Problems of Developing the Model of Class of Objects in Intelligent CAD of Gearbox Systems

O. Malina

Abstract The paper considers the main principles and methods for development of the model for the class of complex objects through the example of a gearbox. This model allows for applying it as the informational foundation of the design system for samples of the class of objects.

Keywords Complex object · Principle of modularity · Principle of emergency · Principle of sufficiency · Graph model · Methods for development of the generalized model: graph · Table · Graph-table · Matrix · Phantom

1 Introduction

The processing and analysis of complex technical objects are problems with which design engineers are faced. These problems require special solutions in each individual case. As a rule, the initial problems arise when attempting to describe the structure (inner structure of the object) and interaction of individual elements of the complex object, which is not divided into the simplest components at its very first iteration. ***The complex object*** is the object consisting of the set of interacting elements due to which the object acquires unique properties, characteristics, and functions that are directly related to the set of initial elements. The complete representation of the complex object is formed not only through the list of its elements, but also through the description of relations between elements and such characteristics as the layout of elements, the production material, etc.

O. Malina (✉)
Kalashnikov Izhevsk State Technical University, Izhevsk, Russia
e-mail: malina_0705@mail.ru

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2 Principles of Description for a Complex Object

Elements of the complex object can be complex objects themselves; in such a case, one should talk about the modular organization of the parent complex object. The guarantee of a correct description of any complex object is obedience to the basic rules that allow for formalizing the object, which are stated as principles [1]. As stated above, complex mechanical objects (such as the gearbox) are described through application of the **principle of modularity** when functionally-related parts are grouped into larger unities—nodes. Modular representation of technical objects that are complex systems allows for describing their organization, accounting for participation of one element of the object in the composition of other structures. This is of crucial importance, since, in accordance with **the principle of emergency**, the properties and characteristics of final elements cannot be attributed to "the maternal" structure, as it possesses unique properties that are not inherent to its component objects.

Complex systems differ by the varieties of their inner organization. In accordance with their structure, complex systems are divided into: structured (represented by hierarchic, cluster, mixed-type structures) and non-structured. It is possible to relate the gearbox, or, to be more exact, its layout, to the class of hierarchic systems by applying the principles of decomposition and composition. They allow the design engineer not only to determine the direction of analysis (that is, decomposing the product into units, sub-units, assembled units, assembled sub-units, parts and their surfaces), but also to check the correctness of the performed decomposition.

Formalization of the real object requires determination of the necessary and sufficient degree of specification of description and division into elements. Furthermore, it influences the efficiency of operation of the system of computer-aided design as a whole. The necessary degree of specification for describing the object is determined by **principles of sufficiency and necessity** (**principle of sufficient foundation**).

The principle of sufficient foundation is one of the main principles of the description of complex systems, since it regulates the completeness of information of systems. In accordance with this principle, description of the layout of the object allows for creating such a model of the object of mechanical engineering that accounts for all the features that distinguish the considered object from variations of its layout version.

However, this principle only demonstrates the reasonable description of the object. In our case, this principle should be used with refinement and restrictions on two ends: the maximum description (no greater is needed) and a limiting minimum (no less is allowed). Let us call such a differentiation **the principle of sufficiency from above and the principle of sufficiency from below**.

Meeting the requirement of sufficiency from above allows us to avoid the application of inessential principles of describing the object in regard to features, characteristics, parameters, modules that unreasonably widen the information database of the classifier. One can relate here the specification of the structure, for example, standard parts (such as bearings or threaded surfaces). Sufficiency from below regulates the minimum volume of information about the object, which allows for identifying it unambiguously among similar objects and obtaining the complete representation of their inner organization. Therefore, due to application of the pointed principles of sufficiency, the optimal balanced state of the system is achieved and its function and productivity are maximized.

3 Order of Description for the Design Solution

It is evident from that stated above that description of the structure of the individual complex technical object is the revelation of features of its division into simpler modules and plotting of the "skeleton" of the layout into a united hierarchical tree-type structure; it is also the establishment of layout features and the characteristics of modules [2].

Plotting the skeleton is the process of step-by-step division of the layout into structure-forming modules in accordance with the practice of design engineering activity. Thus, the spiroid gearbox is decomposed into the gearwheel unit, the worm unit, and the casing unit (Fig. 1).

All elements are inter-related by links that indicate the hierarchy of the elements between each other (Fig. 1).

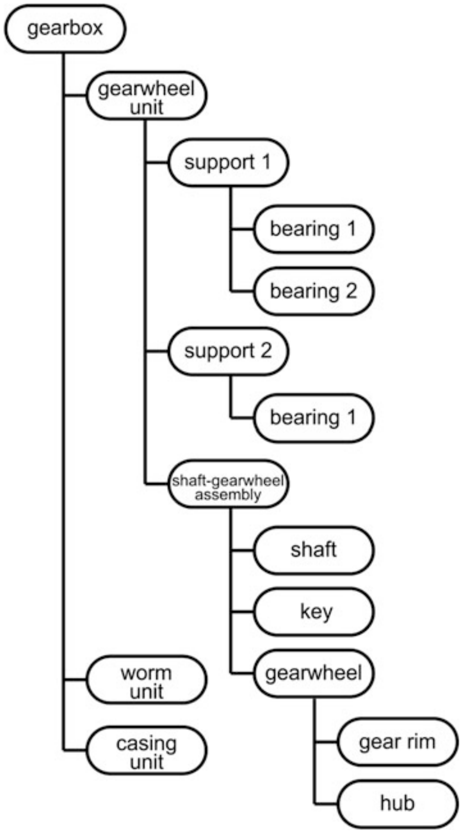
Therefore, the process of decomposition of the object is advanced from above (from the complex one) downwards (to the simpler one).

The next step in describing the object is the characterization, that is, separation, of specific features, namely characteristics that are inherent to modules of the object. Only an account of the characteristics of modules, along with the structural skeleton, gives us a structurally complete description of the object (Figs. 2, 3 and 4).

Revelation and description of characteristics is a complex process, since it requires analysis of the relevance of each characteristic. Among the whole set of potential characteristics, one should separate only those that are valuable and essential for the design process. Especially valuable characteristics are those that distinguish one object from another. The structure of the characteristic contains two fields: statement of the feature and the value of this feature that is inherent to this version of the module of the object. For example, the characteristic of the gearbox "gear ratio—50" consists of the feature "gear ratio" and the value "50".

During analysis of existing features as components of characteristics, the principle possibility of their uniting into groups has been revealed. Each of the five groups of features describes an independent area of the qualities of the object and its components. The first group involves characteristics of the mutual arrangement of objects with respect to each other. For example, supports of the gearwheel unit are separated. The second group is formed by parameters of manufacturing peculiarities or the manner of operation of functional structure-forming modules. The examples of such characteristics are versions of the assembly of the gearwheel and the shaft

Fig. 1 Version of decomposition of the spiroid gearbox layout (fragment) for structure-forming modules



(press-fit or with the key). The third group describes the material of the module: aluminum, alloys, wood, plastics, etc. The fourth group involves parameters of the shape. The fifth and final group comprises quantitative characteristics: diameter of the gearwheel, 50 mm, gear ratio, 63, etc.

Note here that this classification of features only addresses the design problem. When developing the model of the class of objects to solve other problems, for instance, to implement the complete cycle of product repair, it can be necessary to know the manufacturers, suppliers or testing information for individual parts within the layout analysis.

Both structure-forming modules and their corresponding characteristics are inter-related by unidirectional links. The following types of links are present here: those between structure-forming modules and characteristics and those between characteristics and characteristics. The latter type of relation appears when the value of the characteristic is refined by additional information, for instance: the module is "spiroid gearwheel," the module characteristic is "material—bronze," the description of the characteristic is "temperature of the material melting."

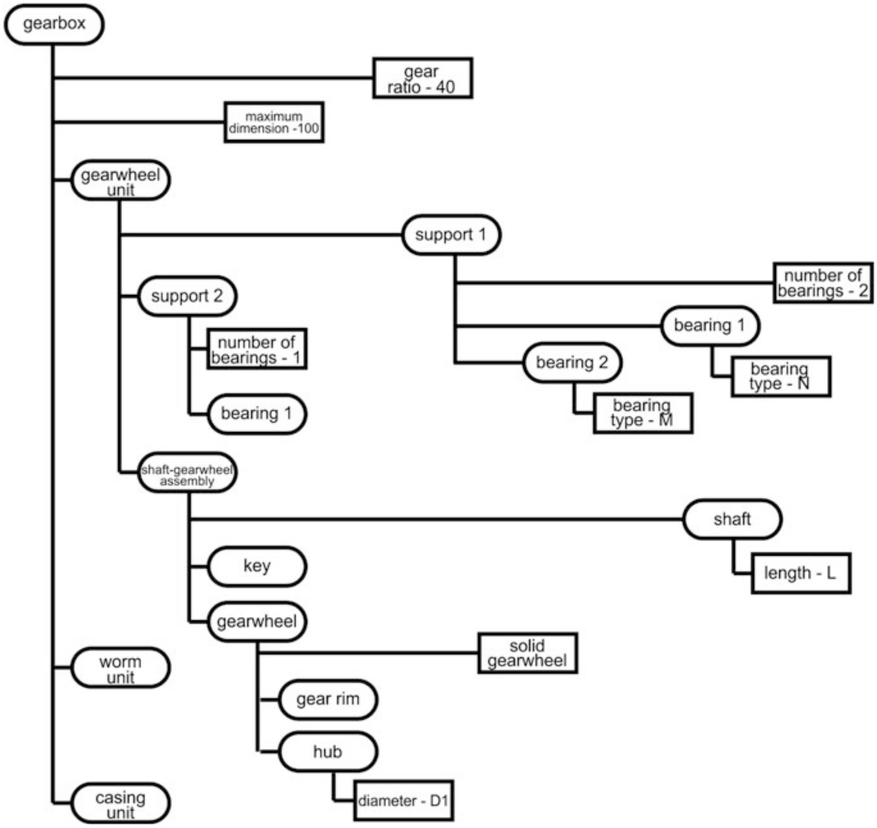


Fig. 2 Graph of decomposition of the 1st version of the spiroid gearbox layout (fragment)

Such a characteristic can be timely if the extreme conditions of the object's operation need to be taken into account.

The obtained models have a hierarchic structure.

4 Basic Background for Development of the Generalized Model

However, the description of individual objects does not have any practical importance without information on the whole class of objects through generalization of the information on its separate representatives. When comparing the description of individual structures that have been previously obtained and when generalizing the information on the structure and its design features and

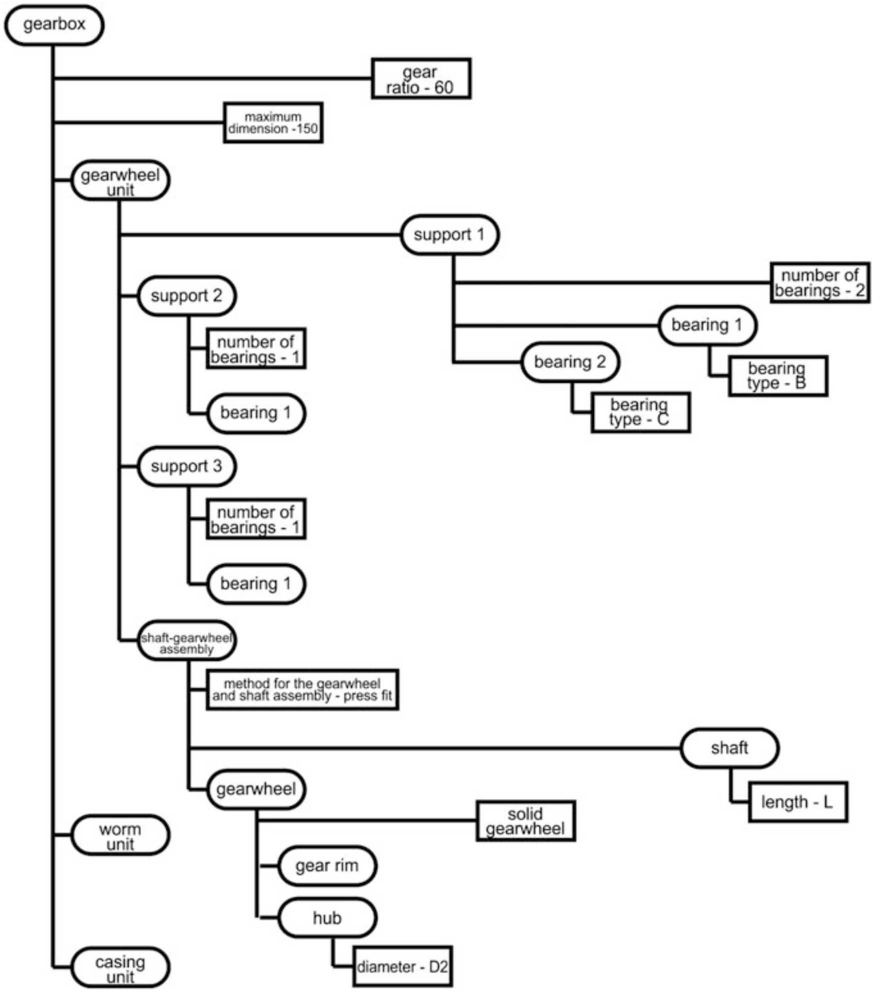


Fig. 3 Graph of decomposition of the 2nd version of the spiroid gearbox layout (fragment)

characteristics, one can obtain representation of essential distinctions between assorted technical solutions for one class of objects.

There are three principle types of distinction:

(a) for the set of structure-forming modules (units, assemblies, parts): presence/absence of a certain module with/without its substitution with the analog;
(b) for the set of characteristics that provide the structural completeness: presence/absence of a characteristic in the part of the feature, different values of characteristics in the part of the value.

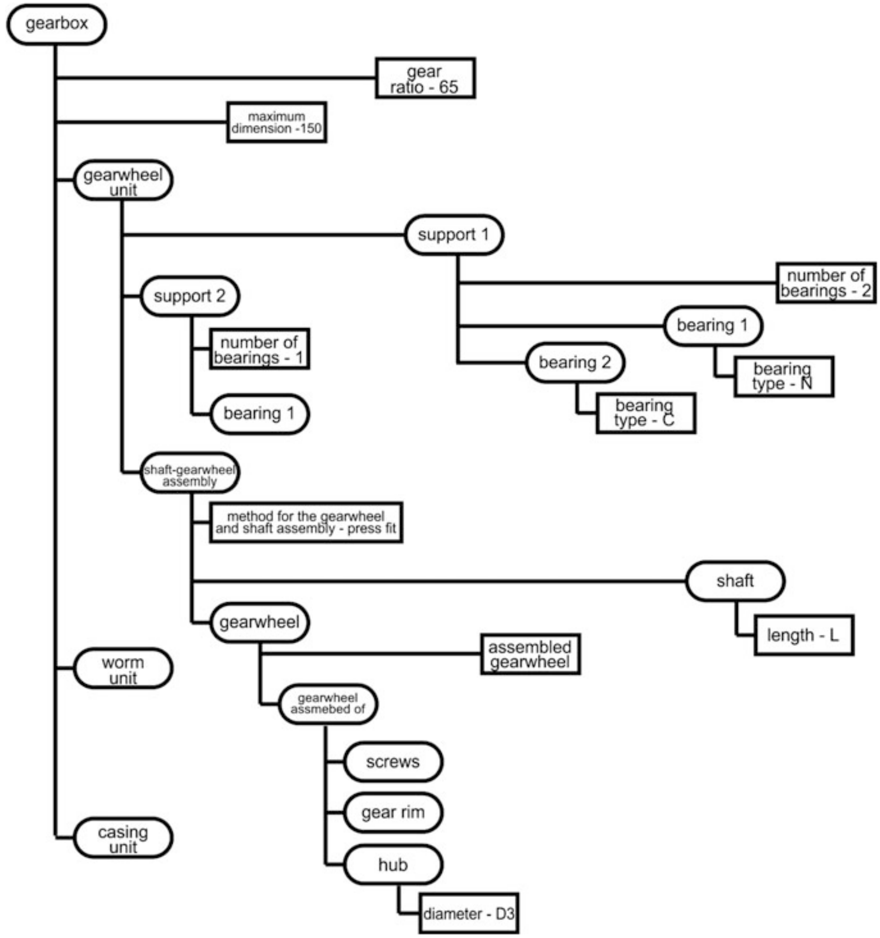


Fig. 4 Graph of decomposition of the 3rd version of the spiroid gearbox layout (fragment)

(c) for the set of links: presence/absence of the link.

The types of distinction considered allow for concluding that the structure of the model comprises both obligatory (always present in any version of the layout) and optional elements, their presence and character determining the different versions of one object within the class.

In accordance with the principle of inheritance of optionality, this optionality, in turn, may have a different character:

– with regard to the model as a whole;
– with regard to the maternal vertex in the hierarchical structure.

Optionality of the element with regard to the model as a whole indicates its alternative character within one class (it can be absent in certain versions of the layout).

Such optionality is passed down from the maternal vertex to its descendants.

Optionality with regards to the maternal vertex indicates that, moving along the model from the root downwards through this vertex within the given module, the change in character from obligatory to optional is possible.

It is important to keep this exact information about these elements in the generalized model of the class of objects. It is desirable here that the generalized model possess a tree-type structure to maintain the principle of inheritance of optionality.

When developing the algorithm of such a generalized model, one should consider that it must allow for solving the following assignments:

1. Generalization of all available information about many objects of the given class;
2. Widening of the existing model without change in the concept of its structure;
3. Generation of new information as the result of analysis of data present in the model (synthesis).

One such algorithm has been proposed in works by Polovinkin [3]. His model is based on representation of information on prototypes or known technical solutions as an “AND-OR” tree (“AND-OR” graph) in which functional modules that are at the same level and components of one functional module of a higher order are united by the operation “AND”; and modules and characteristics that are alternative (interchangeable) with respect to each other are united by means of the vertex “OR,” shown in the form of rectangles (Fig. 5).

In order to synthesize a new layout of the object, it is necessary to move from the root vertex along all links united by vertexes “AND” by choosing an alternative version at each vertex “OR.” In addition, checking the choice of the correct alternative is also necessary. In practice, implementation of such an algorithm of synthesis is complicated by the necessity to traverse a tree-type structure with an unlimited number of branches. The problem of keeping the tree-type structure also arises in cases when, for different technical solutions, one and the same module is related to different maternal vertexes that can be both hierarchically dependent upon and hierarchically independent of each other.

5 Graph Method for Development of the Generalized Model

To solve the problem of traversing the tree-type structure, an approach to organization of the model for generalization has been changed. It has been proposed by Malina [4, 5] that the “OR” vertex only be applied for uniting characteristics of modules, rather than the modules themselves. In this model, the characteristic has

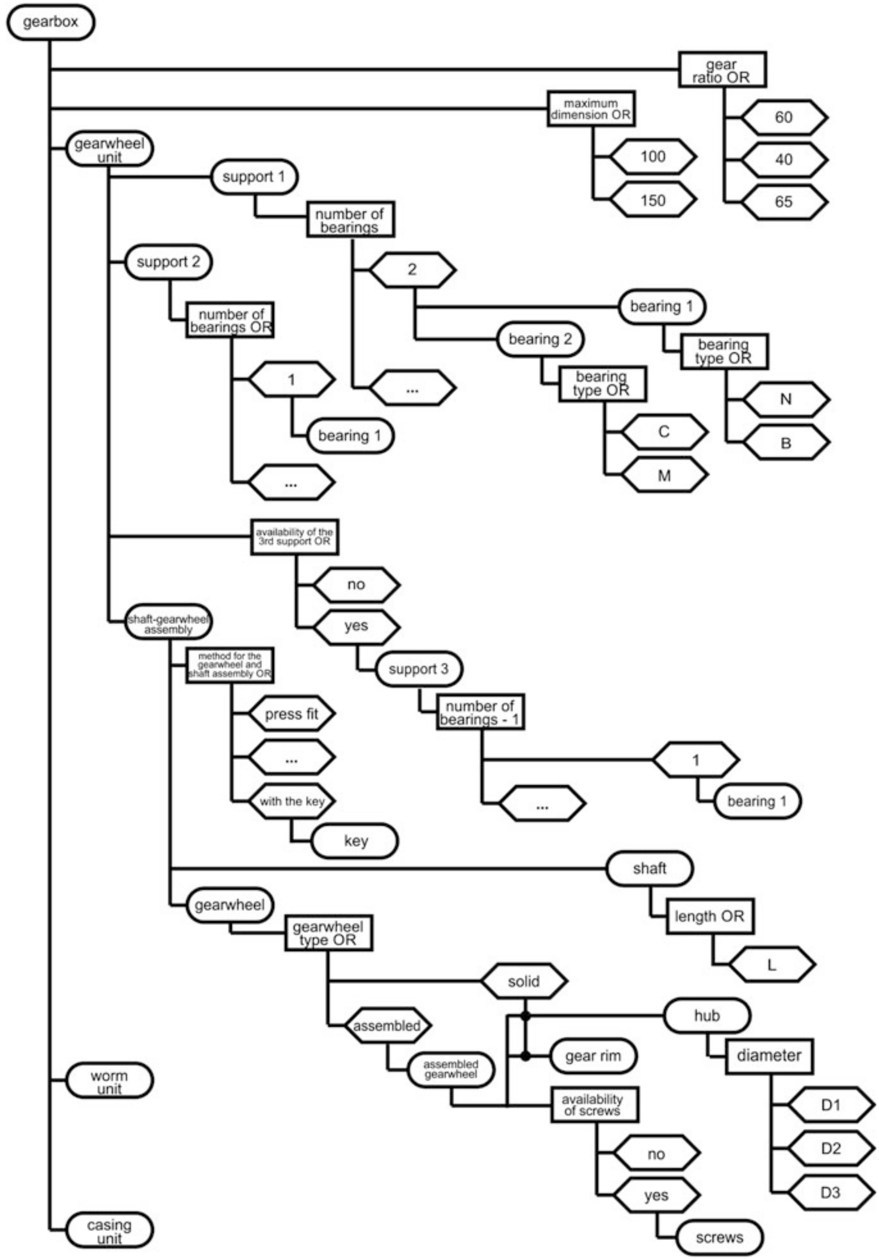


Fig. 5 The generalized "AND-OR" graph designed on the basis of the above-considered versions

been structurally decomposed into individual fields: the “OR” vertex designates the feature to which the values are related.

The proposed graph method for developing the generalized model implies the logical superposition (composition) of graphs of individual decompositions in order to obtain the unified graph that contains all vertexes of graphs and considers all relations between modules that have been called functional vertexes. The algorithm for obtaining the generalized graph is given below:

1. Graphs of individual versions of layouts are united and the graph is obtained having all vertexes and all links of the initial graphs (Fig. 6).
2. All vertexes that conform to characteristics and the corresponding links to these vertexes are eliminated from the obtained graph (Fig. 7).
3. Maintenance of the tree-type structure of the obtained graph is checked. If the tree-type structure is broken, that is, one daughter vertex has several maternal vertexes, the graph is upgraded: phantom structures are introduced. In practice, this means doubling the sub-trees of the daughter vertex in order to recover the tree-type structure (Fig. 8).
4. Each vertex is checked for its presence in all initial graphs. If it is absent, the feature (“OR” vertex) is generated at the maternal vertex with the statement “availability of the daughter vertex” and with two values “yes” and “no”; this daughter vertex is then marked with the attribute “optional—A.” The same is done if the vertex that is present in all initial graphs is accepted as being optional by the expert.
5. For each functional vertex, alternative values of characteristics are considered. The feature meeting the corresponding field of the characteristics and values is generated at the functional vertex in this case. If not all initial graphs involved the characteristic with the pointed feature, the number of alternatives of the feature is supplemented with the “NILL” vertex; it designates the presence of the imaginary alternative.
6. “NILL” vertexes are added as values of all features of all functional vertexes accepted as being alternative ones.

“OR” vertexes that unite the alternatives allow for generating the set of features and their values (Fig. 9).

The set of features that are generated in accordance with the graph model will have the following character (Table 1). Features p13 and p14 are in italics, because they are obtained from the part of the graph structure, where the tree-type character is broken.

In this case, the process of synthesis can be considered as a Cartesian multiplication of all features with consequent analysis of the correctness of the sets.

It is possible to widen the scope of information resulting from expert survey by answering the questions stated in regard to features with obtainment of new values. The problem of breaking the tree-type structure does not influence the synthesis process, since the synthesis is not related to traversal of the tree. The drawback of the pointed approach is the complexity of the analysis, the need to account for alternative characteristics, and the presence of doubled features of phantom structures.

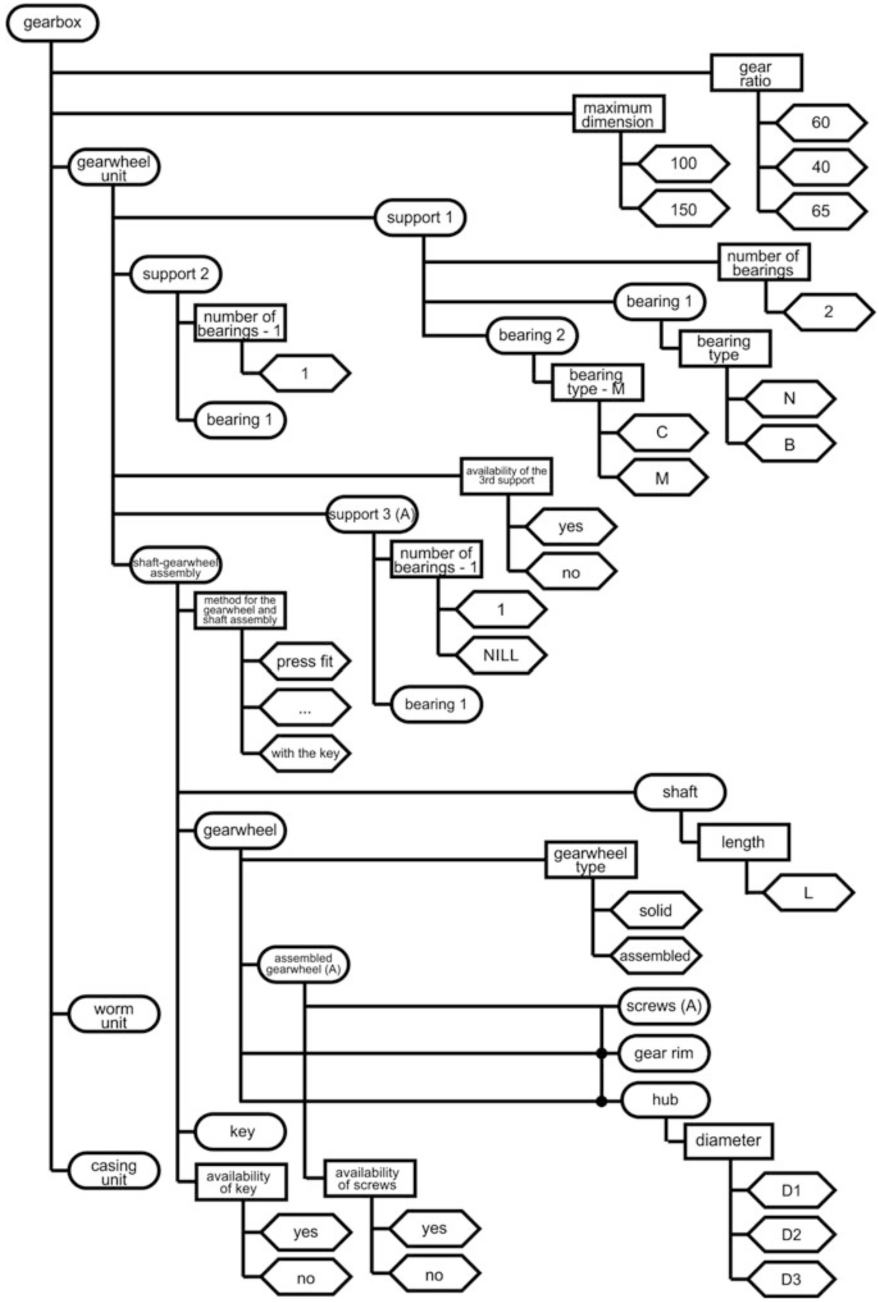


Fig. 6 Result of the 1st step of development of the generalized model

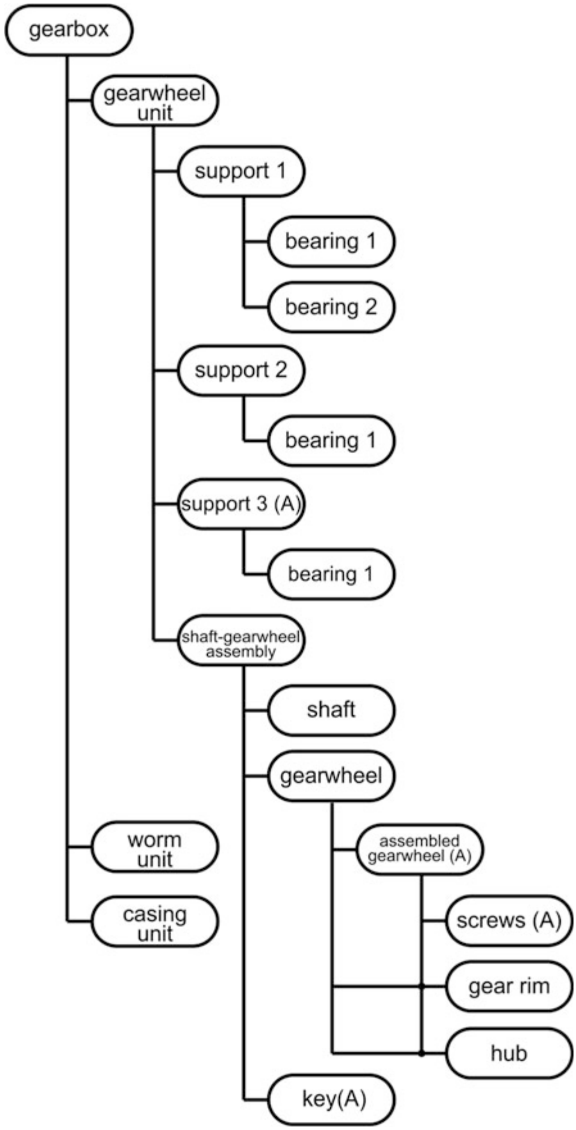
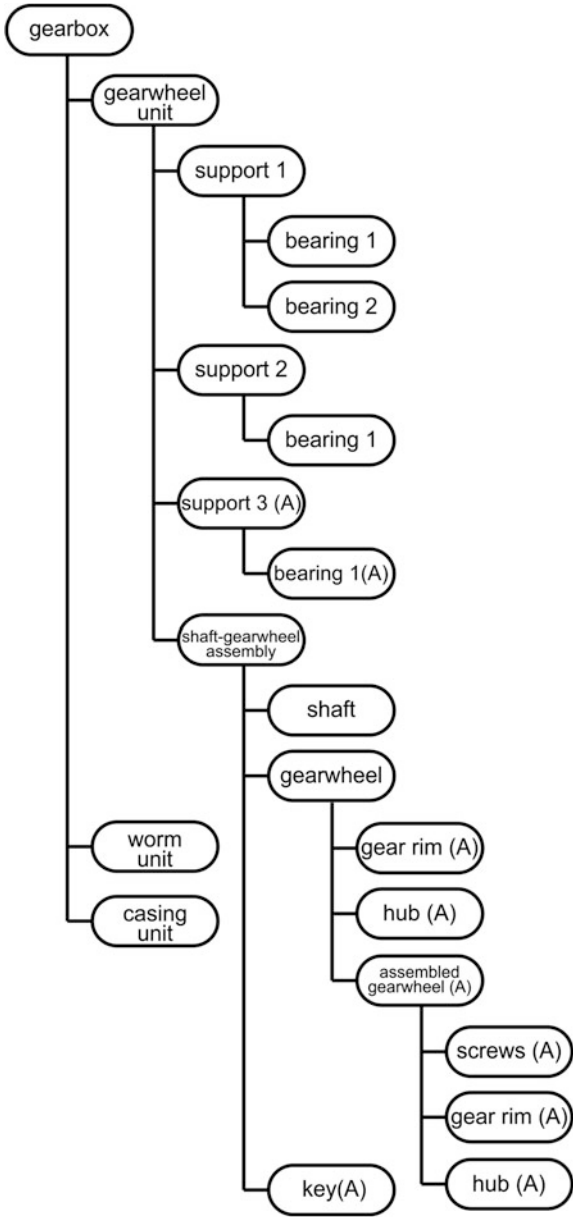


Fig. 7 Result of the 2nd step of development of the generalized model

6 Table Method for Developing the Generalized Model

The table method allows for generalizing the characteristics of the functional vertexes described in decompositions of samples of objects. In this case, the generalized model is represented as a table in which all vertexes of the generalized graph

Fig. 8 Result of the 3rd step of development of the generalized model



model and their related characteristics are written down. The complete set of characteristics for each vertex is accumulated here as the result of knowledge of the generalization of this vertex in the graph model and generalization of the sets of characteristics of all decompositions.

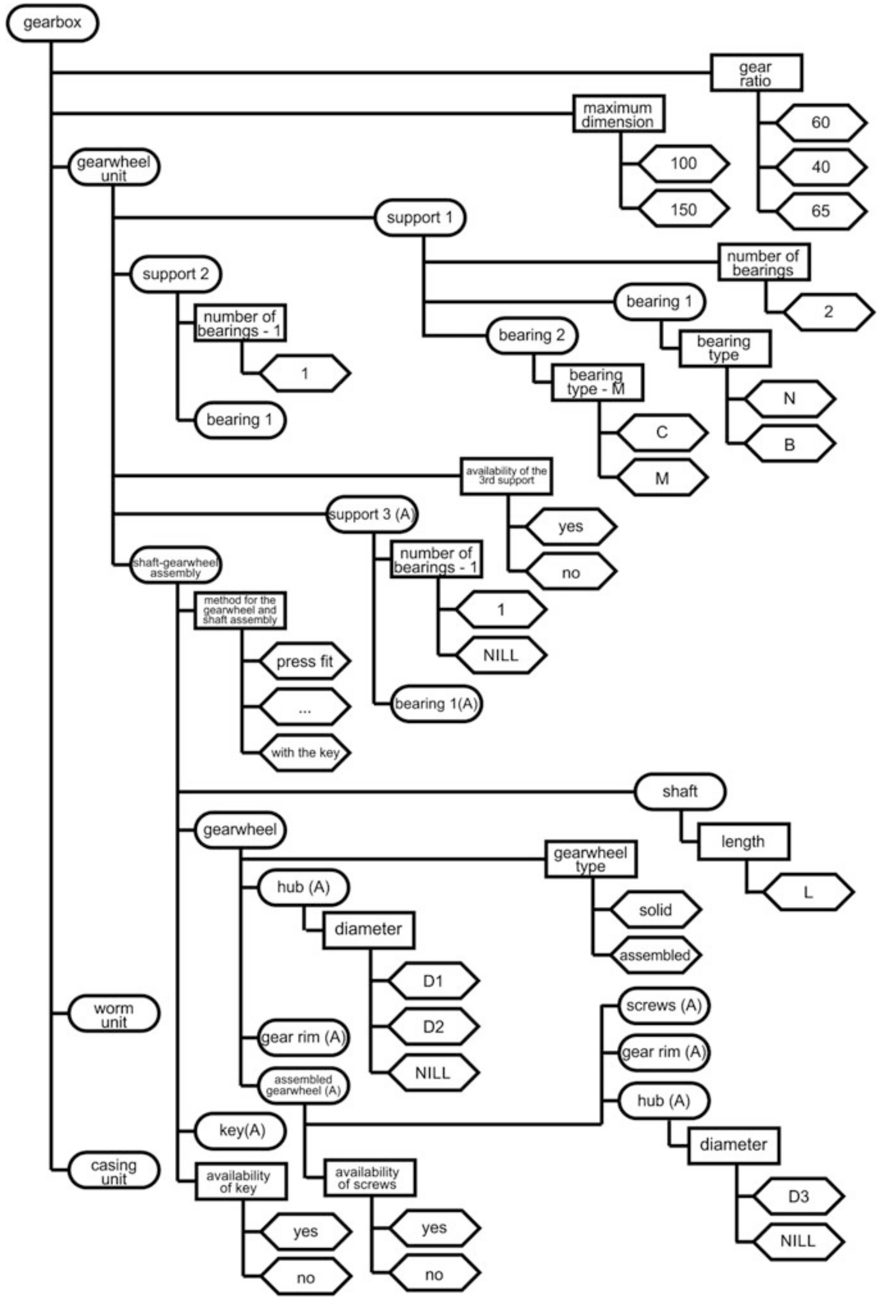


Fig. 9 The generalized graph model of the class of spiroid gearboxes (fragment)

Table 1 The set of features generated by the graph method

Functional vertex	Feature		Values	
Gearbox	Gear ratio	p1	60	a11
			40	a12
			65	a13
			Other	–
	Overall dimension	p2	100	a21
			150	a22
			Other	–
Support 1	Number of bearings	p3	2	a31
			Other	–
Bearing 1	Type of bearing	p4	N	a41
			B	a42
			Other	–
Bearing 2	Type of bearing	p5	M	a51
			C	a52
			Other	–
Support 2	Number of bearings	p6	1	a61
			Other	–
Gearwheel unit	Availability of the 3rd support	p7	Yes	a71
			No	a72
Support 3	Number of bearings	p8	1	a81
			Other	–
			NILL	a82
Shaft-gearwheel assembly	Method for the gearwheel and shaft assembly	p9	Press-fit	a91
			With the key	a92
			Other	–
	Availability of the key	p10	Yes	a101
			No	a102
Shaft of the gearwheel unit	Length	p11	L	a111
			Other	a112
Gearwheel	Type of the gearwheel	p12	Solid	a121
			Assembled	a122
Gearwheel hub	*Diameter*	*p13*	D1	a131
			D2	a132
			NILL	a133
			Other	–
Assembled gearwheel hub	*Diameter*	*p14*	D3	a141
			NILL	a142
			Other	–
Assembled gearwheel	Availability of screws	p15	Yes	a151
			No	a152

The resulting table can be obtained using the following steps:

1. The set of unique functional vertexes of the class of objects is generated by uniting the sets of functional vertexes of individual versions of layouts (decompositions);
2. Each vertex of the set is considered separately, having preliminarily been added to the set of unique functional vertexes. Then, all copies of this vertex are searched for in the set, the copies probably being available in other decompositions, in accordance with the comparability mark, name and functional purpose. After that, the found vertex and the vertex of the search are marked as those considered within this analysis.
3. Each line of the table is correlated with the identifying number and name of the functional vertex of the set; and each column of the table is correlated with the decomposition of the object as its identifying number.
4. For each set of the table, the identifying number and the value of the characteristic are fixed, being correspondent to the version of the layout (decomposition) and to the considered functional vertex. The identifying number of the characteristics is represented by the line «X.Y.Z», where X is the identifying number of the functional vertex, Y is the identifying number of the version of the layout (decomposition), and Z is the number of the group of alternative (correlated) characteristics. The choice of alternative characteristics is made through comparison of categories.
5. In case of the absence of a characteristic of the Z group for the X vertex of any of the graphs Y, the number below «X.Y.Z» should be written as NILL.

The specific value of the feature is chosen according to rules similar to those for developing the graph-generalized model.

Let us consider implementation of the table method with regard to the previously proposed example (Table 2).

After processing the obtained table, the following set of features is obtained (Table 3).

The comparative analysis shows that after applying the table method, features 7, 10, 14 and 15 are excluded from the set of features.

The disappearance of feature 14 has a favorable affect on the generalized model: there is no loss of data. Disappearance of features 7, 10 and 15 complicates the process of studying the obligatory character of vertexes.

7 Graph-Table Method

When analyzing and comparing the graph and table methods, their advantages and drawbacks become evident. The graph method is complicated by the necessity to analyze whether each vertex of the generalized model belongs in each of the individually-considered decompositions in order to reveal the optionality of the

Table 2 Summary table for description of versions of spiroid gearbox layouts (fragment)

No.	Functional vertex	1st graph		2nd graph		3rd graph	
1	Gearbox	1.1.1	Gear ratio—40	1.2.1	Gear ratio—60	1.3.1	Gear ratio—65
		1.1.2	Overall dimension—100	1.2.2	Overall dimension—150	1.3.2	Overall dimension—150
2	Gearwheel unit	2.1.1		2.2.1		2.3.1	
3	Support 1 of the gearwheel unit	3.1.1	Number of bearings—2	3.2.1	Number of bearings—2	3.3.1	Number of bearings—2
4	Bearing 1 of the support 1	4.1.1	Type of bearing—N	4.2.1	Type of bearing—B	4.3.1	Type of bearing—N
5	Bearing 2 of the support 1	5.1.1	Type of bearing—M	5.2.1	Type of bearing—C	5.3.1	Type of bearing—C
6	Support 2 of the gearwheel unit	6.1.1	Number of bearings—1	6.2.1	Number of bearings—1	6.3.1	Number of bearings—1
7	Bearing 1 of the support 2	7.1.1		7.2.1		7.3.1	
8	Support 3 of the gearwheel unit		NILL	8.2.1	Number of bearings—1		NILL
9	Bearing 1 of the support 3			9.2.1			
10	Shaft-gearwheel assembly	10.1.1	Method for assembly—not indicated	10.2.1	Method for assembly—press-fit	10.3.1	Method for assembly—press-fit
11	Shaft	11.1.1	L	11.2.1	L	11.3.1	L
12	Key	12.1.1					
13	Gearwheel	13.1.1	Type of gearwheel—solid	13.2.1	Type of gearwheel—solid	13.3.1	Type of gearwheel—assembled
14	Assembled gearwheel					14.3.1	
15	Screws					15.3.1	
16	Gear rim	16.1.1		16.2.1		16.3.1	
17	Gear hub	17.1.1	Diameter—D1	17.2.1	Diameter—D2	17.3.1	Diameter—D3

Table 3 The set of features generated by the table method

Functional vertex	Feature		Values	
Gearbox	Gear ratio	p1	60	a11
			40	a12
			65	a13
			Other	–
	Overall dimension	p2	100	a21
			150	a22
			Other	–
Support 1	Number of bearings	p3	2	a31
			Other	–
Bearing 1	Type of bearing	p4	N	a41
			B	a42
			Other	–
Bearing 2	Type of bearing	p5	M	a51
			C	a52
			Other	–
Support 2	Number of bearings	p6	1	a61
			Other	–
Support 3	Number of bearings	p8	1	a81
			Other	–
			NILL	a82
Shaft-gearwheel assembly	Method for the gearwheel and shaft assembly	p9	Press-fit	a91
			With the key	a92
			Other	–
Shaft of the gearwheel unit	Length	p11	L	a111
			Other	a112
Gearwheel	Type of gearwheel	p12	Solid	a121
			Assembled	a122
Gearwheel hub	Diameter	p13	D1	a131
			D2	a132
			NILL	a133
			Other	–

vertex and need for use of the NILL mark. The table method easily allows for revealing the necessity of using the optionality NILL marks, but is harder in regard to following the hierarchic links between elements of the generalized graph in order to form the “availability of the optional vertex” feature.

Accounting for the advantages and drawbacks of both methods, a hybrid graph-table method for developing the generalized model has been designed. Application of the graph within this method is stipulated by visualization of representing the structure of the object accounting for all hierarchic links between its vertexes, revelation of the connection component, the obligatory component of the graph, and vertexes that are alternative to each other. The table method is convenient for processing the characteristics of objects and revealing the necessity to use the optionality NILL mark, the character of which is specified by the graph. The table method does not require analysis of the presence of the functional vertex in each considered decomposition.

The algorithm for developing the generalized model by means of the graph-table method is given below.

1. Graphs of individual versions of layouts are united and the graph is obtained that has all the vertexes and links of the initial graphs.
2. All vertexes corresponding to the characteristics and the correlated links to these vertexes are excluded from the obtained graph.
3. Each vertex is checked for its presence in all initial graphs. If it is absent, the feature ("OR" vertex) is formed at the maternal vertex with the statement "availability of the daughter feature" and with two values "yes" and "no"; this daughter vertex is then marked with the attribute "optional—A." If there are several maternal vertexes, the feature "availability …" is characterized at each maternal vertex. The same is done if the vertex that is present in all initial graphs is accepted as being optional by the expert.
4. For each vertex, an individual table is developed in accordance with the table principle of the model formation.

The pointed approach allows for not losing the features' "availability," thus simplifying the process of inheriting the optionality, as well as simplifying other features due to the ease of the table comparison.

8 Matrix Method

The graph-table method allows for developing the generalized model of the class of objects; however, it is rather bulky from the generalization point of view: graphs need to be visually compared, and at large numbers of decomposition, they require considerable effort for generalization. The table method is also rather bulky and it is not visual without its relation to the graph. The proposed matrix method [6] essentially simplifies the process of generalization of decompositions into a single model, revelation of pseudo-obligatory, non-obligatory components of the generalized graph and, use of the optionality NILL marks.

In order to describe each individual sample of the class of objects, the adjacency matrix is used; it is "… the rectangular matrix, each line of which corresponds to the neighboring node of the net, and each column corresponds to its attributed resource. The record arranged at intersection of the column and the line indicates the type of access to the resource provided by the given node" [7]. In our case, the line corresponds to the maternal vertex and the column corresponds to the daughter;

and the factor "1" is indicated at the intersection, that is, it is the presence of the link between them.

In order to form the matrix, let us use the previously considered example, in which all the functional vertexes have already been revealed and enumerated (Table 4).

On the basis of the obtained matrices (Figs. 10, 11 and 12), the summary matrix (Fig. 13) is developed by imposing the initial matrices.

The result of summation of the columns allows for drawing a conclusion on the optionality of a portion of the vertexes: vertexes with a sum of corresponding columns less than the number of initial versions are optional.

Therefore, the following features have been stated (Table 5). Features p7, p16, p10 and p15 are in italics, since they appeared only as a result of the matrix method, as compared to Table 3.

The necessity of feature "availability" is determined by the maternal vertex, which has the line with a value different from 0 at the corresponding optional vertex.

The matrix method for development of the generalized model as the set of features is the simplest and most visual one.

Table 4 The list of functional vertexes

No.	Functional vertex
1	Gearbox
2	Gearwheel unit
3	Support 1 of the gearwheel unit
4	Bearing 1 of the support 1
5	Bearing 2 of the support 1
6	Support 2 of the gearwheel unit
7	Bearing 1 of the support 2
8	Support 3 of the gearwheel unit
9	Bearing 1 of the support 3
10	Shaft-gearwheel assembly
11	Shaft
12	Key
13	Gearwheel
14	Assembled gearwheel
15	Screws
16	Gear rim
17	Hub
18	Worm unit
19	Casing unit

Matrix	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1		1																1	1
2			1			1				1									
3				1	1														
4																			
5																			
6							1												
7																			
8																			
9																			
10											1	1	1						
11																			
12																			
13																1	1		
14																			
15																			
16																			
17																			
18																			
19																			
Sum	0	1	1	1	1	1	1	0	0	1	1	1	1	0	0	1	1	1	1

Fig. 10 Matrix of conjugacy of the graph for the 1st version

Matrix	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1		1																1	1
2			1			1		1		1									
3				1	1														
4																			
5																			
6							1												
7																			
8									1										
9																			
10											1		1						
11																			
12																			
13																1	1		
14																			
15																			
16																			
17																			
18																			
19																			
Sum	0	1	1	1	1	1	1	1	1	1	1	0	1	0	0	1	1	1	1

Fig. 11 Matrix of conjugacy of the graph for the 2nd version

Matrix	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1		1																1	1
2			1			1				1									
3				1	1														
4																			
5																			
6							1												
7																			
8																			
9																			
10											1		1						
11																			
12																			
13														1					
14															1	1	1		
15																			
16																			
17																			
18																			
19																			
Sum	0	1	1	1	1	1	1	0	0	1	1	0	1	1	1	1	1	1	1

Fig. 12 Matrix of conjugacy of the graph for the 3rd version

Matrix	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1		3																3	3
2			3			3		1		3									
3				3	3														
4																			
5																			
6							3												
7																			
8									1										
9																			
10											3	1	3						
11																			
12																			
13														1		2	2		
14															1	1	1		
15																			
16																			
17																			
18																			
19																			
Sum	0	3	3	3	3	3	3	1	1	3	3	1	3	1	1	3	3	3	3

Fig. 13 Summary matrix

Table 5 The set of features generated by the matrix method

Functional vertex	Feature		Values	
Gearbox	Gear ratio	p1	60	a11
			40	a12
			65	a13
			Other	–
	Overall dimension	p2	100	a21
			150	a22
			Other	–
Support 1	Number of bearings	p3	2	a31
			Other	–
Bearing 1	Type of bearing	p4	N	a41
			B	a42
			Other	–
Bearing 2	Type of bearing	p5	M	a51
			C	a52
			Other	–
Support 2	Number of bearings	p6	1	a61
			Other	–
Gearwheel unit	*Availability of the 3rd support*	*p7*	*Yes*	*a71*
			No	*a72*
Support 3	Number of bearings	p8	1	a81
			Other	–
			NILL	a82
	Availability of the bearing	*p16*	*Yes*	*a161*
			No	*a162*
Shaft-gearwheel assembly	Method for the gearwheel and shaft assembly	p9	Press-fit	a91
			With the key	a92
			Other	–
	Availability of the key	*p10*	*Yes*	*a101*
			No	*a102*
Shaft of the gearwheel unit	Length	p11	L	a111
			Other	a112
Gearwheel	Type of gearwheel	p12	Solid	a121
			Assembled	a122
Gearwheel shaft	Diameter	p13	D1	a131
			D2	a132
			NILL	a133
			Other	–
Assembled gearwheel hub	Diameter	p14	D3	a141
			NILL	a142
			Other	–
Assembled gearwheel	*Availability of screws*	*p15*	*Yes*	*a151*
			No	*a152*

Investigation of this approach allowed for studying non-standard situations. Let us consider some of them.

9 Optional Vertexes of Group Belonging

Functional vertexes of double necessity are present in the generalized model from the example considered above.

They are the vertexes 16 (gear rim) and 17 (hub). Their double necessity is testified to by the non-empty lines of the matrix in the corresponding columns.

Optionality of the vertex of group necessity is testified to by the presence of several filled lines in the column, the sum value of which is less than the number of initial versions of technical solutions subjected to analysis.

10 Phantoms

A phantom is the vertex of the model that describes the single technical solution with two parent vertexes.

The reason for the appearance of the phantom is the peculiarity of hierarchic decomposition, when one and the same vertex of a lower level is the component of two different modules of a higher level. Thus, in the double-stage gearbox, the shaft of the gearwheel of the first stage is actually the shaft of the worm of the second stage (Fig. 14).

As for the adjacency matrix, the phantom is seen at once; the sum value of its column is greater than 1 (Fig. 15).

The presence of phantoms in the initial version that participates in the synthesis of the generalized model modifies the algorithm for determining the optional elements.

After identification of the phantom in accordance with the matrix, and before uniting this matrix with other matrices to synthesize the generalized model, the initial matrix is modified. Values of 1 in the column corresponding to the phantom are replaced by other positive values different from zero, so that their sum can be equal to 1 (Fig. 16).

11 Conclusions

The considered problems of development of the generalized model and methods for their solution allow for talking about formalization of the stage of preparing the informational support of the structural synthesis of complex objects.

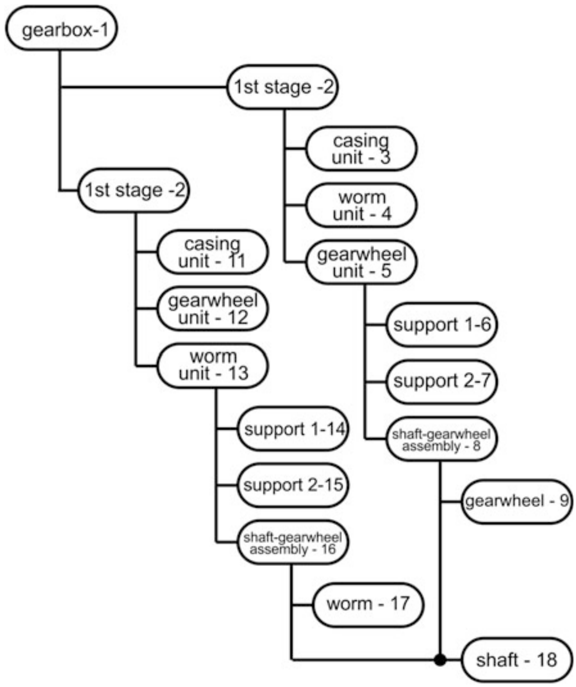


Fig. 14 Graph model of the version that contains the potential phantom

Matrix	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1		1								1								
2			1	1	1													
3																		
4																		
5						1	1	1										
6																		
7																		
8									1									1
9																		
10											1	1	1					
11																		
12																		
13														1	1	1		
14																		
15																		
16																	1	1
17																		
18																		
Sum	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2

Fig. 15 The initial matrix of the version that contains the potential phantom

Matrix	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1		1								1								
2			1	1	1													
3																		
4																		
5						1	1	1										
6																		
7																		
8									1									1
9																		
10											1	1	1					
11																		
12																		
13														1	1	1		
14																		
15																		
16																	1	1
17																		
18																		
Sum	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Fig. 16 Summary matrix of the version that contains the potential phantom

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