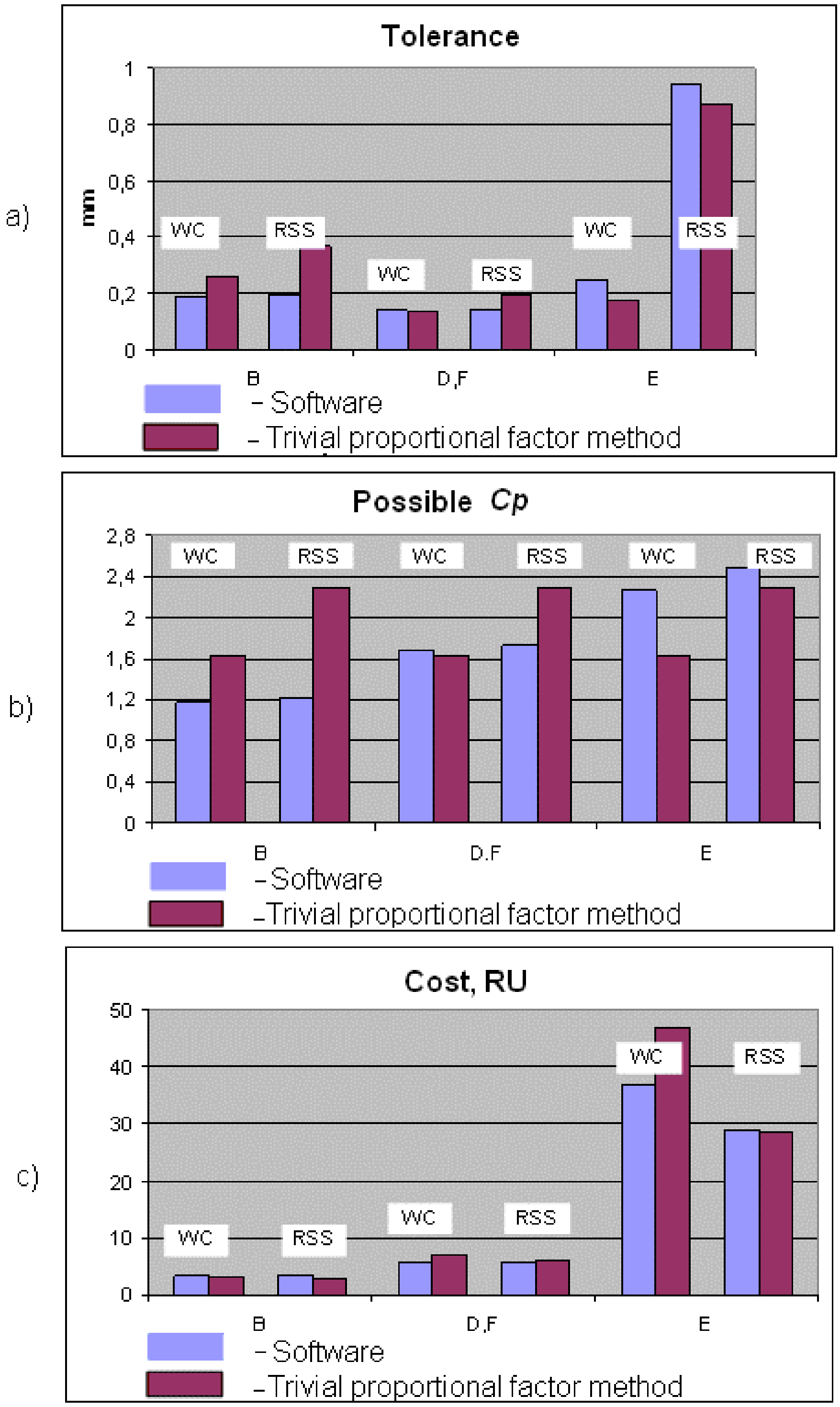

Fig. 5. Compared results of software and trivial proportional factor:
a) tolerance; b) possible *Cp*; c) cost in relative money units

The sequence of developed model work aiming the optimal *Cp* index and manufacturing costs *S* is shown. A typical product of mechanical engineering –gearbox with a fixed dimension chain and various qualitative-quantitative parameters has been taken. The model operation consists of three stages: 1) data extraction from the 3D CAD product model, 2) preliminary calculation of *Cp* index value and manufacturing costs *C* for each chain dimension member of a product, 3) re-allocation the tolerances for each chain dimension member according to the model proposed proportional factors. Moreover, the definition of an optimum *C* considering the possibilities of various manufacturing systems (MS) acquired in different production fields, companies and countries has been investigated and knowledge base (KB) structure for finding the optimal producer was proposed.

RESULTS AND CONCLUSIONS

The sequence of developed model work aiming at the optimal *Cp* index and manufacturing costs *S* is shown at an early stage of the product design. A typical product of mechanical engineering – gear box with a fixed dimension chain and various qualitative-quantitative parameters have been taken. The model operation consists of three stages: 1) data extraction from the 3D CAD product model, 2) preliminary calculation of *Cp* index value and manufacturing costs *C* for each chain dimension member of a product, 3) re-allocation the tolerances for each chain dimension member according to the model proposed proportional factors. Moreover, the definition of an optimum *C* considering the possibilities of various manufacturing systems (MS) acquired in different production fields, companies and countries has been investigated and knowledge base (KB) structure for finding the optimal producer was proposed. The developments described in this paper make it possible to reduce the time and costs for the product and process design and created model helps to disclose the regularity of changes of manufacturing costs by changing the structure of the product and process.

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