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Cost calculation of constructions series of types

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Analysis and modelling

ABSTRACT

Purpose: The main aim of research was to elaborate methods to estimate costs in construction series of types production process.

Design/methodology/approach: Based on manufacturing cost of one element it is possible to determine cost of other elements belonged to the same construction series of types. The four main cost estimating methods were distinguished. The first method is feature-based. The technological operations are dedicated to specified pieces of element. Cost manufacturing of every piece is specified. Based on elementary costs the manufacturing cost of whole part is calculated. The second method uses construction similarity theory. The selected part manufacturing costs are functionally depended on main part manufacturing costs. The CAM method is based on time calculation from manufacturing process simulation. The simplified method uses normalized masses of analyzed parts pieces. The balance coefficients of those pieces are specified.

Findings: Manufacturing cost estimation methods were analyzed. Those methods are based on construction and manufacturing technology. The main conclusion is that CAM method is most accurate.

Research limitations/implications: The CAM method is limited to analyze only manufacturing process based on numerically controlled machines. The Feature-based method require developed database for analyzed part family.

Practical implications: Presented method was applied in hydraulic props manufacturing cost analysis.

Originality/value: Described analysis puts together and compares different cost estimating methods which allows choosing most suitable method for analyzed manufacturing process.

Keywords: Technological design; CAD/CAM; Series of types

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1. Introduction

To be competitive on modern market, which changes very dynamically, the producer has to readjust to customers expectations. The technological progress is still speeding up and this creates very hard tasks for manufacturer. He must provide product compatible with requirements and the price must satisfy both sides. To achieve that, the series of types may be applied. The customer will be satisfied and the production costs will be low.

There is no tool to estimate production costs during designing – constructional stage. Analyzes says that decisions made on this very early stage are very important to product manufacturing costs [8], (Fig. 1).

The designing – constructional stage influence on production costs is 70% high [15]. This is evidence, that developing of estimation methods is needed in designing – constructional stage.

That costs are directly depend on selected technology. Now, there are computer based tools which aid selection of construction attributes stage [9, 10, 13]. But production cost estimating process is still based on workers experience (Fig. 2).

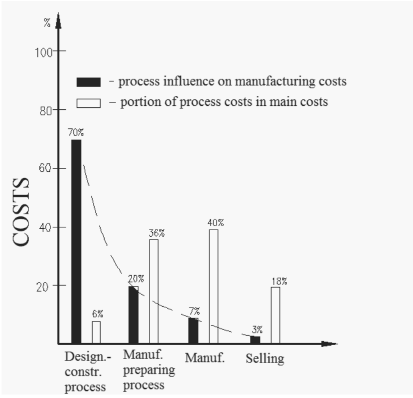

Fig. 1. Costs in designing – constructional and manufacturing preparing stages

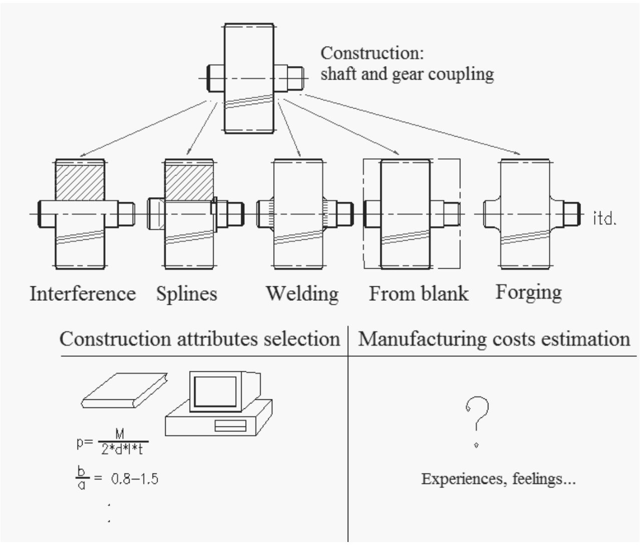

Fig. 2. Designing – construction stages and aiding tools

This is the reason that manufacturing cost estimating methods especially in machines constructions series of types creating process must be developed.

2. Construction similarity theory

The main assumption of construction similarity theory is that basing on construction model is possible to elaborate construction series of types, when states will be the same in whole series. Those states are described by system and they are defined by similarity conditions and unified characteristic attributes [2, 3, 5, 11].

The system is coupling and transforming relations arrangement. Those relations can be described by mathematical functions which describe physical effect states, stereomechanical states or other simple states. The main aim is to maintain constant states in whole series, according to construction model.

The Figure 3 presents relations graph.

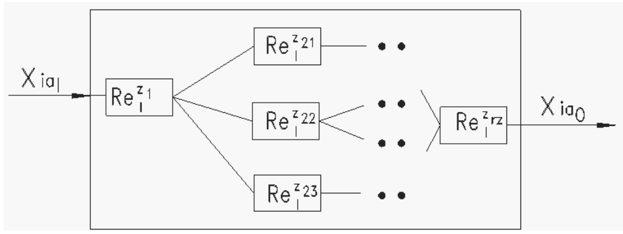

Fig. 3. Relation graph

In the Figure 4 states are described by mathematical functions.

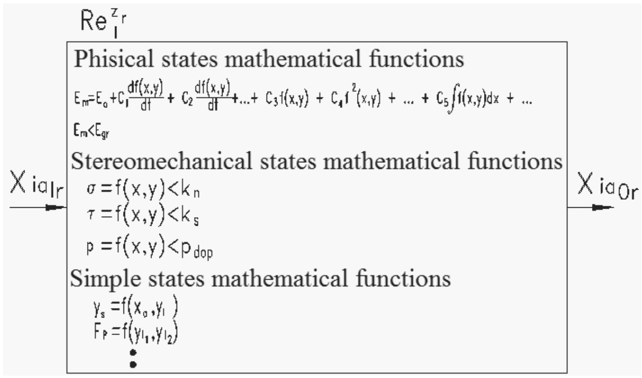

Fig. 4. States mathematical description

Construction similarity theory fulfilment in the stereomechanical states range, called Cauchy problem, tells that the material effort, strain and factor of safety is the same [4, 5, 12]. That can be achieved with finite element method or limit state design method use.

2.1. Construction model creating process

The construction series of types is based on construction model. Because of that, the construction model has to be practical verified and optimized in reference to criteria which follow from Technical Purposefulness Rights, Manufacture Potential Rights and Economic Rights. The manufactured product has to be practically verified.

The construction model elaborating process will be presented on clutch example. The clutch is torsional non-susceptible, stiff, flange without protecting rim (PN/M-85252).

The construction was modeled in advanced graphical program NX 6.0. Then it was optimized in Altair HyperOpt module. This module allows full shape optimization with Nastran solver use. The solution attributes are:

- design objective – minimize model weight ,
- design constraints –Von Mises Stress Model, upper limit = 235 MPa,
- design variables – part dimensions: outer diameters, sleeve and flange length, holes positioning circle diameter,
- maximum number of Iterations – 20,
- convergence parameters:
  - max constraint violation (%) – 5.0,
  - relative convergence (%) – 2.5,
  - absolute convergence – 0.001,
  - perturbation fraction – 0.2.

The optimization process had two stages. The first told that dimensions can be as low as come from element construction (for example the sleeve diameter must be so large that groove can be placed).

The second stage was concentrated on sleeve length. The results are presented below in Table 1 and Figure 5.

Table 1.
Stress and sleeve length values in cycles

	0	1	2	3	4	5	6
Mass [kg]	14.1	13.1	12.9	11.9	11.0	11.1	11.2
Sleeve length [mm]	160	134	128	104	83	86	86
Stress [MPa]	168	179	186	202	241	238	238

Fig. 5. Stress and sleeve length values chart

After forth iteration the stress values exceeded a limit as presented.

That analysis allows maximizing the material effort. This results a better material use and lower costs.

2.2. Construction similarity conditions

The flange coupling system is presented on Figure 6.

The construction similarity conditions are based on coupling relations. The flange coupling overall verbal system is: *"torque transfer from input shaft to output shaft"*.

The following couplings are distinguished:
R1 – torque transfer from input shaft to key surface,
R2 – torque transfer from active to passive key piece,
R3 – torque transfer from key to sleeve hub,
R4 – torque transfer from sleeve hub to sleeve flange,
R5 – torque transfer from sleeve flange to bolt surfaces (assumption: the stress in every bolt is the same),
R6 – torque transfer from active to passive bolt pieces,
R7 – torque transfer from torque transfer from bolt surfaces to sleeve flange,
R8 – torque transfer from sleeve flange to sleeve hub,
R9 – torque transfer from sleeve hub to key surface,
R10 – torque transfer from active to passive key piece,
R11 – torque transfer from key surface to output shaft.

The analysis input parameters are:
d – input shaft diameter equal to output shaft diameter,
M – torque.

The output parameters, which must be received, based on construction similarity theory, is active and passive clutch half dimensions.

Construction similarity theory conditions are based on states, mainly strength states [6] which are defined by relations:
R1 – torque transfer from input shaft to key surface
Strength condition:

$$p_1 = \frac{4M}{dhl} \le p_{dop} \tag{1}$$

where: h – key height,
l – key length,
p_{dop} – maximum surface stresses,

The related construction similarity condition:

$$\frac{\varphi_M^p}{\left(\varphi_d^p\right)^3 \varphi_{pdop}} = 1, \text{ when } \varphi_h^w = \varphi_l^w = \varphi_d^w = \varphi_d^p \tag{2}$$

R4 – torque transfer from sleeve hub to sleeve flange

$$\tau_1 = \frac{2M}{\pi \cdot D1^2 \cdot g} \le k_t \tag{3}$$

where: $D1$ – sleeve hub diameter.
The related construction similarity condition:

$$\frac{\varphi_M^p}{\left(\varphi_{D1}^p\right)^3 \varphi_{kt}} = 1, \text{ when } \varphi_g^w = \varphi_d^p \tag{4}$$

R5 – torque transfer from sleeve flange to bolt surfaces

$$p_2 = \frac{2M}{D2 \cdot z \cdot d1 \cdot s} \le p_{dop} \tag{5}$$

where: $D2$ – bolts arrangement circle diameter,
$d1$ – bolt diameter.
The related construction similarity condition:

$$\frac{\varphi_M^p}{\left(\varphi_{D2}^w\right)^3 \varphi_{pdop}} = 1, \text{ when } \varphi_{d1}^w = \varphi_s^w = \varphi_{D2}^w \tag{6}$$

where: z – number of bolts,
R6 – torque transfer from active to passive bolt pieces

$$\tau_2 = \frac{8M}{z \cdot D2 \cdot \pi \cdot d1^2} \le k_t \tag{7}$$

The related construction similarity condition:

$$\frac{\varphi_M^p}{\left(\varphi_{D2}^w\right)^3 \varphi_{kt}} = 1, \text{ when } \varphi_{d1}^w = \varphi_{D2}^w \tag{8}$$

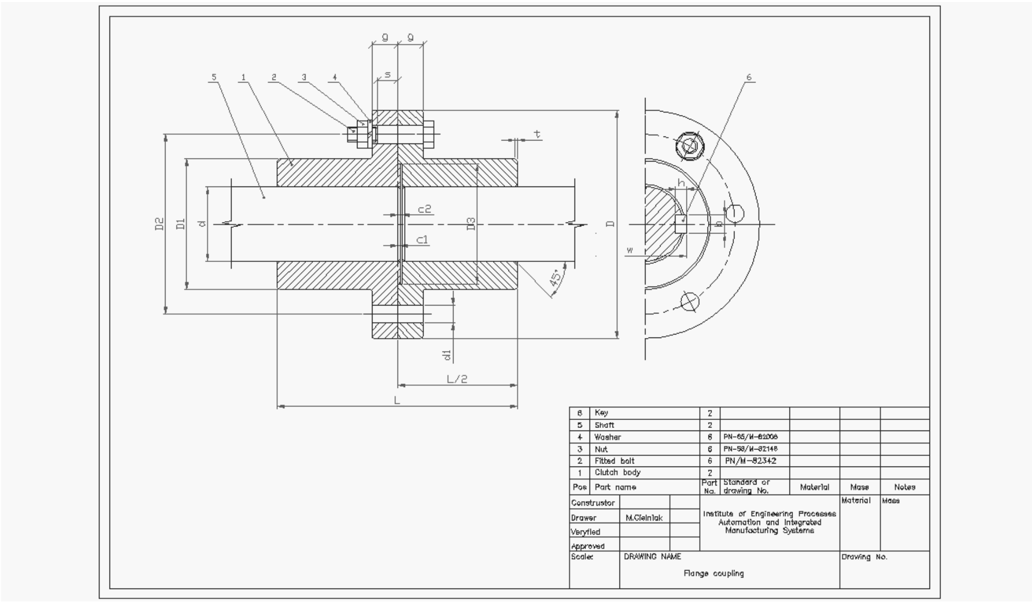

Fig. 6. The flange coupling drawing

Construction similarity conditions which come from relations R7, R8, R9 I R10 are analogical to relations which comes from relations correspondingly: R5, R4, R3 and R1, when relation R1 is more disadvantageous than relation R3, and R5 is more disadvantageous than R7.

The relations R2 and R10 were omitted, because the key is selected from Polish Standards.

When material is the same $(\varphi_{pdop} = \varphi_{kt})$ and after generalization of above relationships:

$$\varphi_d^w = \varphi_d^p = \varphi_{d1}^w = \varphi_{D2}^w = \varphi_s^w = \varphi_g^w = \varphi_k^w = \varphi_l^w \qquad (9)$$

so the result is:

$$\varphi_M^p = \left(\varphi_d^p\right)^3 \qquad (10)$$

The parameters can be unified and dimensions can be based on construction model and created construction similarity conditions (9) and (10).

3. Relative manufacturing costs estimating methods

3.1. Relative manufacturing costs

Relative costs are estimated relatively to construction model, based on identical calculation model (name A^{e_j}). They allow considering variable costs (direct) – which vary of construction attributes and the indirect cost can be omit (like overall plant costs, special costs, buildings amortization costs.

Proportional costs model is used in identical products serial manufacturing. That model varies of volume of production.

To low or medium rate production of parts which has diversified parameters congruent constructions relative cost model is applied.

The relative manufacturing cost model is used when production is low rate or elementary and the product has variant construction.

The estimating process precision varies of:

- products construction attributes,
- manufacturing process,
- production rate,
- production conditions: technical, organizational.

3.2. Relative manufacturing costs estimating methods

Manufacturing costs models A^{e_j} (calculation models) are relation models between construction attributes $CK_{il}^{e_j}$ and manufacturing costs $ko_i^{e_j}$.

The four main methods were distinguished [5]:

- feature elements method,
- construction similarity method,
- manufacturing process simulation with CAM programs use,
- simplified method.

Those methods are based on existing cost estimating methods.

Feature elements method

In the feature elements method the pieces of part are selected. The specified manufacturing process is assign to those pieces. The futures manufacturing costs estimation is based on elementary constructional – technological futures [5, 14]. Manufacturing costs model of element $A_o^{e_j}$ is generated.

Construction similarity method

The main point of construction similarity method is that construction model $\left(ko_i^{e_j}\right)$ production cost is calculated. A relative manufacturing cost of other elements in series functionally depends on construction model manufacturing costs [5].

The dimensions similarity number $\varphi_{il}^{e_j}$ is an argument of the function:

$$rk_i^{e_j} = \frac{ko_i^{e_j}}{ko_o^{e_j}} = f\left(\varphi_{il}^{e_j}\right) \tag{11}$$

where:

$rk_i^{e_j}$ - manufacturing costs similarity number,

$ko_i^{e_j}$ - new construction manufacturing costs,

$ko_o^{e_j}$ - construction model manufacturing costs,

(for constructions identical with construction model $rk_i^{e_j} = 1$),

φ_{il} - dimension similarity number.

There are two main cases:

1) complete similarity [7] $\left(\varphi_{il}^{e_j};\left(l = 1, lz_j\right) = \varphi_l^{e_j}\right)$:

$$rk_i^{e_j} = a_3 \cdot \varphi_l^3 + a_2 \cdot \varphi_l^2 + a_1 \cdot \varphi_l^1 + \frac{a_0}{\varphi_s} \tag{12}$$

where:

$\varphi_s = \frac{s_i}{s_o}$,

s – production rate.

2) Incomplete similarity [7]:

$$rk_i^{e_j} = \sum_{op=1}^{opz}\left(a_{op} \cdot \prod_{l=1}^{lz} \varphi_{il}^{x_i}\right) \tag{13}$$

where:

op – operation designation (0 – corresponds to constant costs),

a_{op} – operation parameter based on construction model manufacturing cost,

φ_{il} – dimension similarity number matched to operation $(l = 1, lz_o)$,

x_l – dimension similarity number exponent based on experimental research in specified plant.

Value of operation parameter a_{op} is computed in reference to construction model manufacturing costs in operation op. Exponent x_l is valued by manufacturing costs approximation, when several elements are machined with identical operations.

a_3, a_2, a_1, a_0 constants are calculated from equations:

$$a_3 = \frac{\sum Costs\_dependent\_on\_\varphi_l^3}{ko_o^{e_j}} \tag{14}$$

$$a_2 = \frac{\sum Costs\_dependent\_on\_\varphi_l^2}{ko_o^{e_j}} \tag{15}$$

$$a_1 = \frac{\sum Costs\_dependent\_on\_\varphi_l^1}{ko_o^{e_j}} \tag{16}$$

$$a_1 = \frac{\sum Const.\_Costs}{ko_o^{e_j}} \tag{17}$$

Table 2 presents constants values in reference to construction model manufacturing costs.

The manufacturing cost estimating process example will be presented with half of clutch use.

Similarity conditions are:

- preparation and termination expenses: $\varphi_{Kpz} = \varphi_l^0$
- material costs: $\varphi_M = \varphi_l^3$
- operation costs:
  - rough turning: $\varphi_{op1} = \varphi_l^2$
  - finish turning: $\varphi_{op2} = \varphi_l^2$
  - drilling: $\varphi_{op3} = \varphi_l^1$
  - slotting: $\varphi_{op4} = \varphi_l^2$

Table 2.
a_3, a_2, a_1, a_0 constants values

Operation No.	Cost dependent on φ_l^3	Cost dependent on φ_l^2	Cost dependent on φ_l	Constant costs	Operations
1					Material costs
2					Facing
3					Outer turning
4					Drilling
5					Inner turning
6					Threading
	$\sum ko_3^{e_j}$	$\sum ko_2^{e_j}$	$\sum ko_1^{e_j}$	$\sum ko_0^{e_j}$	$ko_0^{e_j}$
	$a_3 = \frac{\sum ko_3^{e_j}}{ko_0^{e_j}}$	$a_2 = \frac{\sum ko_2^{e_j}}{ko_0^{e_j}}$	$a_1 = \frac{\sum ko_1^{e_j}}{ko_0^{e_j}}$	$a_0 = \frac{\sum ko_0^{e_j}}{ko_0^{e_j}}$	$\sum_{x=0.3} a_x = 1$

After replace values from Table 3 to formula:

$$q_i^{e_j} = a_3 \cdot \varphi_l^3 + a_2 \cdot \varphi_l^2 + a_1 \cdot \varphi_l^1 + \frac{a_0}{\varphi_s}$$

when:

$\varphi_s = 1$

The result:

$$q_i^{e_j} = 0.29 \cdot \varphi_l^3 + 0.5 \cdot \varphi_l^2 + 0.09 \cdot \varphi_l^1 + 0.12$$

Construction model manufacturing costs: $ko_o^{e_j} = 172$ zl.

Similarity number for bigger construction when $\varphi_l = 1.12$

$$q_i^{e_j} = 0.29 \cdot 1.12^3 + 0.5 \cdot 1.12^2 + 0.09 \cdot 1.12 + 0.12 = 1.25$$

then:

$$ko_i^{e_j} = q_i^{e_j} = 1.25 \cdot 172 = 215 \text{ zl}$$

The Figure 7 presents manufacturing costs for whole half clutch series of types.

CAM method

The CAM method is based on machining process simulation. Times valuated during simulation are use to estimate manufacturing costs.

Costs estimating process starts from construction collection $Ks_w^{e_j} = \{ks_l^{e_j}, ..ks_o^{e_j}, ..ks_{oz}^{e_j}\}$ selection. For that constructions the machining process simulation (from 3 to $\frac{iz}{3}$) will be created. The construction model $ks_o^{e_j}$ belongs to this collection. Then manufacturing process model is generated for construction model $ks_o^{e_j}$ with CAM program use. Technological processes creation of other selected constructions $Ks_w^{e_j}$ is based on advanced graphical programs association. After merging manufacturing costs the construction model $ks_o^{e_j}$ manufacturing costs and manufacturing process model costs $te_o^{e_j}$ are estimated.

Manufacturing costs of other elements estimation is calculated in reference to construction similarity. Finally whole values are summarized [1, 5, 14].

The CAM method estimating example is shown below. The Figure 8 presents relationship between manufacturing costs and input material. Figure 9 shows relational manufacturing cost of elements compared to other elements for one piece. The last Figure (10) presents manufacturing costs in reference to series rate.

Table 3.
Clutch half manufacturing costs of construction model

Operation No.	Costs increasing with φ_l^3	Costs increasing with φ_l^2	Costs increasing with φ_l^1	Constant costs	Operations
1.	50	-	-	-	Material costs
2.	-	45	-	-	Rough turning
3.	-	30	-	-	Finish turning
4.	-	-	15	10	Drilling
5.	-	12	-	10	Slotting
	50	87	15	20	172
	$a_3 = \frac{50}{172} = 0.29$	$a_2 = \frac{87}{172} = 0.5$	$a_1 = \frac{15}{172} = 0.09$	$a_0 = \frac{20}{172} = 0.12$	$\sum_{x=0.3} a_x = 1$

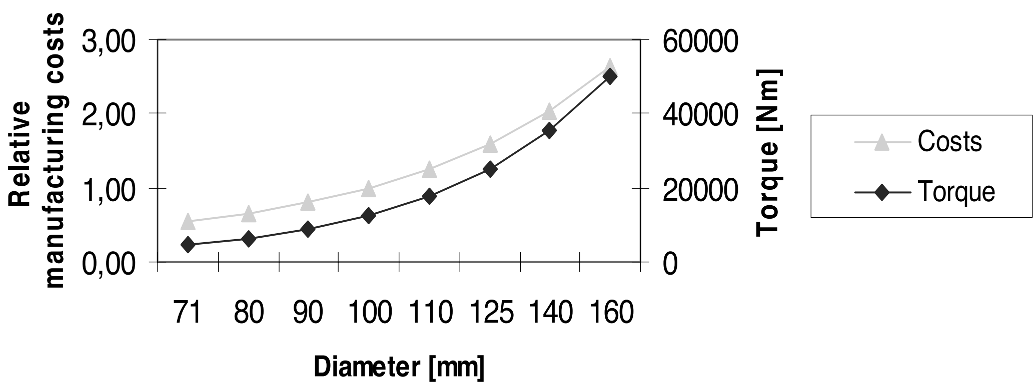

Fig. 7. Manufacturing costs of clutch half series of types

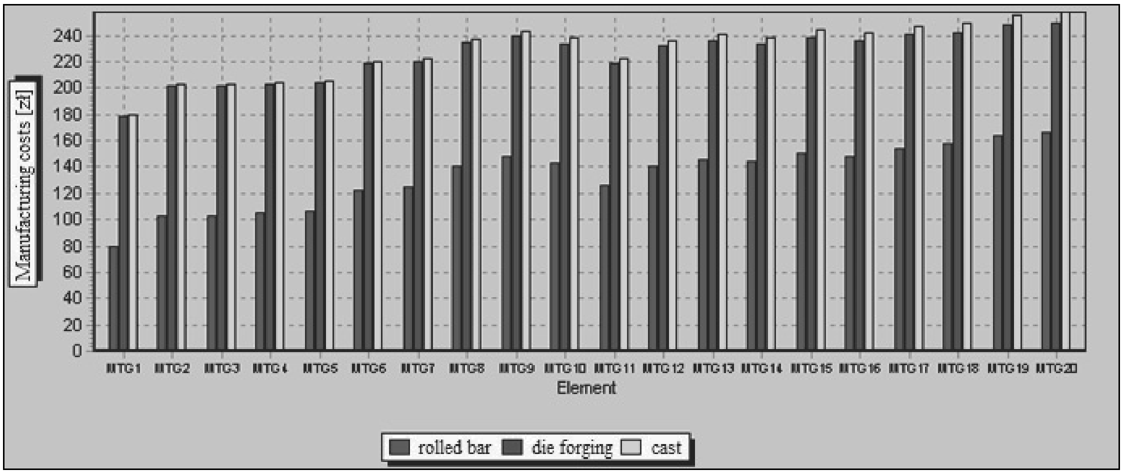

Fig. 8. Manufacturing costs in reference to input material

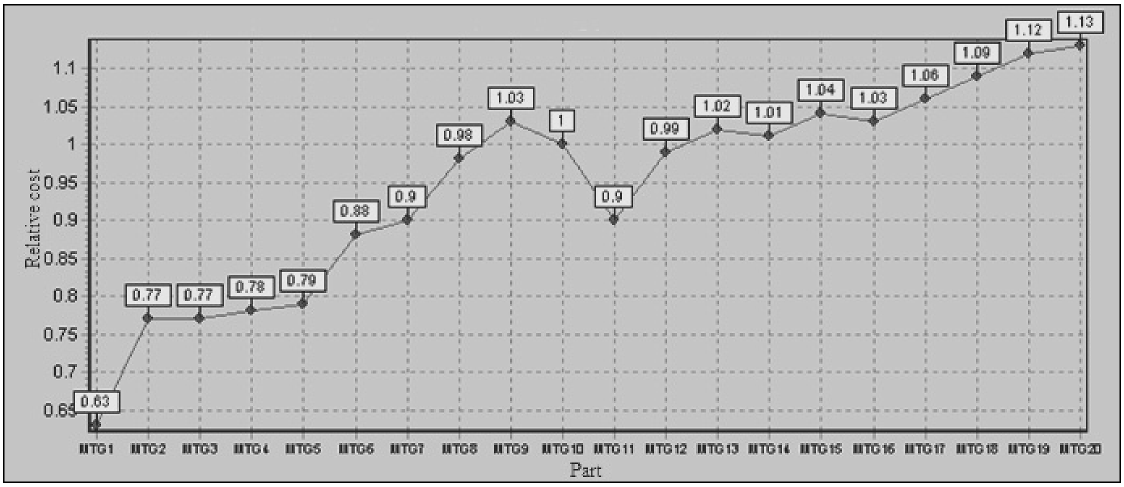

Fig. 9. Relative manufacturing costs

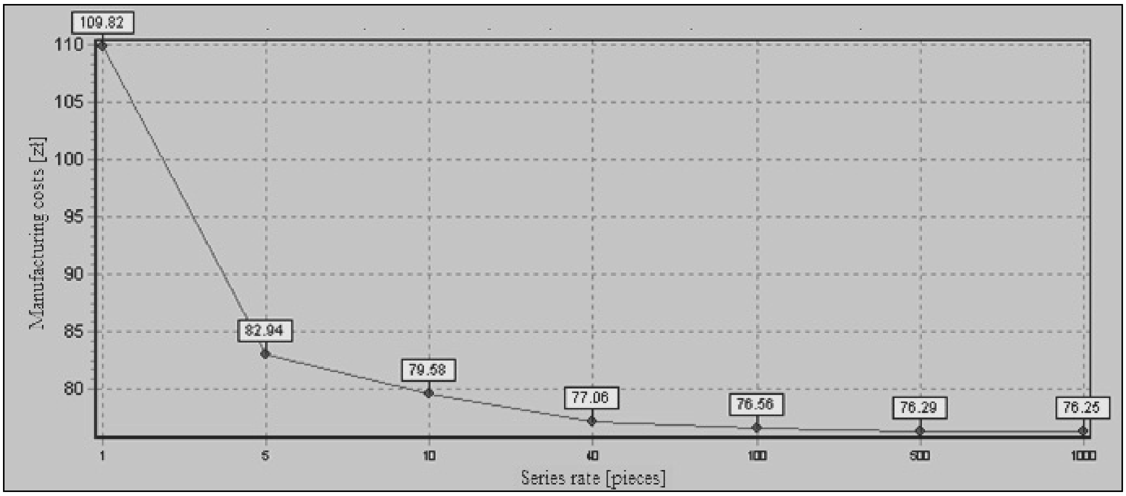

Fig. 10. Comparison of manufacturing costs and series rate

Simplified method

In this method element pieces masses are normalized. The next step is to assign a balance coefficient which depends on manufacturing complexity. The main equation used to normalization process:

$$kw_i^{e_j} = \frac{m_{ij} - m_{\min,j}}{m_{\max,j} - m_{\min,j}} \quad (18)$$

The balance coefficients fulfill the equation:

$$\sum_{j=1}^{jz} w^{e_j} = 100 \quad (19)$$

In this method the complexity is defined by experts' opinions which come from constructional and technological field.

4. Conclusions

Every presented method allows estimating manufacturing costs which depend on construction and technology attributes. That attributes are defined by plant conditions, economical conditions, etc.

The comparison of presented methods tells that the feature elements method result is related to way of part portioning. Because of that, the costs may be different. In addition this method requires cooperation with database. The database defines results quality.

The CAM method gives most accurate calculations. But it can be applied to numerically controlled machines only because they gives required manufacturing times.

The last method – simplified – is less complex. It gives much approximated results.

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] J. Dietrych, Machines Construction Basis, WNT, Warsaw, 1995 (in Polish).

[3] J. Dietrych, System and construction, WNT, Warsaw, 1985 (in Polish).

[4] P. Gendarz, P. Chyra, R. Rząsiński, Constructional similarity in process of ordered construction families creating, Journal of Achievements in Materials and Manufacturing Engineering 29/1 (2009) 53-56.

[5] P. Gendarz, Arranged constructions collection generating methodology, Silesian University of Technology Publisher, Gliwice, 2002 (in Polish).

[6] Z. Orłoś, Strength of materials, WNT, Warsaw, 1996 (in Polish).

[7] G. Pahl, K.H. Beelich, Determination of manufacturing costs for similar components, VDI-Berichte 347 (1979).

[8] G. Pahl, W. Beitz, Construction science, WNT, Warsaw, 1984 (in Polish).

[9] W. Plinke, Industrial Cost, Springer – Verlag, Berlin – Heidelberg - New York – London – Paris – Tokyo - Hong Kong – Barcelona – Budapest, 1991 (in German).

[10] M. Steiner, K. Ehrlenspiel, W. Schnitzlein, Experience with the introduction of knowledge-based extensions of a CAD - system for supporting construction cost estimate, VDI Berichte 1079 (1993) 33-43 (in German).

[11] R. Rzasiński, P. Gendarz, Methods of creation series of types of technology, Journal of Achievements in Materials and Manufacturing Engineering 36/2 (2009) 150-159.

[12] R. Rzasinski, P. Gendarz, The creation of ordered technologies on the basic of ordered constructions of machines, Proceedings of the 3rd Scientific Conference "Materials, Mechanical and Manufacturing Engineering" MMME'2005, Gliwice - Wisła, 2005, 203-207.

[13] S. Tkaczyk, M. Skucha, The application of the Balanced Scorecard Method in Organization Management, Proceedings of the 9th International Scientific Conference "Achievements in Mechanical and Materials Engineering" AMME'2000, Gliwice - Sopot - Gdańsk, 2000, 549-552.

[14] Y.-J. Tseng, B.C. Jiang, Evaluating Multiple Feature-Based Machining Methods Using an Activity-Based Cost Analysis Model, International Journal of Advanced Manufacturing Technology 16 (2000) 617-623.

[15] VDI – Richtlinie 2235: Economic decisions at the construction stage, methods and tools, VDI – Verlag, Dusseldorf, 1987 (in German).