Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 56
ISSUE 1
January
2013

Relative manufacturing costs of machines elements based on constructional similarity

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Received 22.11.2012; published in revised form 01.01.2013

Analysis and modelling

ABSTRACT

Purpose: The main aim of research was to analyse the exponents values assigned to operations in relative manufacturing costs estimation method based on the similarity theory.
Design/methodology/approach: The manufacturing costs were calculated with similarity theory use. This method uses exponents assigned to operations. This exponents were estimated for such operations like: facing, inner and outer turning: rough, semi finished and finished. The manufacturing process was simulated in CAM module of advanced graphical program Siemens NX.
Findings: The manufacturing costs estimation method based on costs similarity uses exponents assigned to operations. The CAM simulation can be applied to calculate the exponents values. This approach improves accuracy of the method results.
Research limitations/implications: The estimated exponents values can be applied only to previously analyzed operations.
Practical implications: The exponents estimation process was applied to manufacturing process of shaft and sleeve simulated in CAM module.
Originality/value: Described analysis presents the estimation process of exponents assigned to operations with CAM simulation use.
Keywords: Constructional design; Engineering design

Reference to this paper should be given in the following way:
M. Cielniak, P. Gendarz, Relative manufacturing costs of machines elements based on constructional similarity, Journal of Achievements in Materials and Manufacturing Engineering 56/1 (2013) 20-28.

1. Introduction

The modern market forces the producers to meet the demands of customers. Still accelerating technological progress makes this goal very hard to achieve. The manufacturer must provide product which meet the customers' expectations, while maintaining a satisfactory price both sides.

The manufacturing costs has key influence to final price of the product. It is very important to develop new methods of manufacturing cost estimation and improve the existing ones.

This paper presents manufacturing costs estimation method based on costs similarity with calculated exponents values use.

2. Relative manufacturing costs

Relative manufacturing costs are defined as costs calculated in reference to pattern construction as a function of quantitative constructional attributes, based on identical calculation model A^{e_j} [2,3]. This model describes the relation between manufacturing costs of one of the element size and pattern construction [5,8].

$$rk_i^{e_j} = \frac{\text{new constr. manuf. costs}}{\text{model constr. manuf. costs}} = \frac{ko_i^{e_j}}{ko_0^{e_j}} = f\left(\varphi_{il}^{e_j}\right) \quad (1)$$

where:

$rk_i^{e_j}$ - manufacturing costs similarity number (for identical construction with model construction $rk_i^{e_j} = 1$)

φ_{il} - dimension similarity number.

The model of relative costs estimation process applied to series of types is presented on Fig. 1.

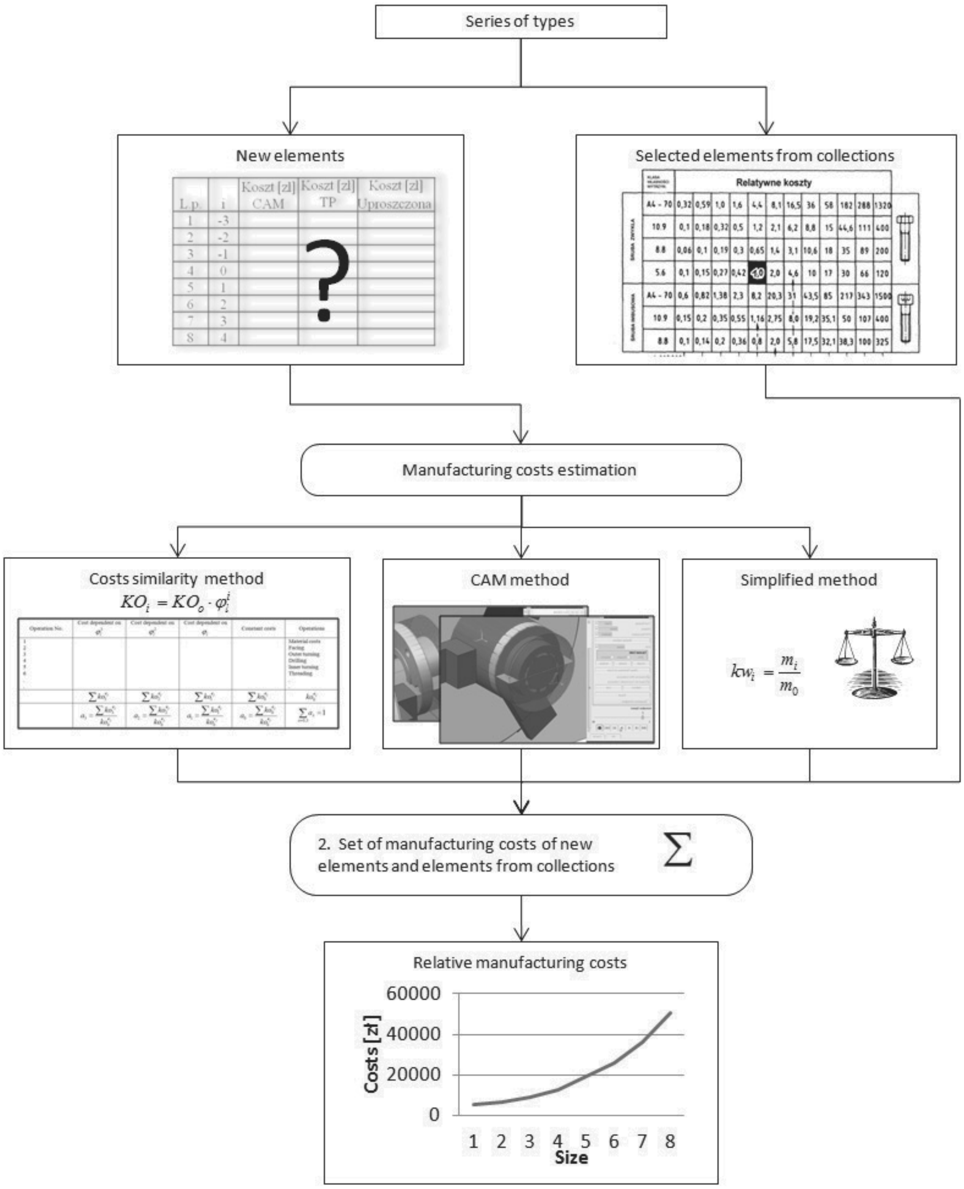

Fig. 1. Manufacturing costs estimation process based on similarity

The series of types are consist of manufactured components and elements selected from collections, such as standardized elements and catalog parts [9,14]. The manufacturing costs of elements selected from collections are known. This costs values are provided by manufacturer or can be estimated in reference to relative manufacturing costs tables. The manufacturing costs of new elements has to be calculated. The three main method of calculation are presented:

- the costs similarity method,
- the method based on CAM simulation
- the simplified method.

The costs similarity method is based on functional dependency between manufacturing costs of pattern construction and manufacturing costs of other element sizes. The independent variable of function is the similarity number $\varphi_{il}^{e_j}$. The research presented in this paper is focused on method based on costs similarity.

3. Manufacturing costs components

Based on [15] the following costs types are distinguished:

- average unit costs,
- overhead costs,
- constant costs,
- variable costs.

The manufacturing costs [4]:

$$K_W = K_M + K_r + K_{obr} + K_n \tag{2}$$

where:
K_M - material costs,
K_r - labor costs,
K_{obr} - machining costs,
K_n - tooling costs.

The material costs:

$$K_M = M_W C(1 + Nm) - M_0 C_0 \tag{3}$$

were:
M_w - material in [kg],
C - price of 1 kg of material in [zł/kg],
Nm - material overheads,
M_0 - waste mass [kg],
C_o - price of 1kg of waste [zł].

Labor costs:

$$K_r = \frac{t_j \cdot s_r \cdot k_s}{60} \tag{4}$$

Setup costs:

$$K_r = \frac{t_{pz} \cdot s_u \cdot k_s}{60} \tag{5}$$

where:
t_j - time per unit [min],
t_{pz} - setup time [min],
s_r - hourly rate of worker [zł/h],
s_u - hourly rate of setup man [zł/h],
k_s - social coefficient.

Machining cost:

$$K_{obr} = (K_a + K_e) \cdot K_p \tag{6}$$

where:
K_a - machine amortization charges [zł],
K_e - cost of energy used in machining [zł],
K_p - other costs coefficient e. g.: repair, consumable materials.

$$K_a = \frac{W \cdot a \cdot t_j}{100 \cdot 60 \cdot F} \tag{7}$$

where:
W - machine catalog price [zł],
a - amortization percentage [%],
F -work hours amount in year [h/year].

$$K_e = \frac{N \cdot t_j \cdot s_e}{60} \tag{8}$$

where:
N - machine engine power [kW],
s_e - energy cost [zł/h].

Tools costs:

$$K_n = \frac{t_{pi} \cdot k_{ui} \cdot C_{ni}}{t_{zi}} \tag{9}$$

where:
t_{pi} - operating time of tool [min],
t_{zi} - wear time of tool [min],
C_{ni} - price of tool [zł],
k_{ui} - failure coefficient of tool.

Operational time per unit:

$$t_j = \sum_{i=1}^{n_z} \left[(t_g + t_p) \cdot (1 + k_{uz}) \right] \tag{10}$$

where:
t_g - main time [min],
n_z - number of cuttings,
t_p - auxiliary time [min],
k_{uz} - auxiliary time coefficient.

Based on equations (2-10) it can be noticed that manufacturing costs is directly connected to main time t_g.

4. Costs similarity method

The first step in costs similarity method is to calculate the manufacturing costs of pattern construction $ko_o^{e_j}$. The relative costs of other sizes of elements $q_i^{e_j};(i=1;iz)$ functionally depends on model element manufacturing costs.

The dimensions similarity number $\varphi_{il}^{e_j}$ is the independent variable [2,7,10]:

$$\varphi_i^{e_j} = \sum_{op=1}^{opz}\left(a_{op}\cdot\prod_{l=1}^{iz_0}\varphi_{il}^{X_l}\right) \tag{11}$$

where:

op - operation (0 - constant costs),

a_{op} - operation parameter based on costs which corresponds to model construction,

$\varphi_{il}^{e_j}$ - dimensions similarity number assigned to operation $(l=1,lz_o)$,

x_l - exponent of dimension similarity number.

Very important stage in this method is selection of proper exponents values.

4.1. Standard exponents values

The exponent values are assigned to operations. For example the exponent value for turning is equal to two [11,12]. The reason is that turning tool moves in two axis (Fig. 2).

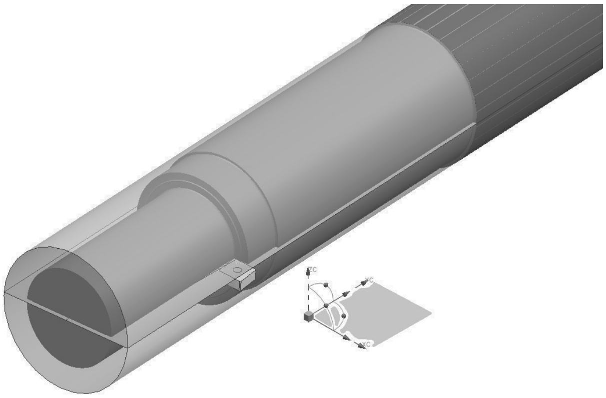

Fig. 2. The tool movement

The exponent values for common operations are collected in Table 1.

The method for improvement the method results accuracy is the assigning of the exponents to cutting processes. This approach was the subject of the earlier research performed by authors. The results are presented in Table 2.

Table 1.
Operations exponents [2]

Operation	Exponent
Material costs Milling	3
Turning Slotting	2
Drilling	1

Table 2.
Cutting processes exponents [1]

Cutting processes	Exponent
Material costs Pocket milling	3
Planar milling Rough outer turning Rough inner turning Slotting	2
Splineway milling Shaft facing Finish outer turning Finish inner turning Thread turning Grooving Drilling	1

4.2. Calculated exponents values

There is a relation between manufacturing costs and manufacturing main time. The manufacturing main time of turning depends on length of the shaft and its diameter.

$$\varphi_{t_g} = f\left(\varphi_l,\varphi_d\right) \tag{12}$$

In facing the time depends on diameter and number of passes:

$$\varphi_{t_g} = f\left(\varphi_d,\varphi_{lp}\right) \tag{13}$$

The CAM simulation for turning was performed. Basing on times retrieved from simulation the exponents values were calculated.

5. CAM simulation

The manufacturing process was simulated in CAM module of advanced graphical program Siemens NX [6,13]. The simulation was applied to series of types of hydraulic prop component. The constructional shape is presented on Fig. 3.

The trimetric view of hydraulic prop glad is presented on Fig. 4.

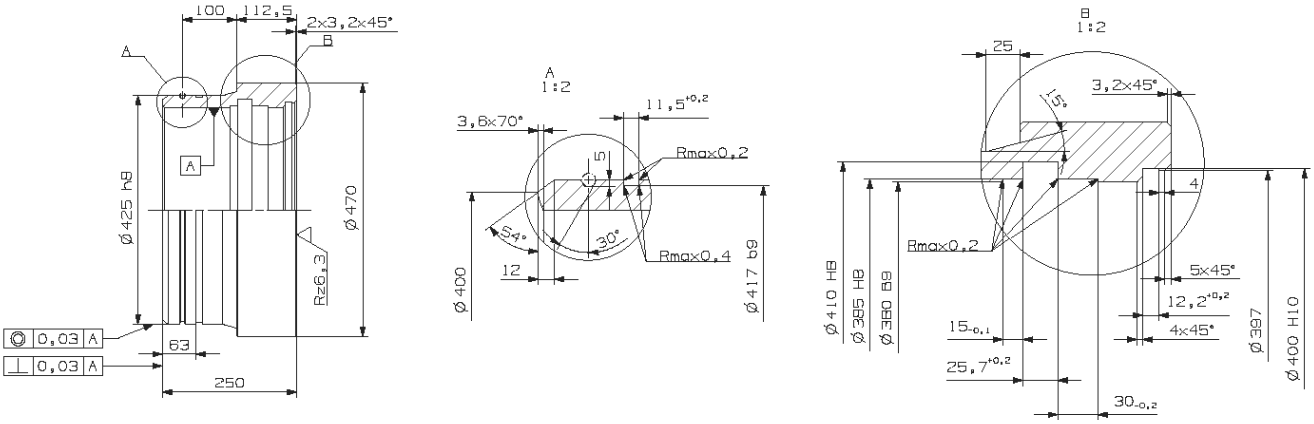

Fig. 3. Hydraulic prop gland

Fig. 4. Glad trimetric view

There are five sizes of this element. The both side machining was applied. The structure of manufacturing process is shown on Fig. 5.

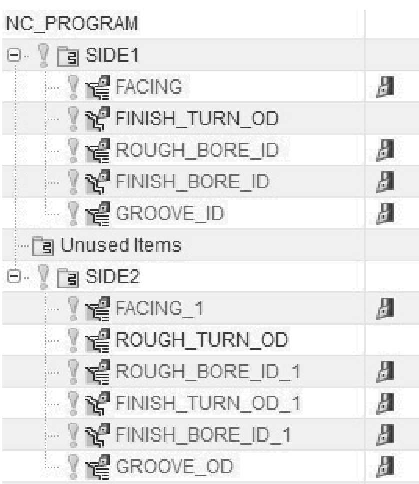

Fig. 5. Manufacturing process structure

5.1. Facing

The facing was the first analyzed cutting process. The exponents between main time of pairs of sizes were calculated based on expression:

$$x_{li} = \log_{\varphi_{il}^{ej}} \left(\frac{t_{g(i+1)}}{t_{gi}} \right) \tag{14}$$

where:
x_{li} - exponent value,
φ_{il}^{ej} - dimension similarity number,

The mean value was calculated. The main time and exponents values are collected in Tables 3 and 4.

The values of facing exponents are presented on Fig. 6.

Table 3.
Facing - side 1

No.	i	Main time [sec.]	Exponents
1	-2	129.1	
2	-1	203.2	2.03
3	0	438.9	3.45
4	1	843.5	2.93
5	2	1645.5	2.99
			Mean value = 3.45

Table 4.
Facing - side 2

No.	i	Main time [sec.]	Exponents
1	-2	110.8	
2	-1	162	1.70
3	0	336.4	3.27
4	1	671.5	3.10
5	2	1279.2	2.89
			Mean value = 2.74

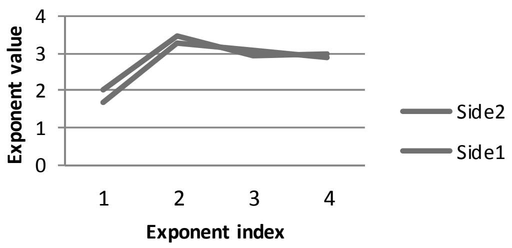

Fig. 6. Rough turning exponents

5.2. Rough turning

The same steps was performed for rough turning. The rough turning on first side is made in one pass only and it will be calculated as finish turning. Because of that there is one rough turning on second side only (Table 5).

Table 5.
Rough turning - side 2

No.	i	Main time [sec.]	Exponents
1	-2	139	
2	-1	224.9	2.16
3	0	507.8	3.65
4	1	968.8	2.89
5	2	1868.9	2.94
			Mean value = 2.91

The values of exponents assigned to rough turning are presented on Fig. 7.

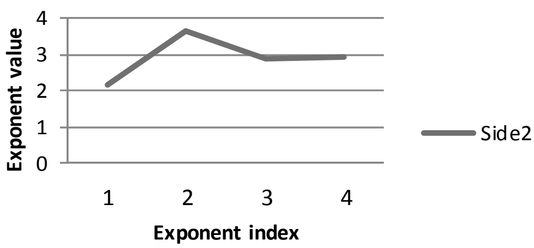

Fig. 7. Rough turning exponents

5.3. Finish turning

The exponents for finish turning are shown in Tables 6, 7 and on Fig. 7.

Table 6.
Finish turning - side 1

No.	i	Main time [sec.]	Exponents
1	-2	12.5	
2	-1	15.4	0.93
3	0	19.5	1.06
4	1	24.1	0.95
5	2	30.9	1.11
			Mean value = 1.01

Table 7.
Finish turning - side 2

No.	i	Main time [sec.]	Exponents
1	-2	61.3	
2	-1	93.1	1.87
3	0	149	2.11
4	1	227.6	1.90
5	2	354.3	1.98
			Mean value = 1.97

The values of finish turning exponents are presented on Fig. 8.

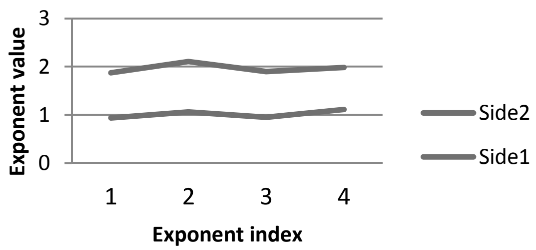

Fig. 8. Finish turning exponents

5.4. Rough inner turning

Rough inner turning exponents are presented in Tables 8, 9 and on Fig. 9.

Table 8.
Rough inner turning - side 1

No.	i	Main time [sec.]	Exponents
1	-2	145.8	
2	-1	251.7	2.45
3	0	479.9	2.89
4	1	574.6	0.81
5	2	1267.4	3.55
			Mean value = 2.42

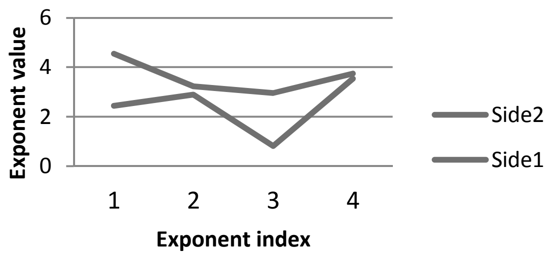

Fig. 9. Finish turning exponents

Table 9.
Rough inner turning - side 2

No.	i	Main time [sec.]	Exponents
1	-2	74.5	
2	-1	205.3	4.54
3	0	422.3	3.23
4	1	817.7	2.96
5	2	1888.7	3.75
			Mean value = 3.62

5.5. Finish inner turning

The exponents for finish inner turning are shown in Tables 10, 11 and on Fig. 9.

Table 10.
Finish inner turning - side 1

No.	i	Main time [sec.]	Exponents
1	-2	145.8	
2	-1	251.7	2.45
3	0	479.9	2.89
4	1	574.6	0.81
5	2	1267.4	3.55
			Mean value = 2.42

Table 11.
Finish inner turning - side 2

No.	i	Main time [sec.]	Exponents
1	-2	74.5	
2	-1	205.3	4.54
3	0	422.3	3.23
4	1	817.7	2.96
5	2	1888.7	3.75
			Mean value = 3.62

The values of finish inner turning exponents are presented on Fig. 10.

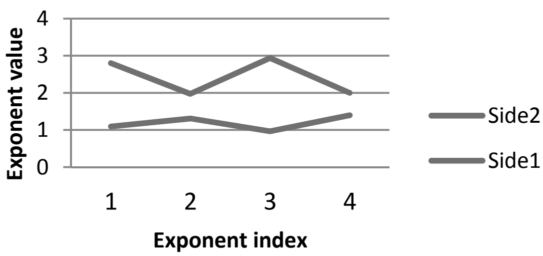

Fig. 10. Finish turning exponents

5.6. Grooving

Finally the exponents for grooving are collected in Tables 12, 13 and are presented on Fig. 11.

Table 12.
Grooving - side 1

No.	i	Main time [sec.]	Exponents
1	-2	124.8	
2	-1	207.5	2.28
3	0	258.1	0.98
4	1	314.8	0.89
5	2	391	0.97
			Mean value = 1.28

Table 13.
Grooving - side 2

No.	i	Main time [sec.]	Exponents
1	-2	24	
2	-1	30.3	1.04
3	0	48.4	2.10
4	1	73.5	1.87
5	2	113.9	1.96
			Mean value = 1.74

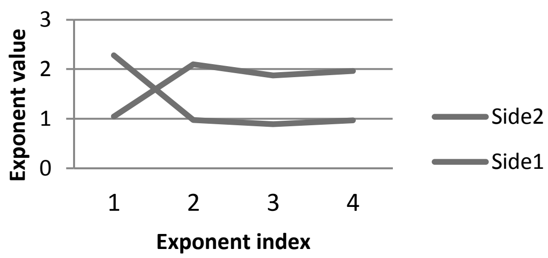

Fig. 11. Grooving exponents

6. Verification

The standard and calculated exponents values are compared in Table 14.

Table 14.
Comparison of exponents values

Cutting processes	Standard exponent	Calculated exponent
Material costs	3	3
Facing		2.8
Rough outer turning	2	2.4
Rough inner turning		3
Finish outer turning		1.5
Finish inner turning	1	1.8
Grooving		1.5

The manufacturing costs of hydraulic prop glad were estimated with costs similarity method with standard and calculated exponents values use and they were compared to CAM simulation method [1]. The results of all types of methods are presented on Fig. 12 and in Table 15.

Table 15.
Manufacturing costs

No.	i	Costs with standard exponents use [zł]	Costs with calculated exponents use [zł]	CAM simulation use [zł]	Standard exponents - CAM [%]	Calculated exponents - CAM [%]
1	-2	339.76	333.95	334.38	-1.61	0.13
2	-1	459.47	454.31	447.24	-2.73	-1.58
3	0	685.67	685.68	685.67	0.00	0.00
4	1	1115.61	1131.82	1139.47	2.09	0.67
5	2	1936.79	1994.16	2127.39	8.96	6.26

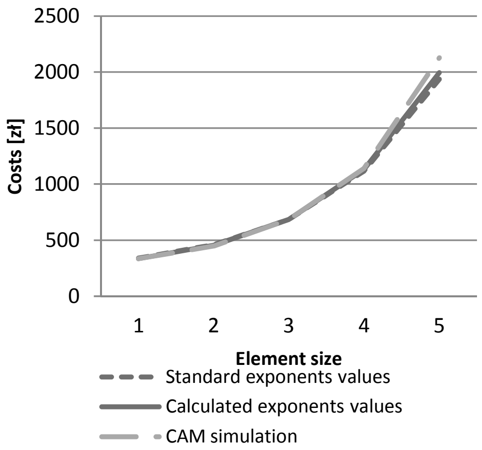

Fig. 12. Cost values

The CAM simulation method gives most precise result because it reflects all details of manufacturing process. The maximum difference between CAM method and method based on costs similarity with standard exponents values is equal to 8.96% for biggest size. The use of calculated exponents values decrease the maximum difference to 6.26%. This means that the application of calculated values instead of standard ones can improve the accuracy of manufacturing costs estimation process based on costs similarity.

7. Conclusions

Manufacturing costs estimation process is very important stage of the design-construction process. The decisions made on this stage has big impact on the product final price.

The series of types manufacturing costs estimation method presented in this paper is based on costs similarity. This method results quality depends on exponents values. The standard values of exponents are known and they are described in many publications. That values were compared to values calculated on the basis of practical simulation of manufacturing process. The differences between standard and calculated values can be noticed. The standard values assigned to operation should give proper results for every kind of cut type (e. g. rough and finish turning). The values based on simulation result from real situations and they are specified for every type of to cut process. This approach can improve the results accuracy of method based on costs similarity.

The exponents values based on simulation were estimated for turning on hydraulic prop glad example. The difference between method result with calculated exponents use and CAM simulation method is smaller than between CAM method and method with standard exponents values use. This is the proof that proposed method is effective. It is possible to calculate the exponents values for other cuttings such as milling. slotting etc.

The application of calculated exponents values can improve the accuracy of manufacturing costs estimation method results and finally this method will help to provide the economic profit of the company.

Acknowledgements

This work was supported by Polish Ministry of Science and Higher Education - National Science Center as a part of the research project No. 6786/T02/2011/40.

References

[1] Z. Adamczyk. K. Kociolek, CAD/CAM technological environment creation as an interactive application on the Web, Journal of Materials Processing Technology 109/3 (2001) 222-228.
[2] M. Cielniak. P. Gendarz, Relative manufacturing costs in series of types with partial similarity, Journal of Achievements in Materials and Manufacturing Engineering 53/1 (2012) 21-27.
[3] J. Dietrych, Machines Construction Basis, WNT, Warsaw, 1995 (in Polish).
[4] M. Feld, Design and automation of technological processes of typical machines elements, WNT, Warsaw, 2003 (in Polish).
[5] P. Gendarz, Calculation of dimensions for the construction series of types, Construction 50/10 (1998) 23-28 (in German).
[6] D. Marsh, Applied geometry for computer graphics and CAD, Springer, London, 2005.
[7] J.L. Nazareth, An optimization primer, on models. algorithms. and duality, Springer, New York, 2004.
[8] G. Pahl. W. Beitz, Construction science, WNT, Warsaw, 1984 (in Polish).
[9] K. Roth, Designing with design catalogues 2, Springer-Verlag, Berlin, 1994.

[10] R. Rząsiński, Databases and computer programs selection of technological features. Journal of Achievements in Materials and Manufacturing Engineering 49/2 (2011) 350-359.
[11] R. Rząsiński, The theory of similarity in turning operations. Journal of Achievements in Materials and Manufacturing Engineering 53/1 (2012) 37-46.
[12] R. Rząsiński. P. Gendarz, Technological operators of series of types technology creating, Journal of Achievements in Materials and Manufacturing Engineering 41/1-2 (2010) 155-163.
[13] S. Samuel. E. Weeks. B. Stevenson, Advanced simulation using Nastran NX5/NX6, Design Visionaries, USA, 2008.
[14] S. Tkaczyk. M. Skucha, The application of the balanced scorecard method in organization management, Proceedings of the 9th International Scientific Conference on "Achievements in Mechanical and Materials Engineering" AMME'2000, Gliwice-Zakopane, 2000, 549-552.
[15] H.J. Warnecke. H.J. Bullinger. R. Hichert. A. Voegele, Costs calculation for engineers, WNT, Warsaw, 1995 (in Polish).