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Models of construction attributes selection process in ordered construction families

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Analysis and modelling

ABSTRACT

Purpose: The main aim of research was to elaborate models of construction attributes selection process in ordered construction families.
Design/methodology/approach: Based on selection models of quantitative construction attributes in reference to unified characteristic attributes it is possible to generate ordered construction families like: series of types, modular systems.
Findings: Selection models of quantitative construction attributes were analyzed. Those methods are based on construction congruence.
Research limitations/implications: The neural network model limitations come from the neural network structure. The accuracy of neural network work results vary of neural network quality. The constructional similarity model can be applied only to that states which are described by similarity theory.
Practical implications: Presented method was applied in grippers series of types generation process.
Originality/value: Described models give simple and quick ways to select construction attributes in ordered construction families.
Keywords: Constructional design; Series of types; Modular systems; Constructional similarity

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1. Introduction

This paper describes the analysis of construction families. The construction family is a set of constructions that characterizes the same general system. The examples of such sets of constructions are: overhead travelling cranes, overload couplings, grippers and hydraulic cylinders. In construction families development it is possible to distinguish two main phases: extensive and intensive development. In the extensive phase the technical level of constructions is unstable. It is caused by realization of individual designing – constructional assumptions in the non-ordered way.
The intensive development integrally encloses construction family development. It starts from ordered area of needs, variety construction optimization, field tests and recycling. Such procedure ensures the economical success.

In many countries there are conducted researches that should provide procedures for the transfer from the extensive phase of development to the intensive one. In German these works are consider with development of the “Baukastensysteme”. In United

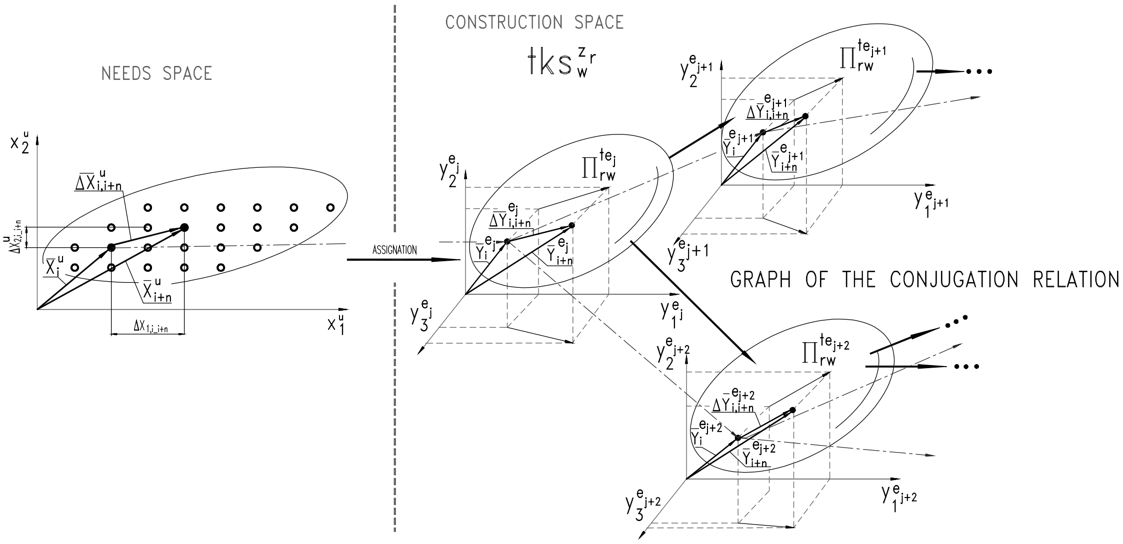

Fig. 1. Model of choosing the quantitative constructional features

States and Japan these work is concentrated on the logic of assemblies manufacturing. These assemblies are based on the standard elements construction or element with the defined alternatives capability. In Russia works are conducted in the area of standardization.

Quantitative constructional features are chosen according to the unified values of characteristic attributes [5, 6] (assignation **γ**),

$$cch^u_{ic} \to w^{e_j}_{il} \, (j=1, jz) \tag{1}$$

Because of the notation formalization the construction families parameters are distinguished from main quantitative and characteristic attributes [4, 5, 6].

Parameters matrix is the independent variable in the determining process of the elements quantitative constructional attributes,

$$x^u_{ia} = pa^u_{ia} \tag{2}$$

The choice of elements constructional features is made according to the need that is described by the row of the parameters matrix, called the *vector of needs*.

Elements constructions $ks^{te_j}_m \, (j=1, jz)$ self-relation is described by the relation graph $G\langle \Pi^{te_j}_{rw} \rangle$ [5, 6, 14]. These constructions are represented by the groups of constructional attributes like: constant constructional forms of elements $\Pi^{te_j}_{rw} \, (j=1, jz)$ and dimensions sets UW^{te_j}. In the dimensions sets there are constant dimensions sets WC^{te_j} and variable dimensions sets WV^{te_j}.

$$ks^{te_j}_m = (\Pi^{te_j}_{rw} \cup WC^{te_j})_{const} \cup (WV^{te_j})_{\mathrm{var}} \tag{3}$$

In reference to condition (3), called the ***condition of constructional congruence***, the constructional variability of elements is represented by the variable dimensions sets $WV^{te_j}\{wv^{te_j}_{ml}(l=1,lv_j)\}$, which values are chosen according to the vectors of needs $\overline{X}^u_i$. Such defined ***congruence constructions*** are determined by the quantitative features values matrix of constructional elements (the matrix of dependent variables),

$$y^{e_j}_{ml}(m=i,iz;l=1,lv_j) = wv^{e_j}_{ml}(m=i,iz;l=1,lv_j) \tag{4}$$

The row of the matrix $y^{e_j}_{ml}$ that represents the element construction is called the ***construction vector***. The model of variability between parameters values and quantitative constructional attributes is presented on the Fig.1.

2. Models of choosing the quantitative constructional features

In work [5, 6] the models of choosing the quantity constructional features are distinguished:

- traditional model,
- constructional similarity model,
- algorithmic model,
- neural networks model.

2.1. Traditional model

The traditional model of choosing the quantitative constructional attributes is based on the designing the solutions of the sequential vectors of needs in the non-algorithmic way using the knowledge and experience of the constructional departments. Traditionally, the quantitative constructional attributes, which belong to the conjunction relation graph, are selected in reference to the vector of needs of the elements. The next vector of needs is chosen and for this vector the next quantitative element attributes are determined.

2.2. Constructional similarity model

The model of selecting the dimensions values with constructional similarity use has been elaborated in reference to physical similarity theory. The construction model is the practically verified construction that has been already manufactured and the final product has been experimentally verified. The constructional similarity theory says that new construction has the same coupling and transfer relations like construction model [2, 3]. This gives optimally varied construction sets. These relations are described by mathematical functions which general model is shown on fig. 2. Fig.2a presents system block notation, where each relation is connected to the set of mathematical functions (Fig.2b) that describes [6, 7, 10]: physical phenomena states, stereomechanical states and other simple states (e.g. coupling relations between cooperating elements, geometrical dependencies between elements dimensions).

a)

b)

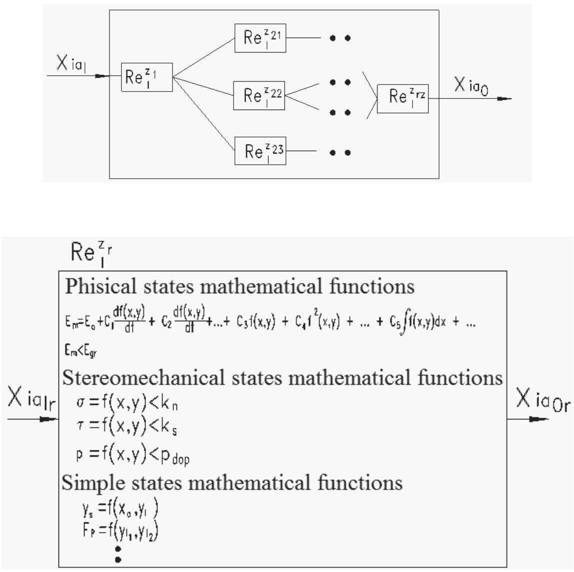

Fig. 2. Mathematical description of states of the future technical means

The theory of constructional similarity can be the base for the selection process of the quantitative constructional attributes and it fulfils the above described states which correspond to the construction model [11].

Let the general mathematical function correspond to the construction model,

$$C_0 f_{0A} = C_1 f_{0B} + C_2 f_{0C} + C_3 f_{0D} \tag{5}$$

where:

$$\bigwedge_{I=A,B,C,D} f_{0I} \to f(y_{0I}^{e_j}, x_{0a}^{u}); j \in 1, jz; l \in 1, lv_j; a \in 1, az,$$

C_0, C_1, C_2, C_3 – constant values of the function.

The general form of the mathematical function corresponding to the generated construction,

$$C_0 f_{iA} = C_1 f_{iB} + C_2 f_{iC} + C_3 f_{iD} \tag{6}$$

where:

$$\bigwedge_{I=A,B,C,D} f_{iI} \to f(y_{iI}^{e_j}, x_{ia}^{u}); j \in 1, jz; l \in 1, lv_j; a \in 1, az.$$

Based on the similarity measures,

$$\varphi_{iA} = \frac{|f_{iA}|}{|f_{0A}|}, \varphi_{iB} = \frac{|f_{iB}|}{|f_{0B}|}, \varphi_{iC} = \frac{|f_{iC}|}{|f_{0C}|}, \varphi_{iD} = \frac{|f_{iD}|}{|f_{0D}|} \tag{7}$$

where: $|f_{0I}|, |f_{iI}|$ - value of the function.

Described mathematical functions (5) and (6) and the dependencies (7) create the equations:

$$\begin{cases} C_0 f_{0A} = C_1 f_{0B} + C_2 f_{0C} + C_3 f_{0D} \\ \varphi_{iA} C_0 f_{0A} = \varphi_{iB} C_1 f_{0B} + \varphi_{iC} C_1 f_{0C} + \varphi_{iD} C_1 f_{0D} \end{cases} \tag{8}$$

Because both mathematical functions in the equations describe identical states of the isomorphic relation $\mathrm{Re}_l^{z_r}$, the fulfilling of the equations is possible when:

$$\varphi_{iA} = \varphi_{iB} = \varphi_{iC} = \varphi_{iD} \tag{9}$$

Because of the invariable system structure on the level of isomorphic relations $\mathrm{Re}_l^{z_r}$, based on the dependencies (8) it is possible to elaborate the ***constructional similarity conditions*** based on equation (9) which are fulfilled in the construction family area.

2.3. Algorithmic model

The algorithmic method in the ordered construction family is the method of creation the assignment γ of an element construction for all parameters vectors, in the sequence and connection created upon the conjugation relations graph and with the application of the operators [O], according to the dependence,

$$y_{ml}^{e_j}(j=1,jz)=[O]\cdot x_{ia}^{u}\text{, for m = i,} \quad (10)$$

The operators [O] are the base for selection of the quantitative constructional attributes, like:

- geometrical operators OG
- strength operators OW
- selected elements operators OD
- manufacturing operators OP
- constructional similarity operators OC
- coupled dimensions operators OS

The operators like: arithmetic, trigonometric, conditional and readjusting the values to the series of normal numbers, belong to the group of ***geometrical operators***. They let to determine the values of unknown dimensions on the base of parameters values or values of known dimensions,

$$x_{ia}^{u} \xrightarrow{O_G} y_{m,nz}^{e_j} \cup y_{m,zn}^{e_j} \xrightarrow{O_G} y_{m,nz}^{e_j} \quad (11)$$

The conditions of the strength verification are dependent from the selected dimensions and this is why they could be the base for variable dimensions values selection.

$$\begin{aligned} &\sigma = f(y_{m,nz}^{e_j}) \le k_\sigma \\ &\tau = f(y_{m,nz}^{e_j}) \le k_\tau \xrightarrow{O_w} y_{m,nz}^{e_j} \\ &p = f(y_{m,nz}^{e_j}) \le k_p \end{aligned} \quad (12)$$

The group of ***strength operators*** is divided on two subgroups: the direct operators O_{BE} and operators with the limit conditions O_{OG}

$$O_W = O_{BE} \cup O_{OG} \quad (13)$$

The direct strength operators O_{BE} are applied to estimation of unknown dimensions values using the values of: unified parameters, known dimensions values and material dimensions.

$$x_{ia}^{u}, y_{m,zn}^{e_j}, y_{(t)m,zn}^{e_j} \xrightarrow{O_{BE}} y_{m,nz}^{e_j} \quad (14)$$

The strength operators O_{OG} are applied for the modification of the initially selected value of a dimension $y_{0,nz}$ (e.g. estimated in reference to other operator) or the value that is selected from the range of limiting values $y_{max,nz}$ $y_{min,nz}$ (e.g. determined by the boundary conditions) that fulfil the limited criteria K_{OG} according to the procedure:

$$y_{\max,nz}^{e_j} \le y_{0,nz}^{e_j} \le y_{\min,nz}^{e_j} \quad (15)$$

$$y_{m,nz}^{e_j} = y_{0,nz}^{e_j} \quad (16)$$

$$x_{ia}^{u}, y_{m,zn}^{e_j}, y_{(t)m,zn}^{e_j}, y_{0,nz}^{e_j} \xrightarrow{O_{OG}} K_{OG} \quad (17)$$

The limitation criterion is the most often the fact that the permissible stresses K_σ, the permissible strains K_δ or minimal mass K_M are not exceeded. The special tool of this form of selection of variable dimensions values is ***variant analysis*** developed by an American firm SDRC (Structural Dynamics Research Corporation) in the advanced graphical program I-DEAS.

In the process of determining the dimensions values first are used the ***operators of selected elements*** (catalogue, normalised, manufactured by co-operating parties). In reference to known dimensions values, in this operators group, the element of series selection criterion must be fulfilled by vector of needs determination. Secondly the placement criterion must be fulfilled by dimensions values of placement selection [4]. The placement dimensions are the base for determining the values of unknown dimensions. The general model of application of the selected elements operators determines next dependences:

$$y_{m,zn}^{e_j} \xrightarrow{O_D} \overline{X}_j^D; \overline{X}_j^D \xrightarrow{O_D} w_{zab}^D; y_{m,nz}^{e_j} = f(w_{zab}^D) \quad (18)$$

Fulfilling the criteria that come from the manufacturing requirement, the dimensions values can be determined in reference to the selected manufacturing process. This allows determining the ***manufacturing process operators***. Based on these operators it is possible to determine the dimensions: lead-in chamfers, technological undercuts, the surfaces faced for the manufacturing fixtures, holes and grooves facilitating the assembly and disassembly thread joints. The criterions must be fulfilled: the element of series selection criterion and unknown dimensions values with element of series dimensions identity criterion.

In comparison to normalized elements construction selection, the consideration is about elements whose dimensions come from selected element of series.

$$y_{m,zn}^{e_j} \xrightarrow{O_P} \overline{X}_j^P; \overline{X}_j^P \xrightarrow{O_P} w_c^P; y_{m,nz}^{e_j} = w_c^P \quad (19)$$

Constructional similarity operators could be described as below: if for the given values of parameters are known the values of dimensions, then preserving the congruence condition (3), the values of new designed elements for new vectors of needs are determined as:

$$\overline{X}_0^u \to \overline{Y}_0^{e_j}(y_{0,zn}^{e_j}); \overline{X}_i^u \xrightarrow{O_C} \overline{Y}_m^{e_j}(y_{m,nz}^{e_j}). \quad (20)$$

Cooperation of elements could be possible when coupled dimensions of cooperating surfaces will be in a proper relation. The most often these are the identity relations. The base for creation of the ***conjugated dimensions operators*** is the graph of conjugations relation. Based on coupled dimensions operators and known dimensions it is possible to determine the values of unknown dimensions.

$$y_{m,zn}^{e_j} \xrightarrow{O_S} y_{m,nz}^{e_{j+1}} \quad (21)$$

Using described operators the algorithms are created, then the computer programs are generated which correspond to the system and variant structure of construction family [1, 15].

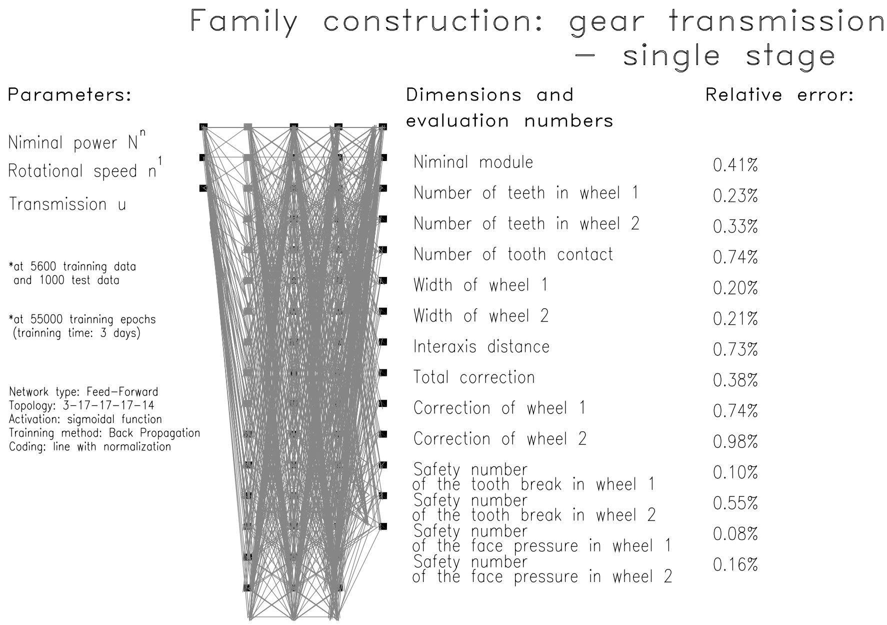

Fig. 3. Creation the γ assignment using a neural network

2.4. Neural network model

Application of neural networks gives us large possibilities [8] of creation the γ assignment. The unified values of characteristic features are the input data. The output data are values of variable dimensions. In this paper the Feed-Forward network with counter propagation or Jordan with feedback has been applied. The research was made on toothed gear construction example. Results are presented on the Fig.3. In the column are presented the percent errors.

3. Example

The construction attributes selection process will be presented on gripper example. This example shows the stages from construction model development through similarity conditions and relations between elements defining process up to construction attributes selection for all types in series. In this work the constructional similarity model and algorithmic model will be applied. This work was made with advanced graphical program NX 7.0 use.

3.1. Construction model

The construction model is based on construction MHZ2 manufactured by SMC corporation.
The main criterions, which construction model has to fulfil, are [12, 13]:

- maximal compactness of construction,
- minimal mass,
- minimal number of elements,

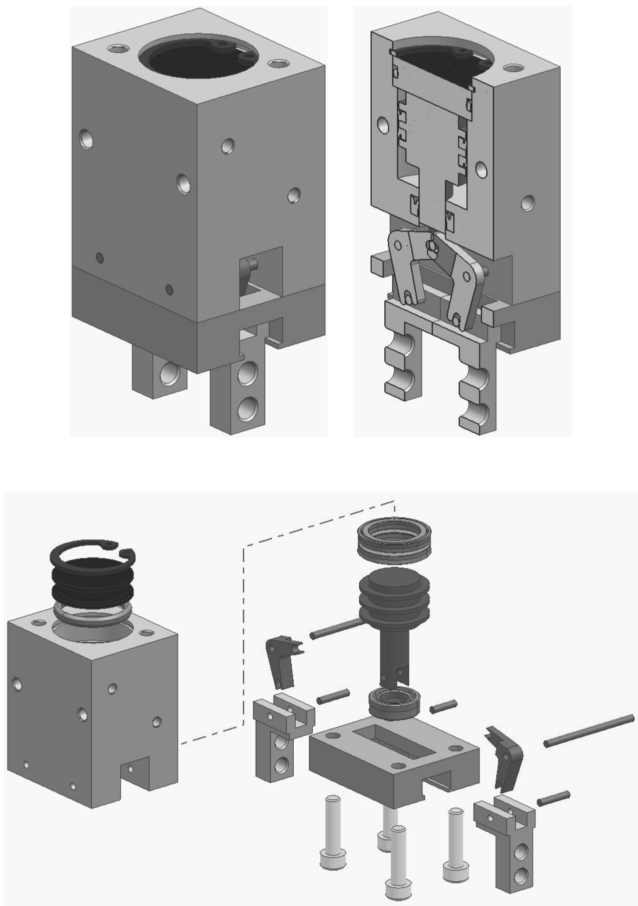
Fig. 4. Gripper Construction

- maximal number of elements from catalogues, normalized,
- simplicity of assembly process,
- simplicity of assembly the gripper to the robot,
- linear movement of gripper fingers,
- stabilized movement and force characteristic,
- constant or increasing force value in reference to the manipulated element diameter.

The construction of gripper is shown on Fig. 4.

Three main structures are distinguished:

- drive:
  - body KR with seals, cover PO with ring PS,
  - piston TL with seals,
  - bolt SWA,
- drive transfer:
  - down body KN with screws SRA,
  - arms RA,
  - trolleys PA,
  - bolts SWB, SWC,
- fingers

3.2. System structure

Program NX 7.0 has special tool for system structure presentation named *Relation Browser*. It shows the relations between parameters and elements dimensions. The relation browser dependences are presented on Fig. 5. Relations are specified in Table 1. For example the notation like: TL1="KR"::KR4-0.5 says that element TL first dimension (TL1) is equal to dimension of element KR minus 0.5 [mm].

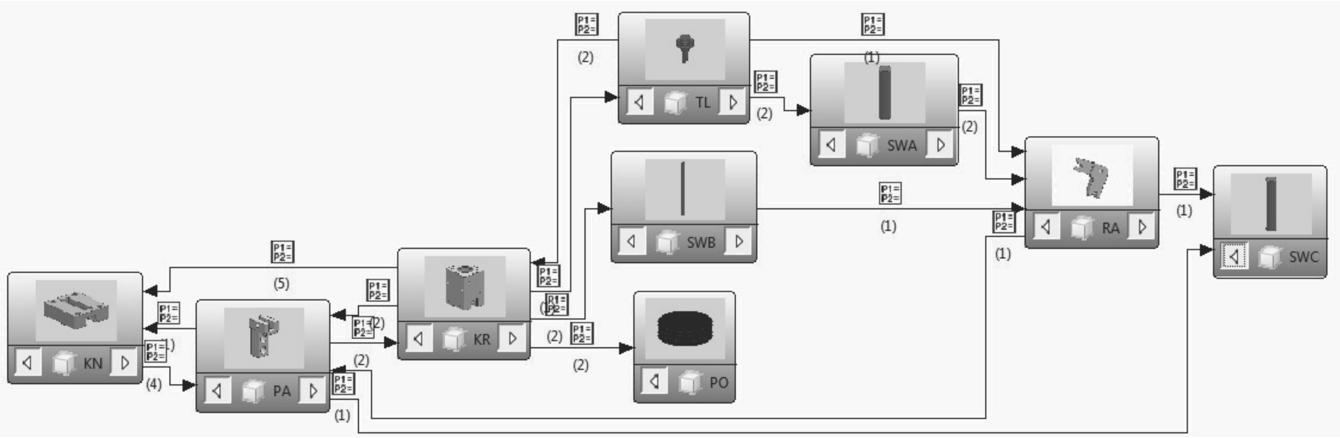

Fig. 5. Model of choosing the quantitative constructional features

Table 1.
Relations between element dimensions

No.	Coupling relation	Overriding element	Subordinate element	Overriding element dimension
1	TL1="KR"::KR4-0.5	KR	TL	KR4
2	SWC2="PA"::PA1	PA	SWC	PA1
3	SWC1="RA"::RA5	RA	SWC	RA5
4	SWB2=KR::KR2	KR	SWB	KR2
5	SWA2=TL::TL3*2	TL	SWA	TL3
6	SWA1=TL::TL10	TL	SWA	TL10
7	SBW1=KR::KR22	KR	SWB	KR22
8	RA7=TL::TL8	TL	RA	TL8
9	RA4="SWB"::SBW1	SWB	RA	SBW1
10	RA3="SWA"::SWA1	SWA	RA	SWA1
11	PO1=KR::KR36	KR	PO	KR36
12	PO4=KR::KR37 -KR::KR8-KR::KR9	KR	PO	KR37, KR8, KR9
13	PA4="KN"::KN9+1	KN	PA	KN9
14	PA3="KN"::KN7+1	KN	PA	KN7
15	PA2="KN"::KN8	KN	PA	KN8
16	PA1="KN"::KN6	KN	PA	KN6
17	PA11="RA"::RA7	RA	PA	RA7
18	KN2=KR::KR2	KR	KN	KR2
19	KN11="KR"::KR38	KR	KN	KR38
20	KN10="KR"::KR26	KR	KN	KR26

3.3. Constructional similarity conditions

Condition which describes ***physical similarity*** defines the dependency between dimensions values and gripping force (relation R1). This condition comes from pressure equation:

$$p = \frac{F}{A} \tag{22}$$

where:
P – medium pressure [MPa],
F – actuator force [N],
A – piston work area [mm^2].

The piston work area:

$$A = \pi r^2 \tag{23}$$

So:

$$p = \frac{F}{\pi r^2} \tag{24}$$

The constructional similarity condition (constant pressure):

$$\frac{\varphi_F^p}{\left(\varphi_r^p\right)^2} = 1 \tag{25}$$

The dependency between piston diameter and force is square.

The condition which comes from strength similarity said that strength in whole series of types is the same. In this case the arm RA is verified due to bending. So the tension is [9]:

$$\sigma_g = \frac{M_g}{W_x} \le k_g \tag{26}$$

If the cross section is rectangle and if:

$$M_g = F \cdot l \tag{27}$$

where:

l – arm of force [mm],

So:

$$\sigma_g = \frac{6Fl}{bh^2} \le k_g \tag{27}$$

The constructional similarity condition:

$$\frac{\varphi_F^w \varphi_l^w}{\varphi_b^w \left(\varphi_h^w\right)^2 \varphi_{kg}} = 1 \tag{28}$$

After substitute equation (25) into (28)

$$\frac{\left(\varphi_r^p\right)^2 \varphi_l^w}{\varphi_b^w \left(\varphi_h^w\right)^2 \varphi_{kg}} = 1 \tag{29}$$

If the material is the same $\left(\varphi_{kg} = 1\right)$ the equation (29) said that diameter value and the gripping force is increasing. The strength ratio is increasing too so the constancy of strength is conserved

3.4. Finite Element Analysis. Mesh adaptation and optimization

The gripper arm was analyzed. The verification showed that stress exceeds 1000 MPa. To decrease this value the end radius value of the arm has been changed to maximum. The maximum value comes from geometrical operators. Then the mesh was manually adopted to load state. The estimated error of FEM was 4,5%. In the next step the mesh was automatically adopted to load state by *Adaptivity* NX tool. The new error was 2,17% (Fig. 6).

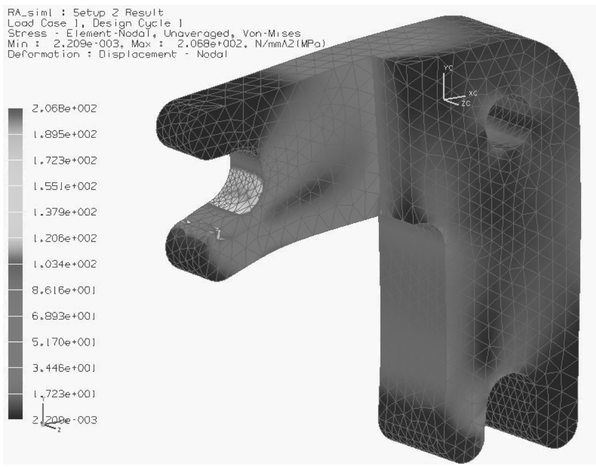

Fig. 6. Model of choosing the quantitative constructional features

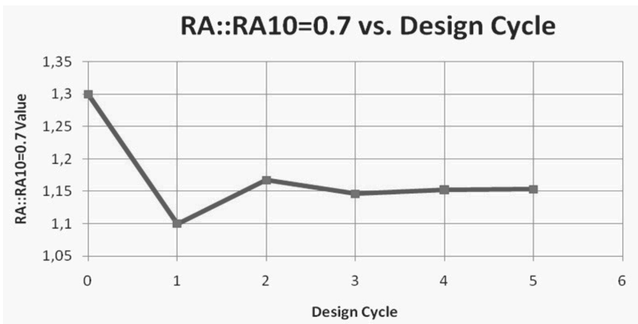

Fig. 7. Iterations of radius optimization process

Finally the end radius value of arm (named RA10) was optimized by *Optimization* NX tool. The results are shown on Fig. 7.

Table 2.
The radius values of arms

	-4	-2	0	2	4
RA10 [mm]	0,71	0,9	1,3	1,6	2,0
Stress [MPa]	234,4	229,2	206,8	194,2	223,2

The other arms in series of types were analized (Table 2.)

3.5. The parameters unification process

Final construction attributes selection process was parameters unification. The parameters of gripper are (Table 3.):

- minimum gripping range,
- maximum gripping range,
- finger stroke,
- gripping force.

Table 3.
Unified parameters values

Size	φ	Min. range [mm]	Max. range [mm]	Finger stroke [mm]	Gripping force [N] $\varphi^{(2*n)}$
-4	φ^{-4}	16.00	24	4,00	80.00
-2	φ^{-2}	20.00	30	5.00	125.00
0	φ^{0}	25.00	37.6	6.30	200.00
2	φ^{2}	31.5	47.5	8	315.00
4	φ^{4}	40	60	10	500.00

To reach those values the simple linear equations were defined. That formulas set together dimension values of gripper elements.

3.6. Grippers series of types

Based on presented models of construction attributes the selection the complete series of types was generated (Fig. 8).

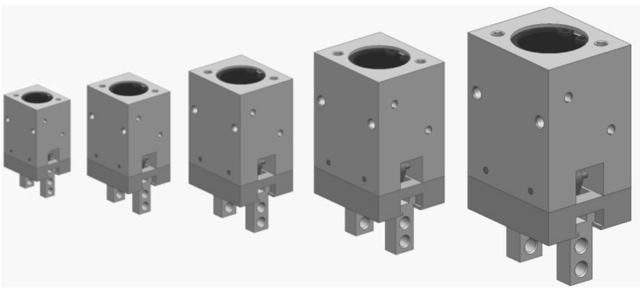

Fig. 8. Grippers series of types

4. Conclusions

Elaborating methods of the transformation from extensive to the intensive ways of develop is important in modern market. They allow selecting construction attributes in reference to the vector of needs very accurately. The four main models were distinguished: traditional model, constructional similarity model, algorithmic model and neural networks model.

Each of them has advantages and disadvantages.

Traditional model is in common use. It is applicable for well known areas. Based on the experts it gives accurate results. But for new or very complicated constructions the second, constructional similarity model, will be more appropriate. In connection with algorithmic model gives very powerful tool to select the construction attributes. The accuracy of last, neural network, work results vary of neural network quality.

Acknowledgements

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