



DIMENSIONAL ASPECT OF THE CAPABILITY OF CNC-MACHINING TECHNOLOGIES

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Abstract: The paper refers to the dimensional aspect of ensuring the CNC machining capability of parts with complex dimensional structures. CNC machining capability is treated as a correlated pair of characteristics: machining allowance – machining accuracy. In complex technological dimensional structures, 3 structural effects are manifested: 1) increasing the precision requirements imposed on technological dimensions, 2) increasing the machining allowance tolerances, and 3) reducing the machining allowance tolerances and technological dimension tolerances due to error compensation mechanisms. These structural effects for the dimensional structures “fan-shaped”, “displaced fan-shaped,” and “chain” have been analyzed and characterized. The possibility of increasing the CNC machining capability by equivalently replacing dimensional structures that do not ensure CNC machining capability with others is demonstrated. The positive effects of the structural transformations: “fan-shaped” - “displaced fan-shaped”, “chain” - “fan-shaped”, and “chain” - “displaced fan-shaped” are analyzed.

Key words: machining capability, dimensional structure, precision, technological assurance, tolerance, machining allowance.

1. INTRODUCTION

Functionality is the essential objective of the overall constructive projects of the mechanical product and its components (parts). The development process of a product includes the definition of functional requirements, of technical design requirements, identification of dimensional chains, establishment of tolerances, analysis of variations and reconstruction of technical specifications [12]. The mentioned variations show that the constructive project can be realized in several equivalent variants. The dimensional aspect of the constructive project of the mechanical product (assembly) consists of the definition of dimensional structures with the allocation of tolerances of component dimensions. The dimensional structures in tolerances of the parts derive directly from the dimensional structure of the mechanical assembly.

In technological dimensional design, the tolerance chart [5, 4] is widely used to determine the cumulation of tolerances of the resulting dimensions. The latter are compared with the tolerances of the constructive dimensions to ensure that the part can be processed in accordance with the technical precision requirements specified in the part's drawing. The tolerance chart is also used to determine the values and tolerances of the machining allowances. This ensures that there is enough material left for the following machining phases, but also that the technical conditions for ensuring accuracy are met. As a result, this tool allows the values and tolerances of both the technological dimensions and the machining allowances to be established under the conditions of an already formulated process plan. The tolerance chart method is a technical evaluation tool, but not a design tool.

The success of the technological project is largely determined by the links between the tolerances assigned to the constructive dimensions of the part and the tolerances assigned to the technological dimensions. An adequate solution can be obtained with the involvement of the higher level, the constructive design of the mechanical assembly. In this case, the design of the assembly also involves a parallel process of assigning technological tolerances appropriate to the tolerances of the constructive dimensions of the parts [2]. This concurrent approach makes the constructive and technological projects more flexible, and the assembly (product) can be manufactured more economically.

2. MATERIALS AND METHODS

If the technological project provides for excessive precision requirements or inadequate conditions for technological assurance of precision, then it is possible to resort to redesigning the constructive dimensional structure of the mechanical assembly and/or the part.

As a tool for establishing links between the constructive and technological dimensional structures, the graph-based approach is used. The graph language makes it possible to represent a complex problem in a structured way, in a simple manner with a double effect: overview and in-depth view [13]. The constructive dimensional structure (design dimension trees) is the source of definition of a technological dimensional structure (ideal datum-hierarchy tree of a process plan) [7, 8]. Tolerance charts integrated with the datum hierarchy tree are a suitable integrating tool [5]. For an adequate allocation of technological tolerances, the dimensional structure of machining must take into account the dimensional aspects of the characteristics of machining methods, machine tools, and adjustment procedures [3].

Starting from the fact that any constructive dimension $A_c(T_{Ac})$ is formed in an optimal regime if, in technology, it is represented exclusively by its own technological dimension, and $\omega_{At} \leq T_{Ac}$ (Fig. 1), in the work [9] to create the technological dimensional structure adequate to the constructive dimensional structure through the similarity of their graphs, it was proposed.

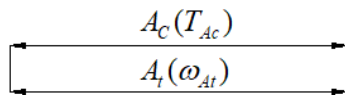


Fig. 1. Optimal elementary technological dimensional structure

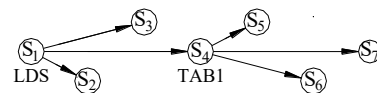


Fig. 2. Technological dimensional structures characteristic of CNC machining

The paper analyzes the situation of machining parts from cast or die forging blanks with a dimensional structure defined at the technological design stage. Thus, the structural similarity can be extended to blank to be processed [6].

As for CNC machine tools, they offer the possibility of generating at least three forms of technologic dimensional structures – technologic dimensional modules (Fig. 2): “fan-shaped” (S1, S2, S3), „displaced fan-shaped” (S1, S4, S5, S6) and „chain” (S1, S4, S5; S1, S4, S6; S1, S4, S7). More complex dimensional structures will include these forms in various combinations.

The strategy of technologies realized on CNC machine tools is based on the principle of machining's centralization. This principle provides for "centering" on the workpiece, the formation of several surfaces through different processing methods, and the machine tool periodically transforms morphologically, passing from one quality to another. The effect represents very complex technological dimensional structures.

It is known that the properties of a system are determined by the properties of the elements, but especially by the properties of the links between the elements [10]. The links between the technological dimensions in a complex structure inevitably make their characteristics different from those outside it. In a complex structure, the technological dimensions interact with each other, so that their characteristics under systemic constraints are formed.

Such an analysis was performed for a series of similar constructive and technological dimensional structures, involving machining the front surfaces S1, S2, S3, and S4, positioned relative to surface 0 at 200, 150, 100, and 50 mm, respectively [11]. It was found that systemic constraints manifest themselves through three structural effects:

1. Increasing precision requirements for technological dimensions, if the formation of the constructive dimension A_c takes place through its own technological dimension A_t and through another technological dimension B_t , so that $\omega_{At} + \omega_{Bt} \leq T_{Ac}$ (Fig. 3) higher requirements on the precision of technological dimensions are imposed.

2.

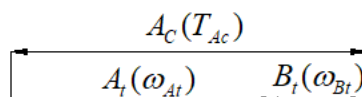


Fig. 3. Non-optimal elementary technological dimensional structure

2. Increasing the tolerances of machining allowances according to the relationship (1), which reflects the fact that the tolerance of the machining allowance cumulates all the tolerances of the previous and current technological dimensions along the dimensional chain starting with the LDS technological base [11]. The most intensive accumulation of allowance tolerances occurs in the first stages of blank's machining.

$$\omega_{Alln} = \sum_{i=1}^n (\omega_{Li}^0 + \omega_{Li}^1) \quad (1)$$

Here ω_{Li}^0 and ω_{Li}^1 are the dimensional tolerances on the blank and after the first technological operation elements. An excessive increase in the machining tolerance can drive the technical limit of technological assurance of precision to be exceeded. In this way, the technological assurance of machining accuracy is worsened by the structural particularities.

3. Error compensation, as a result of which both the tolerances of machining allowances and the tolerances of technological dimensions are reduced. The technical conditions for ensuring accuracy are improved, and simultaneously, the precision requirements imposed on technological dimensions are reduced. Taking into account the error compensation effect, relation (1) can be rewritten as follows:

$$\omega_{Alln} = \sum_{i=1}^n (\omega_{Li}^0 + \omega_{Li}^1 - 2 \cdot \omega_{Li}^c / L_i^c) \quad (2)$$

3. RESULTS AND DISCUSSIONS

The mentioned earlier structural effects for several technologic dimensional structures similar to the constructive ones of the “fan-shaped”, “displaced fan-shaped” and “chain” types were analyzed (Fig. 4) [11].

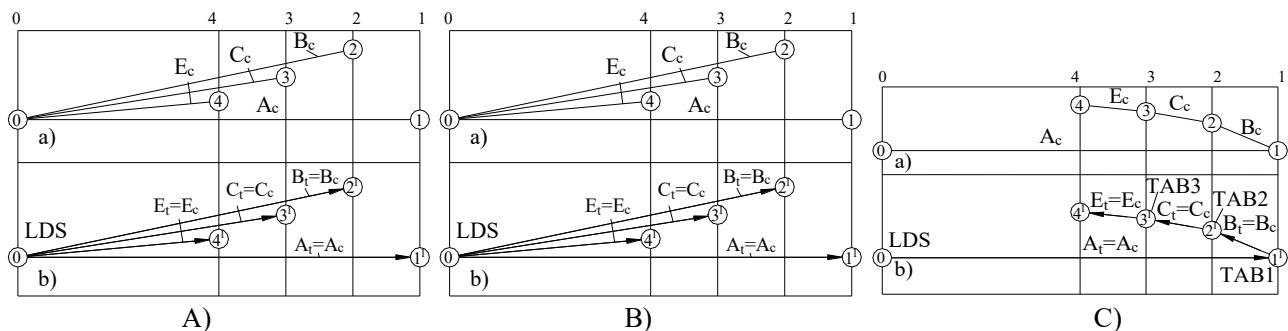


Fig. 4. Technological dimensional structures similar to constructive ones [11]: a) “Fan-shaped” type structure; b) “Displaced fan-shaped” type structure; c) “Chain” type structure

The results of the analysis presented in Table 1 are given in relative values, related to the statistical tolerance of the allowance established in machining conditions according to the scheme in Figure 5. This scheme is a development of the situation in Figure 1 with reference to the previous and current technologic dimensions, which together with the machining allowance's dimension (closing element) form a dimensional structure. The allowance's tolerance can be represented by the relation $\omega_{All} = \omega_{A_i^0} + \omega_{A_i^1}$.

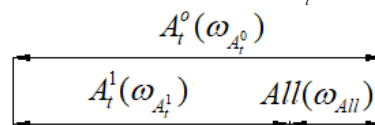


Fig. 5. Statistically recognized conditions for ensuring accuracy

Table 1. Structural effects of increasing or decreasing machining allowance's tolerance in the similar technological dimensional structure of the "fan-shaped", "displaced fan-shaped", "chain" types [11]

Ratio of the machining allowance's tolerances	Evaluated by method: * - Maximum and minimum ** - Idem, with errors compensation												
	increased by	"fan-shaped"				"displaced fan-shaped"				"chain"			
		Machined surfaces				Machined surfaces				Machined surfaces			
		S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄	S ₁	S ₂	S ₃	S ₄
Structural/Statistical	times*	1	1	1	1	1	2.69	2.30	2.12	1	2.69	3.69	4.69
Structural/Statistical	times**	1	1	1	1	1	2.60	2,28	2.10	1	2,6	3,6	4,6

From the presented data it is observed (Tab. 1), that the similar constructive technological dimensional structure of the "fan-shaped" type does not cause an increase in the tolerances of the machining allowances and is an advantageous one. In the technological dimensional structure of the "displaced fan-shaped" type a structural effect of increasing the tolerance of the machining allowances up to 2.69 times is observed. The increase is slightly attenuated by the error compensation effects. In the technological dimensional structure of the "chain" type, a structural effect of increasing the tolerance of the machining allowances up to 4.69 times is observed. This increase in the tolerance of the machining allowances places the "chain" dimensional structure in the category of the disadvantageous ones. These different structural effects are due to the length of the dimensional chains from the technological base, respectively: 1, 2, and 4.

3.1. Technological assurance of dimensional precision through the equivalent constructive resizing

If at the constructive design stage, technologically acceptable dimensional structures are not achieved, equivalent constructive resizing of the part in variants with the evaluation of structural effects can be resorted to. The main reason for constructive resizing is the technological failure to ensure machining accuracy due to large tolerances of machining allowances. The part is resized differently, with recalculation of the tolerances and limit deviations of the new constructive dimensions, the old dimensions being respected as closing elements of the resizing chains. Since any resizing consists of replacing one dimension with two or more others, the accuracy requirements of the component dimensions increase. Thus, the equivalent constructive resizing is done in order to reduce the tolerances of the machining allowances at the expense of increasing the accuracy of the machining. After resizing, the principle of similarity of the technological and constructive dimensional structure is applied once again. Next, the effects of equivalent constructive resizing are analyzed. The required accuracy for the technological dimensions formed in the analysis is at an accuracy level of 13.

3.2. Equivalent constructive resizing from "displaced fan-shaped" to "fan-shaped" type

The transition from the initial "displaced fan-shaped" type constructive dimensioning $L_c^0 \rightarrow L_c^1$ in Figure 6 is represented. The technological dimensional structure is adopted, similar to the new constructive structure. The constructive dimensions A_c^0 , B_c^0 , C_c^0 and E_c^0 are replaced by, respectively, new constructive ones A_c^1 , B_c^1 , C_c^1 and E_c^1 .

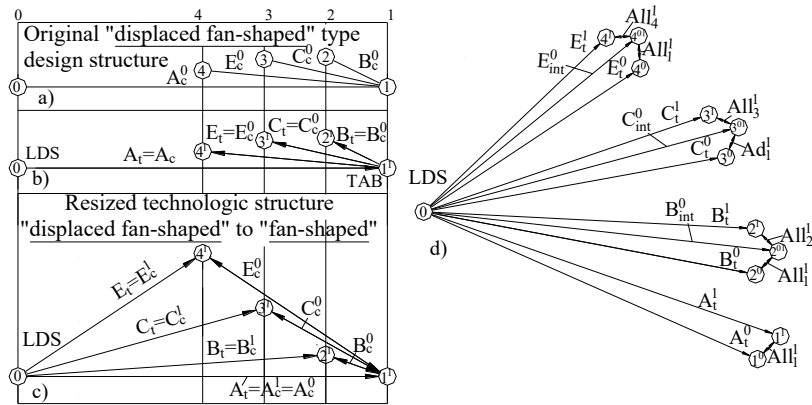


Fig. 6. Structural resizing from "displaced fan-shaped" to "fan-shaped" types

From the dimensional link graphs (Fig. 6c) it is observed that the conditions for ensuring dimensional precision are not favorable, because the precision of technological dimensions B_t , C_t and E_t , are conditioned by the precision of the previous dimensions in the chain in accordance with the relations (3).

$$\begin{aligned}
 \omega_{A_t} &\leq \omega_{A_c^1}, \\
 \omega_{B_t} + \omega_{A_t} - 2 \cdot \omega_{1^c 2^1} &\leq \omega_{B_c^1}, \\
 \omega_{C_t} + \omega_{A_t} - 2 \cdot \omega_{1^c 3^1} &\leq \omega_{C_c^1}, \\
 \omega_{E_t} + \omega_{A_t} - 2 \cdot \omega_{1^c 4^1} &\leq \omega_{E_c^1}
 \end{aligned} \tag{3}$$

The result of structural constraints is an increase in the accuracy of all technological dimensions (reduction in the tolerances of technological dimensions) compared to the ideal case of equal accuracy of constructive and technological dimensions. This imposed reduction of the tolerances of the technological dimensions A_t , B_t , C_t and E_t is represented by the coefficients α , β , γ and δ respectively.

The error compensation is given by the u coefficient and applied to the lower technological dimensions of each possible pair. Conditions (1) can be written in the form of equation (4).

$$\begin{aligned} \alpha \cdot (i_{A_t} \cdot a_{A_t}) &\leq \omega_{A_t^1}, \\ \beta \cdot (i_{B_t} \cdot a_{B_t}) + \alpha \cdot (i_{A_t} \cdot a_{A_t}) - u \cdot \beta \cdot (i_{B_t} \cdot a_{B_t}) &\leq \omega_{B_t^1}, \\ \gamma \cdot (i_{C_t} \cdot a_{C_t}) + \alpha \cdot (i_{A_t} \cdot a_{A_t}) - u \cdot \gamma \cdot (i_{C_t} \cdot a_{C_t}) &\leq \omega_{C_t^1}, \\ \delta \cdot (i_{E_t} \cdot a_{E_t}) + \alpha \cdot (i_{A_t} \cdot a_{A_t}) - u \cdot \delta \cdot (i_{E_t} \cdot a_{E_t}) &\leq \omega_{E_t^1} \end{aligned} \quad (4)$$

Here, tolerance is represented by multiplying the tolerance units a and the dimensional parameter i . The ideal solution would be to form all dimensions to the same precision level, higher than IT13, but balanced. A solution for the coefficients β , γ , δ , expressed by α is given by the following relations (5).

$$\beta = \frac{\omega_{B_t^1} - \alpha \cdot i_{A_t} \cdot a_{A_t}}{(1-u) \cdot i_{B_t} \cdot a_{B_t}}, \quad \gamma = \frac{\omega_{C_t^1} - \alpha \cdot i_{A_t} \cdot a_{A_t}}{(1-u) \cdot i_{C_t} \cdot a_{C_t}}, \quad \delta = \frac{\omega_{E_t^1} - \alpha \cdot i_{A_t} \cdot a_{A_t}}{(1-u) \cdot i_{E_t} \cdot a_{E_t}} \quad (5)$$

The solution obtained in tolerance units (Tab. 2) is acceptable from the point of view of the machining allowance's tolerances, as they do not exceed the statistical values. However, the technological dimensions A_t and B_t must be formed at 72 tolerance units each, which may make the resizing in this formula unacceptable.

The dimensional relationships for the machining allowances of surfaces 2, 3 and 4 include as constituent elements the tolerance of the machining allowance of surface 1 - - Ad_1^l (Fig. 6,c). Thus, the machining allowance's tolerances for surfaces 1, 2, 3 and 4, taking into account also the effects of error compensation, can be determined as follows in relations (6).

$$\begin{aligned} \omega_{Al_1^l} &= (\omega_{A_t^1} + \omega_{A_t^0}) - 2 \cdot \omega_{1_1^0}^c, \\ \omega_{Al_2^l} &= (\omega_{B_t^1} + \omega_{B_t^0}) - 2 \cdot \omega_{2_2^0}^c + (\omega_{A_t^1} + \omega_{A_t^0}) - 2 \cdot \omega_{1_1^0}^c, \\ \omega_{Al_3^l} &= (\omega_{C_t^1} + \omega_{C_t^0}) - 2 \cdot \omega_{3_3^0}^c + (\omega_{A_t^1} + \omega_{A_t^0}) - 2 \cdot \omega_{1_1^0}^c, \\ \omega_{Al_4^l} &= (\omega_{E_t^1} + \omega_{E_t^0}) - 2 \cdot \omega_{4_4^0}^c + (\omega_{A_t^1} + \omega_{A_t^0}) - 2 \cdot \omega_{1_1^0}^c \end{aligned} \quad (6)$$

From the graphic representation (Table 2) it is observed that the analyzed equivalent constructive resizing caused decreases in the tolerances of the machining allowances, improving the technological assurance of precision from this point of view. However, for the formation of dimensions and an increase in the precision requirements is observed.

Table 2. Effects of equivalent constructive resizing from "displaced fan-shaped" to "fan-shaped" type

Number of tolerance units a and tolerance grade IT of dimensions:					
constructive	technological by method:				
	* - Maximum and minimum ** - Idem, with errors compensation				
$A_c, B_c,$ C_c, E_c		A_t	B_t	C_t	E_t

$$\begin{aligned}\beta \cdot (i_{B_t} \cdot a_{B_t}) + \alpha \cdot (i_{A_t} \cdot a_{A_t}) - u \cdot \beta \cdot (i_{B_t} \cdot a_{B_t}) &\leq \omega_{B_c^1}, \\ \gamma \cdot (i_{C_t} \cdot a_{C_t}) + \beta \cdot (i_{B_t} \cdot a_{B_t}) - u \cdot \gamma \cdot (i_{C_t} \cdot a_{C_t}) &\leq \omega_{C_c^1}, \\ \delta \cdot (i_{E_t} \cdot a_{E_t}) + \gamma \cdot (i_{C_t} \cdot a_{C_t}) - u \cdot \delta \cdot (i_{E_t} \cdot a_{E_t}) &\leq \omega_{E_c^1}\end{aligned}$$

This system has an infinite number of solutions represented by the following relations (9).

$$\beta = \frac{\omega_{B_c^1} - \alpha \cdot i_{A_t} \cdot a_{A_t}}{(1-u) \cdot i_{B_t} \cdot a_{B_t}}, \quad \gamma = \frac{\omega_{C_c^1} - \beta \cdot i_{B_t} \cdot a_{B_t}}{(1-u) \cdot i_{C_t} \cdot a_{C_t}}, \quad \delta = \frac{\omega_{E_c^1} - \gamma \cdot i_{C_t} \cdot a_{C_t}}{(1-u) \cdot i_{E_t} \cdot a_{E_t}} \quad (9)$$

The acceptable solution is the same as in the previous case – the precision of at least two technological dimensions is equal, the rest may have lower precision (Table 3).

From figure 7,d it can be seen that the dimensional links for the machining allowances of surfaces 2, 3, and 4 include as constituent elements the machining allowances of the previously machined surface. The machining allowance's tolerances for surfaces 1, 2, 3, and 4 can be determined as follows in relations (10).

$$\begin{aligned}\omega_{Al_1^1} &= (\omega_{A_t^1} + \omega_{A_t^0}) - 2 \cdot \omega_{1^0}, \\ \omega_{Al_2^1} &= (\omega_{B_t^1} + \omega_{B_t^0}) - 2 \cdot \omega_{2^0} + (\omega_{A_t^1} + \omega_{A_t^0}) - 2 \cdot \omega_{1^0}, \\ \omega_{Al_3^1} &= (\omega_{C_t^1} + \omega_{C_t^0}) - 2 \cdot \omega_{3^0} + (\omega_{B_t^1} + \omega_{B_t^0}) - 2 \cdot \omega_{2^0}, \\ \omega_{Al_4^1} &= (\omega_{E_t^1} + \omega_{E_t^0}) - 2 \cdot \omega_{4^0} + (\omega_{C_t^1} + \omega_{C_t^0}) - 2 \cdot \omega_{3^0}.\end{aligned} \quad (10)$$

Table 3. Effects of equivalent constructive resizing from "chain" to "fan-shaped" type

Number of tolerance units a and tolerance grade IT of dimensions:						
constructive	technologic by method:					
A_c, B_c, C_c, E_c	A_t	B_t	C_t	E_t		
250 IT13	a* IT*	72 10–11	72 10–11	96 11	117 11–12	
	a** IT**	84 <11	84 <11	152 <12	125 <12	

The graphic representation (Table 3) shows that the analyzed equivalent constructive resizing causes a decrease of the machining allowance's tolerances except for the one on surface 2, being, from this point of view, only relatively improved the technological assurance of precision. At the same time, there are clear increases in the precision requirements for all technological dimensions. These two aspects show that the transition from the least advantageous type of dimensional structure, "chain" to the most advantageous type, "fan-shaped" (Table 1) is not successful.

3.4. Equivalent constructive resizing from "chain" to "displaced fan-shaped" type

The transition from the initial "chain" type constructive dimension structure to the new equivalent "displaced fan-shaped" type $L_c^0 \rightarrow L_c^1$ is represented in Figure 8. In the new constructive dimensional structure, the dimensions A_c^1, B_c^1, C_c^1 and E_c^1 , replace the constructive dimensions A_c^0, B_c^0, C_c^0 and E_c^0 . The technological dimensional structure is adopted, similar to the new constructive dimensional structure.

From the dimensional link graphs (Fig. 8,b-d) it is observed that the conditions for ensuring dimensional precision are not optimal, because the accuracies of technological dimensions B_t, C_t and E_t , are constrained, conditioned by the technological dimension A_t in accordance with the relationships (11).

$$\begin{aligned}
\omega_{A_i} &\leq \omega_{A_c^1}, \\
\omega_{B_i} &\leq \omega_{B_c^1}, \\
\omega_{C_i} + \omega_{B_i} - 2 \cdot \omega_{2^1 3^1}^c &\leq \omega_{C_c^1}, \\
\omega_{E_i} + \omega_{C_i} - 2 \cdot \omega_{3^1 4^1}^c &\leq \omega_{E_c^1}
\end{aligned} \tag{11}$$

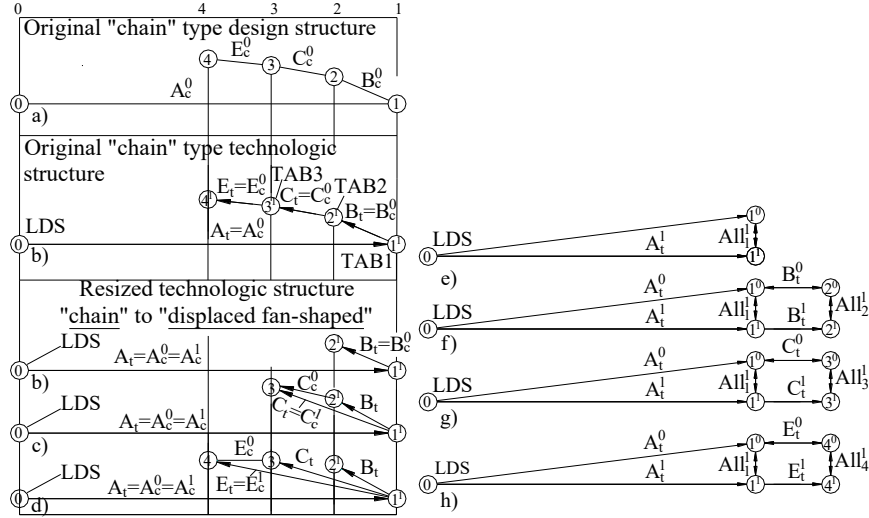


Fig. 8. Structural resizing from "chain" to "displaced fan-shaped" type

Structural constraints are manifested by increasing the precision requirements of technological dimensions (reducing the number of tolerance units), except dimension A_t , which is formed at a statistical level independently of other dimensions.

The decrease in tolerances of technological dimensions B_t , C_t and E_t is represented by the coefficients β , γ and δ . Error compensation takes into account the u coefficient, applied to the smaller technological dimensions of each possible pair.

Conditions (9) can be written in the form of equations (12).

$$\begin{aligned}
\beta \cdot i_{B_t} \cdot a_{B_t} &\leq \omega_{B_c^1}, \\
\gamma \cdot i_{C_t} \cdot a_{C_t} + \beta \cdot i_{B_t} \cdot a_{B_t} - u \cdot \gamma \cdot i_{C_t} \cdot a_{C_t} &\leq \omega_{C_c^1}, \\
\delta \cdot i_{E_t} \cdot a_{E_t} + \gamma \cdot i_{C_t} \cdot a_{C_t} - u \cdot \delta \cdot i_{E_t} \cdot a_{E_t} &\leq \omega_{E_c^1}
\end{aligned} \tag{12}$$

This system has an infinity of solutions represented by the following relations (13).

$$\gamma = \frac{\omega_{C_c^1} - \beta \cdot i_{B_t} \cdot a_{B_t}}{(1-u) \cdot i_{C_t} \cdot a_{C_t}}, \quad \delta = \frac{\omega_{E_c^1} - \gamma \cdot i_{C_t} \cdot a_{C_t}}{(1-u) \cdot i_{E_t} \cdot a_{E_t}} \tag{13}$$

As in the previous cases, the aim was to ensure that the precision of at least two technological dimensions was equal (Table 4).

It can be seen (Fig. 8,e-h) that the dimensional relationships for the machining allowances of surfaces 2, 3, and 4 include as constituent elements the machining allowance of surface 1 (ω_{All^1}). The tolerances of the machining allowances for surfaces 1, 2, 3, and 4 can be determined as follows in relations (14).

$$\begin{aligned}
\omega_{All^1} &= (\omega_{A_t^1} + \omega_{A_t^0}) - 2 \cdot \omega_{1^1 1^0}^c, \\
\omega_{All^2} &= (\omega_{B_t^1} + \omega_{B_t^0}) - 2 \cdot \omega_{2^1 2^0}^c + (\omega_{A_t^1} + \omega_{A_t^0}) - 2 \cdot \omega_{1^1 1^0}^c, \\
\omega_{All^3} &= (\omega_{C_t^1} + \omega_{C_t^0}) - 2 \cdot \omega_{3^1 3^0}^c + (\omega_{A_t^1} + \omega_{A_t^0}) - 2 \cdot \omega_{1^1 1^0}^c,
\end{aligned} \tag{14}$$

$$\omega_{All_4^d} = (\omega_{E_t^1} + \omega_{E_t^0}) - 2 \cdot \omega_{A_t^1} + (\omega_{A_t^1} + \omega_{A_t^0}) - 2 \cdot \omega_{C_t^1}^c$$

The graphic representation (Table 4) demonstrates that the analyzed equivalent constructive resizing caused the decrease of the machining allowance's tolerances of all surfaces, improving the technological assurance of precision from this point of view. At the same time, the need to increase the technological precision requirements is lower, a very important fact if the exponential nature of the cost-tolerance functions is taken into account [1]. These two aspects show that the transition from the "chain" dimensional structure to the "displaced fan-shaped" one is the most successful of the analyzed ones.

Table 4. Effects of equivalent constructive resizing from "chain" to "displaced fan-shaped" type

Number of tolerance units <i>a</i> and tolerance grade IT of dimensions:						
constructive	technologic by method:					
	* - Maximum and minimum ** - Idem, with errors compensation					
$A_c, B_c,$ C_c, E_c		A_t	B_t	C_t	E_t	
250 IT13	a* IT*	250 13	145 <12	133 11-12	133 11-12	
	a** IT**	250 13	147 <12	147 <12	147 <12	

The graphic representation (Table 4) demonstrates that the analyzed equivalent constructive resizing caused a decrease in the tolerances of the machining allowances of all surfaces, being improved the technological assurance of the precision from this point of view. At the same time, the need to increase the technological precision requirements is lower, a very important fact if we take into account the exponential character of the cost-tolerance functions [1]. These two aspects show that the transition from the "chain" dimensional structure to the "displaced fan-shaped" one is a successful one among those analyzed.

CONCLUSIONS

CNC technologies have stimulated the constructive design of the mechanical assemblies and parts in terms of the complexity of dimensional and precision structures. The characteristics of the constructive dimensional structures of the parts have the character of geometric requirements. As a functional response, CNC technologies are manifested by the ability to create technological structures similar to the constructive ones and, obviously, to the same extent of complexity. This response is embodied in geometric form through absolute and incremental programming modes, modes that allow the geometric reproduction of constructive dimensional structures through dimensional modules of the "fan-shaped", "displaced fan-shaped" and "chain" type. In technological dimensional structures, physical and technical phenomena are strongly manifested.

Through physical and technical phenomena, the characteristics (value, tolerance) of a technological dimension in a complex dimensional structure are also influenced by the characteristics of other technological dimensions, and by the characteristics of machining allowances. Systemic constraints are manifested by three structural effects: a) increasing precision requirements for technological dimensions, b) increasing the tolerances of machining allowances by cumulating all the tolerances of previous and current technological dimensions along the dimensional chain starting from the technological base, c) error compensation, as a result of which both the tolerances of machining allowances and the tolerances of technological dimensions are reduced. In this context, a technological dimension that is part of a complex structure is accepted if, as a result of the manifestation of structural effects, the tolerance of the machining allowance does not exceed the technological assurance limit for increased precision requirements.

The most favorable is the "fan-shaped" dimensional structure, followed by the "displaced fan-shaped" type. Unfavorable is the "chain" type structure. with major structural effects. These different structural effects are due to the length of the dimensional chains from the technological base, respectively: 1, 2, and 4.

If at the constructive design stage, technologically acceptable dimensional structures are not achieved, equivalent constructive resizing of the part in diverse variants with the evaluation of structural effects can be resorted to. The equivalent constructive resizing from the "displaced fan-shaped" type to the "fan-shaped" type leads to a decrease in the tolerances of manufacturing allowances, but imposes requirements for increased accuracy for some of the technological dimensions. A similar situation is observed in the case of equivalent constructive resizing from "chain" to "displaced fan-shaped" type. With acceptable effects is the equivalent constructive resizing from "chain" to "displaced fan-shaped" structure type.

Real technological dimensional structures can be very complex with sufficiently long chain-type components. Reducing the length of the chains can make equivalent constructive resizing a real tool for increasing the capability of CNC technologies.

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