SPECIFICITY OF DIMENSIONAL CHAINS SYNTHESIS AND ANALYSIS FOR ASSEMBLED PCM CONSTRUCIONS ACCURACY EVALUATE

Специфика синтеза и анализа размерных цепей для обеспечения точности сборных конструкций из композитных материалов

Specyfika syntezy i analizy łańcuchów wymiarowych dla zapewnienia dokładności konstrukcji montowanych z materiałów kompozytowych

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A b s t r a c t: Approaches of size and accuracy analysis are relevant and universal for complex of ensure constructions at their assembly accuracy and interchangeability tasks decisions. Such approaches are usually based on dimensional chains (DC) theory apparatus, which is sufficiently developed, but, has a number of unsolved problems, such as polymer composites materials (PCM) geometrical parameters accuracy calculation.

Difficulty arises applying above theory, both on DC formation and synthesis stage and on analysis and calculation subsequent stage. There is also a number of assumptions, which simplifies analysis of metallic constructions, but makes significant errors for PCM settlement.

This paper presents an analysis of formation and synthesis procedures for spatial DC (SDC) and all kinds of heterogeneous materials (including PCM), which showed unreasonableness of using “classical” methods and needs to clarify, on issue of taking into account PCM parts constructive-technological specifics parameters.

Different approaches in composite constructions SDC model representation, among which the best approach has been defined, in which geometry of model is a structure of related coordinate systems of constructions parts. This approach allows to take into account the complex PCM structure as possible representation of their subsystems individual structures. Also take into account specific technological factors on PCM production stages and construction assembly stages.

Proposed approach involves the use of general structure model decomposition, which simplifies construction, and makes SDC model universal. Proposed method allows to build effective PCM structures models, designs to perform SDC formation and synthesis procedures, as well as further SDC analysis.

K e y w o r d s: size and accuracy analysis, spatial dimensional chain, PCM construction

Р е з ю м е: Подходы размерно-точностного анализа являются актуальными и универсальными для решения комплексных задач обеспечения точности и взаимозаменяемости конструкций при их сборке. Такие подходы, как правило, основываются на аппарате теории размерных цепей (РЦ), который в свою очередь является достаточно развитым, но несмотря на это, имеет ряд нерешенных задач, например, связанных с расчетом точности геометрических параметров сборных конструкций из полимерно-композитных материалов (ПКМ).

Сложности применения вышеупомянутой теории возникают, как на этапах формирования и синтеза РЦ конструкции, так и на последующих этапах их анализа и расчета. Также имеется ряд допущений, который упрощает анализ металлических конструкций, но для ПКМ вносит значительные погрешности расчетов.

В настоящей работе представлены результаты анализа актуального состояния процедур формирования и синтеза пространственных РЦ (ПРЦ) для сборных конструкций из неоднородных материалов (в т.ч. ПКМ), которые показали нецелесообразность применения «классической» методологии и необходимость ее уточнения, в вопросе учета специфики конструктивно-технологических параметров составных частей конструкции (СЧ) из ПКМ.

Рассмотрены различные подходы в представлении модели ПРЦ сборных конструкций, оптимальным среди которых был определен подход, при котором модель геометрии представляется в виде структур связанных систем координат ее СЧ. Такой подход позволяет учесть сложную структуру ПКМ, т.к. возможно представление отдельных структур их подсистем. Также учитывается специфические технологические факторы, которые возникают на этапах изготовления СЧ из ПКМ и сборки конструкции в целом.

Предложенный подход подразумевает использование декомпозиции общей структуры модели, что упрощает процедуры построения, а саму модель ПРЦ делает универсальной. Предложенная методика позволяет строить эффективные модели структур ПРЦ конструкций из ПКМ для выполнения процедур как формирования и синтеза, так и дальнейшего анализа ПРЦ.

К л ю ч е в ы е с л о в а: Размерно-точностный анализ, пространственная размерная цепь, конструкция из композитных материалов

S t r e s z c z e n i e: Aktualnym i uniwersalnym podejściem do analiz wymiarowo-dokładnościowych i kompleksowych zadań, zapewnienia dokładności i zamienności konstrukcyjnej w montażu jest teoria łańcuchów wymiarowych. Podejście to oparte o aparat teorii łańcuchów wymiarowych (ŁW) jest wystarczająco dopracowane, mimo iż istnieje szereg nierozwiązanych zadań, np. związanych z obliczaniem dokładności parametrów geometrycznych konstrukcji składanych z polimerowo-kompozycyjnych materiałów (PKM). Złożoność zastosowania ww. teorii pojawia się w etapach formowania i syntezy ŁW konstrukcji oraz na kolejnych etapach ich analizy i obliczeń. Istnieje szereg założeń, które upraszczają analizę metalowych konstrukcji, lecz dla PKM są obarczone znacznymi błędami. W pracy przedstawiono wyniki analizy aktualnego stanu procedur kształtowania i syntezy przestrzennych ŁW (PŁW) dla konstrukcji montowanych z niejednorodnych materiałów (w tym PKM), które wykazały

niecelowość stosowania „klasycznej” metodologii i konieczność jej uściślenia w zagadnieniach uwzględnienia specyfiki konstrukcyjno-technologicznych parametrów elementów składowych (ES) konstrukcji z PKM.
Rozpatrzono różne podejścia w przedstawianiu modelu PŁW montowanych konstrukcji, optymalnym wśród których było wyznaczone podejście, przy którym model geometrii przedstawiono w postaci struktur powiązanych systemem współrzędnych z ES. Takie podejście pozwala uwzględnić złożoną strukturę PKM, ponieważ możliwe jest przedstawienie oddzielnych struktur ich podsystemów. Uwzględnia to także specyficzne, technologiczne czynniki, które pojawiają się na etapach wytworzenia ES z PKM oraz montażu całej konstrukcji.
Zaproponowane podejście przewiduje wykorzystanie dekompozycji ogólnej struktury modelu, co upraszcza procedury budowy, a sam model PŁW czyni uniwersalnym. Zaproponowana metoda pozwala budować efektywne modele PŁW konstrukcji z PKM dla wytwarzania procedur oraz formowania i syntezy, jak i dla dalszej analizy PŁW.
Słowa kluczowe: analiza wymiarowo-dokładnościowa, przestrzenny łańcuch wymiarowy, konstrukcje z materiałów kompozytowych

Introduction

With the extension of the polymeric composite materials (PCM) application in various mechanical engineering sectors, is gaining more and more relevance of the issue of their geometrical parameters accuracy ensuring. Particularly acute, this problem becomes for assembled constructions, since in addition to manufacturing step is necessary to ensure accuracy at the stage of assembling such constructions, namely, in coherences and joints.

The main problem in assembled constructions accuracy evaluating and ensuring is a need to take account non-uniform and non-structural constructive and technological PCM characteristics, which will form the components of the overall accuracy of the construction.

The specific structural and technological parameters of PCM components consideration that affect on assembled construction accuracy.

The question of forming the specific requirements methods designing in constructions from the PCM modeling to solve which is necessary to analyze the structural and technological parameters and characteristics of modern aircraft constructions (the example of caisson construction offered (CC)) and perform their systematization, classification and typing. As such, the specific parameters of PCM CC will be available for consideration in solving common tasks of constructive and technological modeling.

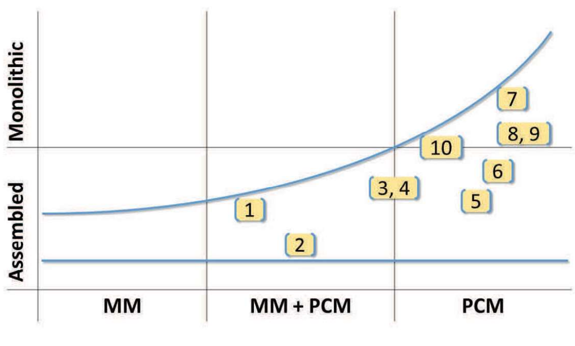


Fig. 1. Connectivity of CC design features and construction materials MM – metal material, PCM – polymeric composite material, 1-10 – according to references in [1]

To understand the place of different technical solutions is necessary to present it in coordinates system “The use of PCM – components CC” (fig. 1).

After analyzing the advantages and disadvantages of the main methods of classification [2], the choice was made in favor of facet method. For the determination of CC facets is necessary to determine specific parameters classification features, which requires a number of assumptions. A typical CC consists of panels (upper – UP and lower LP), spars (front – FS, rear – RS and ordinary – OS) and ribs (root – RR, final – FR, power – PR and typical – TR) (fig. 2).

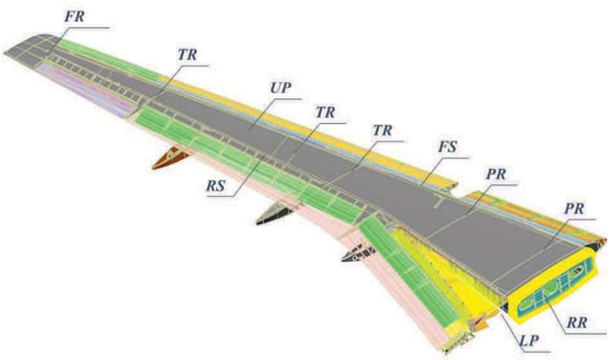


Fig. 2. Typical CC consists of panels (upper – UP and lower LP), spars (front – FS, rear – RS and ordinary – OS) and ribs (root – RR, final – FR, power – PR and typical – TR)

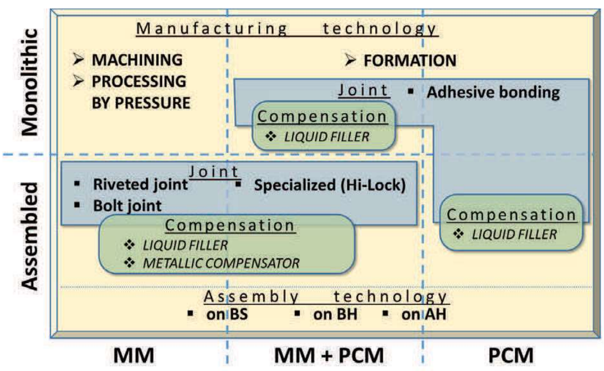


Fig. 3. Facets of PCM CC technology options MM – metal material, PCM – polymeric composite material

Table 1. Facets of PCM CC technological operations of joints

Process operation	Material			Note
	MM	MM+PCM	PCM	
Hole Machining				
Drilling	**true**	**true**	**true**	
Drilling-Out	**true**	**true**	**true**	
Reaming	**true**	**true**	**true**	
Broaching	**true**	**true**	**true**	
Countersinking	**true**	**true**	**true**	
Strengthening	**true**	**false**	**false**	
Mounting process				
Clearance mounting	**true**	**true**	**true**	
Clogging	**true**	**false**	**false**	
Pressing	**true**	**false**	**false**	with sleeve only
Pulling	**true**	**false**	**false**	with sleeve only
Fixing Process				
Impact	**true**	**false**	**false**	only riveted joints
Impulse	**true**	**false**	**false**	only riveted joints
Press	**true**	**true**	**true**	only riveted joints
Reeling out	**true**	**true**	**true**	only riveted joints
Screwing	**true**	**true**	**true**	torque-limiting
Washer fixing	**true**	**true**	**true**	
Additional Process				
Machining	**true**	**false**	**false**	

The use of technology options joints and compensate for deviations for different CC and their components materials is shown in fig. 3.

For the above-mentioned technological parameters of PCM CC special coding system was offered [1].

Technological operations of joints execution, that can be used for different CC components materials is shown in Table. 1, where 1 – the operation applies; 0 – not applicable.

	UP	*LP*	*FS*	*RS*	*OS*	*RR*	*FR*	*PR*	*TR*
UP	**0**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
LP	**0**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
FS	**1**	**1**	**0**	**0**	**0**	**1**	**1**	**1**	**1**
RS	**1**	**1**	**0**	**0**	**0**	**1**	**1**	**1**	**1**
OS	**1**	**1**	**0**	**0**	**0**	**1**	**1**	**1**	**1**
RR	**1**	**1**	**1**	**1**	**1**	**0**	**0**	**0**	**0**
FR	**1**	**1**	**1**	**1**	**1**	**0**	**0**	**0**	**0**
PR	**1**	**1**	**1**	**1**	**1**	**0**	**0**	**0**	**0**
TR	**1**	**1**	**1**	**1**	**1**	**0**	**0**	**0**	**0**

Fig. 4. Truth interfaces matrices for PCM CC components

In solving the aforementioned problems also necessary to analyze joints of considered PCM CC components each other. It is necessary to construct the truth interfaces matrices (fig. 4), which will help to reduce the task by eliminating those that cannot take place in real CC. In truth constructed matrix also adopted coding system is used, where 1 – the combination is present; 0 – no connection.

Influence of specific parameters on the spatial dimension chains synthesis and analysis method for PCM assembly constructions.

Today topical tool for determining the parameters of the accuracy assembled construction is dimensionally-precision analysis, which is based on the apparatus of the dimension chains (DC) theory. This theory, in general representation, is universal and simplified enough.

A significant number of assumptions in the individual positions of DC theory, as a rule, concern the presentation of the assembly facilities components and directly connections between them, as units of the DC. Considering complex PCM construction, above assumptions makes sufficiently high uncertainty at the stage of DC formation and the synthesis.

Thus, the binding components and the closing DC link in assembled construction should take place with the help of related coordinate systems (CS). For further description of the DC synthesis techniques for the PCM constructions, consider the problem of related component CS and construction in general formation and description.

Methods of related PCM component CS and construction in general forming

In the task of DC synthesis, the related CS – is a structure of separately specific each construction component CS. Such structure should be formed taking into account the requirement of strict compliance of these relations in the actual physical model of relations in the actual design. Non-compliance with this requirement will result in an error and greatly complicate the correct DC synthesis.

Analysis of the related CS structure should be based on technological factors too. Particular influence on the related CS structure for PCM assembly constructions will provide specifics components manufacturing technology and construction assembly technology. Such specificity is caused by the impossibility of applying the standard "classical" technology solutions that have been used previously for metal constructions [3].

For the PCM components manufacturing stage, the most important:

- basic CS purpose, which will determine the main assembly base for component mounting during final construction assembly and depend on the type of formation technology;
- forming CS subsystems in which each monolayer has a separate CS, depending on the PCM structure.

Relations in such subsystems will perform functions, variables, which depend on the material properties and formation technology modes. [4]

For the PCM construction assembly stage, the most important:

- consideration of connections between construction components and compensating elements (brackets, compensators, liquid fillers, etc.);
- jig CS formation, as a part of the general related CS structure.

For the PCM constructions assembly appropriate to apply modular jigs, consisting of basic elements, frame and foundation. Last is forms a "zero" base in the general related structure.

For such jigs it is introducing the following CS notation: $CS^{i}_{J\_0}$ – CC assembly jig, which consists of a frame ($CS^{i}_{CC\_FR}$) and basic elements ($CS^{i}_{CC\_BE}$). A hierarchical system of relations in the revised structure is shown in fig. 5.

The above CS structure is quite complicated, due to additional jig elements, but displays the actual structure of construction in production and visualizes technological gaps between the upper panel and the CC frame.

The proposed approach takes into account the assembly construction mounting tension in the future construction and technological modeling the structure under consideration. It is possible to realize due to the description and analysis of the jig elements, as well as basing methods, taking into account real technology solutions in the workplace.

At the same time, current is still the main task of ensuring the geometrical parameters accuracy, for the solution of which is necessary to develop a method for the PCM construction DC formation.

Methods of the PCM construction DC model formation.

Assembled construction DC designing is due to the performance of its geometry model as its components CS. At the same time, the greater its components number

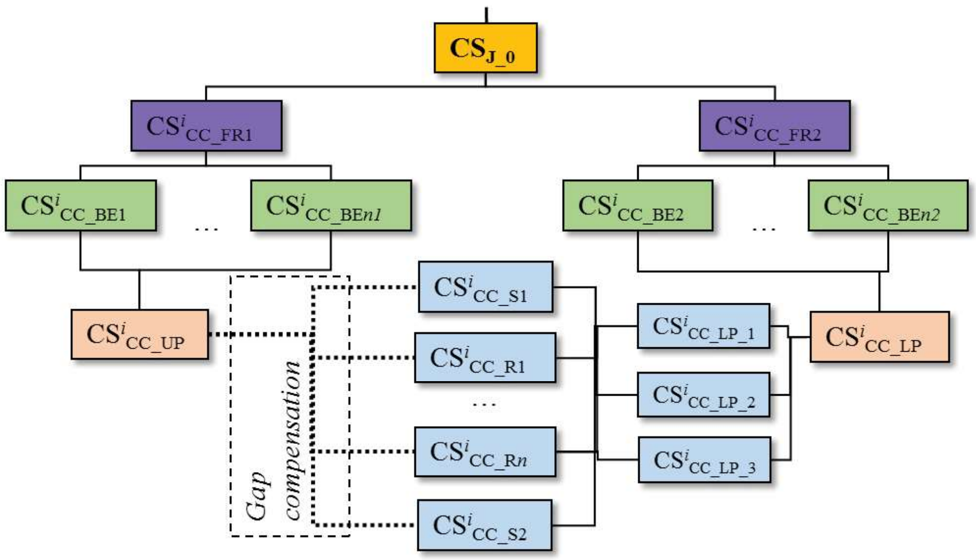


Fig. 5. Hierarchical system of PCM construction in jig relations CS

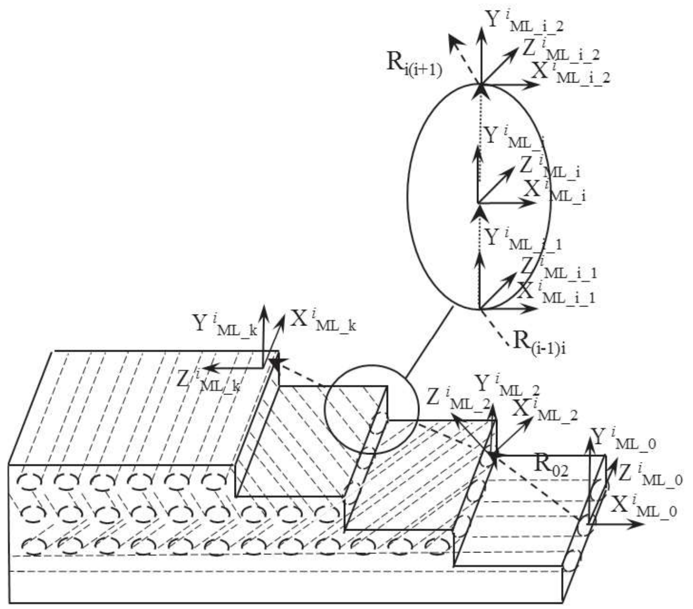
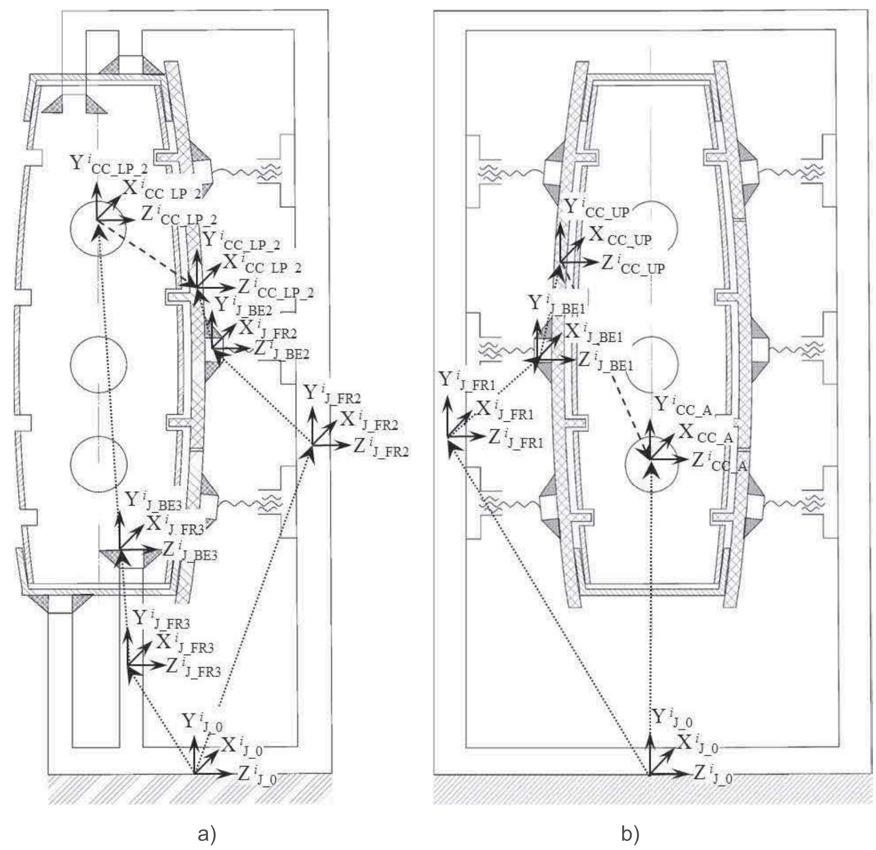


Fig. 6. Typical model of the PCM component DC structure: XYZ_{ML_0} – basic CS, $R_{02} = f(a, b, \dots m)$ – constitutional unit as "m" process parameters function, *k* – monolayers number



a) b)

Fig. 7. DC structure model: a) PCM CC subassembly "A" in jig, b) PCM CC in jig

and the more complex their structure and geometry, the more difficult will be its structure as a whole.

To solve this problem, consider the approach of the general DC structure decomposition. At the lowest level it is necessary to analyze the details of construction and, accordingly, take into account the technological features at the stage of their manufacture. For construction discussed above, the most complex structure has PCM components (upper and lower panels). A typical model of the PCM component DC structure shown in fig. 6.

After PCM component DC synthesis, it is expedient present it in a short form (fig. 7a).

At the highest structure decomposition level of the is necessary to analyze directly up construction. It is possible to simplify this analysis using construction division circuit. So for PCM CC can be distinguished phase "A" – the frame subassembly and lower panels (fig. 7a), and then the mountain of the upper panel and the final CC assembly (fig. 7b).

The proposed model (fig. 7) is universal, what allows adjustments at different levels of its decomposition without destructing the overall model. It is expedient to use such a model in automated systems, not only for the DC formation and synthesis, further for its analysis.

PCM construction DC structure model adequacy assessing

For PCM CC in jig DC structure model synthetic consideration of using possibility for these assessing the adequacy methods of its will be a rational [5]:

- on basis of the tolerance field for the variations in the plan matrix;
- on basis of equivalence radius;
- on basis of stochastic modeling (Monte-Carlo method).

From the above PCM construction DC structure model adequacy assessing methods, stochastic modeling will be preferred, because along with the relative simplicity of task solving assessment procedures, the results will be displayed, as close as possible to the production, the character of the previously synthesized model adequacy.

To implement the evaluation procedures using the Monte-Carlo method is necessary to solve the task of converting a synthetic model in vector-matrix form. To do this, it is also advisable to apply the decomposition approach discussed earlier. So at the lowest level denote the model equations system:

$$\mathbf{R}_{(k-1)k} = \mathbf{f}(\mathbf{a}, \mathbf{b}, \ldots \mathbf{m}), \tag{1}$$

where Y_{PCM} – closing unit, which characterize the deviation in general, as a function of the components: $X_0, X_1, \ldots, X_k$ – characterized filler deflection (fiber material), $R_{01}, \ldots R_{(k-1)k}$ – characterized binder material deflection as a function of "$a, b, \ldots m$" structural and technological parameters.

The following parameters will be considered for further analysis to binder material:

- structural: μ – viscosity, β – expansion,
- technological: t – temperature, P – pressure.

Thus the system (1) will have the following form:

$$\mathbf{R}_{(k-1)k} = \mathbf{f}(\mu, \beta, t, P). \tag{2}$$

To model evaluate, using the Monte-Carlo method, form the tolerance of the closing values on the basis of the model equations:

$$\mathbf{Y}\left(\Delta\mathbf{X}_k^T, \mathbf{R}_{(k-1)k}^T\right) = \mathbf{R}_{(k-1)k} + \Sigma\Delta\mathbf{X}_k,\ \mathbf{i} = 0, \mathbf{k} \tag{3}$$

where Δ – deviation, T – tolerance.

Thus, the nominal tolerance value field is equal to

$$\mathbf{Y}\left(\Delta\mathbf{X}_k^T, \mathbf{R}_{(k-1)k}^T\right) = \mathbf{R}_{(k-1)k}, \tag{4}$$

and tolerance is one of the equations:

$$\mathbf{TY} = \Sigma \left| \mathbf{R}_{(k-1)k} \right| \mathbf{TX}_1$$

– to ensure full interchangeability requirements;
– to provide partial interchangeability requirements.

Thus the tolerance will be the following:

$$\mathbf{Y}_{min}, \mathbf{Y}_{max} = \mathbf{R}_{(k-1)k} \pm \mathbf{TY}. \tag{5}$$

Referring to the equations model system:

$$\mathbf{R}_{(k-1)k} = \mathbf{f}(\mu, \beta, t, P). \tag{6}$$

where X_i, $R_{(i-1)i}$ – nominal amounts values; ΔX_i, $\Delta R_{(i-1)i}$ – deviation amounts to the nominal values.

Let these deviations are random variables ΔX_i, $\Delta R_{(i-1)i}$, $i = 0, k$. The parameters values of random variables distribution laws we choose such that the condition

$$\mathbf{P}\left(\Delta\mathbf{X}_i, \Delta\mathbf{R}_{(i-1)} \in [\Delta\mathbf{X}_{i\,min}, \Delta\mathbf{R}_{(i-1)min}, \Delta\mathbf{X}_{i\,max}, \Delta\mathbf{R}_{(i-1)max}]\right) = 1 - \varepsilon,\ \varepsilon << 1, \tag{7}$$

where $[\Delta X_{i\,min}, \Delta R_{(i-1)i\,min}, \Delta X_{i\,max}, \Delta R_{(i-1)i\,max}]$ – component value tolerance field X_i, $R_{(i-1)i}$.

Model system of equations in this case will have the form:

$$\mathbf{Y}_{PCM}\left(\mathbf{X}_0 + \Delta\mathbf{X}_0, \mathbf{R}_{01} + \Delta\mathbf{R}_{01}, \mathbf{X}_1 + \Delta\mathbf{X}_1, \ldots \mathbf{R}_{(k-1)k} + \Delta\mathbf{R}_{(k-1)k}, \mathbf{X}_k + \Delta\mathbf{X}_k\right) = \mathbf{Y}_{PCM}\left(\mathbf{X}_0, \mathbf{R}_{01}, \mathbf{X}_1, \ldots \mathbf{R}_{(k-1)k}, \mathbf{X}_k\right) = \mathbf{Y} \tag{8}$$

where $X_i = X_i + \Delta X_i$, $R_{(i-1)i} = R_{(i-1)i} + \Delta R_{(i-1)i}$ – occasional arguments equation model.

Equation (8) with random arguments causes the closing value as a random variable Y. Now the condition of the adequacy of the model can be defined as the ratio of

$$\mathbf{P}\left(\mathbf{Y} \in \mathbf{R}_{(k-1)k} \pm \frac{1}{2}\mathbf{TY}\right) \geq 1 - \varepsilon\mathbf{Y},\ \varepsilon\mathbf{Y} << 1. \tag{9}$$

Checking the adequacy of conditions (9) is realized on the basis of stochastic modeling, taking into account the total additional factor accounting for the PCM component deviations.

After solving the model for estimating the current (at the lowest decomposition level) can be solved a complex task structure model assessment as a whole, according to the method described above. For modern assembled PCM constructions automation algorithm requires a large amount of cases settlement.

Conclusions

In the issues considering of formation and synthesis as well as analysis and evaluation of the DC for the PCM assembled construction, the main problem is account specific structural and technological parameters defined anisotropy and heterogeneity of the PCM properties. To solve this problem a method for implies a representation of the model in the form of systems and subsystems related assembled construction CS, connections in which describes specific PCM structural and technological parameters. At the same time, taking into account features of the manufacturing technology and assembly technology of PCM constructions as a whole.

Issues of above-mentioned models analysis and evaluation have been described using a method based on stochastic modeling, which showed its relevance and usefulness for PCM assembled construction. The proposed methodology appropriate to apply construction stages using CAD-systems, to allow further use of automated equipment for the PCM assembled construction production as a whole.

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