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Calculation of linear technological dimensions based on the results of workpiece control

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Calculation of linear technological dimensions based on the results of workpiece control

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Abstract. It is necessary to provide optimal processing conditions for each particular initial workpiece, based on reliable information about the allowances at each transition, during processing on software machines. However, according to the existing methods, the required dimensions of the initial workpiece are determined as a result of the calculation, while the same dimensions can already be known as a result of the control of the workpieces already prepared, i.e., known in advance and should be taken as initial in the calculation. The article presents a method of calculation that solves the given problem, including three main points: calculation of relatively constant dimensional accuracy parameters – technological tolerances, calculation of conditionally variable size-accuracy parameters – allowances and calculation of technological dimensions, ensuring the removal of previously calculated allowances.
Keywords: linear technological dimensions, workpiece, general allowance, operational allowance.

1. Introduction

Technological dimensional calculations are an indispensable stage in the engineering process and determine the quality and economy of production [1, 2, 3, 4, 5]. At present, it is necessary to provide optimal processing conditions for each particular initial workpiece, based on reliable information about the allowances at each transition, during processing on software machines. However, according to the existing methods, the required dimensions of the initial workpiece are determined as a result of the calculation, while the same dimensions can already be known as a result of the control of the workpiece already prepared, i.e., known in advance and should be taken as initial in the calculation.

A method of calculation of linear technological dimensions was proposed, in which the dimensions of the workpiece were taken as initial data in determining the technological dimensions [6]. However, according to this method, the dimensions of the workpiece are determined by the standards for the design of workpiece, i.e. it is assumed that the dimensions of the workpiece must have significant tolerances in comparison with the tolerances of the dimensions of the workpiece as a result of their control.

Below we propose the upgraded method based on the method described in the source [6], which takes into account the requirement for preliminary calculation of the technological dimensions for each particular workpiece with known high precision dimensions based on the results of their control

2. Upgraded method of calculation of linear technological dimensions

We will consider the linear dimensions, these dimensions for the finished part - design, are known - ‘Figure 1’: S_1 = $75_{-0,4}$ mm, S_2 = $25_{-0,35}$ mm, S_3 = $26,5^{+0,1}$ mm, S_4 = $12^{+0,43}$ mm.

The method includes the following stages.

1. Control of dimensional and precision parameters of the workpiece.

All dimensions of the workpiece are controlled according to the drawing of the workpiece ‘Figure 2’.

In the drawing, the sizes with the departures to which the prepared workpieces should correspond are indicated. However, each particular workpiece has its dimensions with the departures, which can be determined by high precision measuring. Let the measurement results be the following (see ‘Figure 2’): $A_{0.1}$ = 19,6±0,1 mm, $A_{0.2}$ = 32,4±0,1 mm, $A_{0.3}$ =50±0,1 mm.

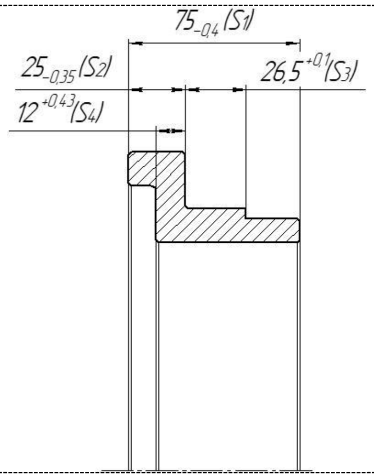

Figure 1. Detail drawing "Bushing"

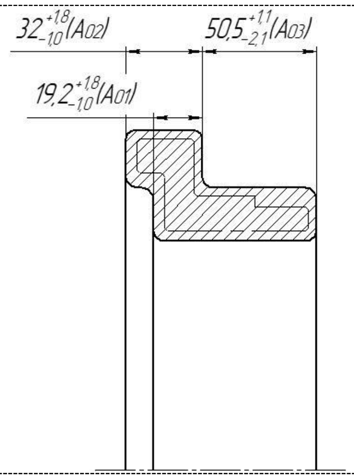

Figure 2. Workpiece drawing of the part "Bushing"

2. Determination of parameters of general processing allowances.

According to the known method [1], a processing scheme ‘Figure 3’ and a graph are constructed according to the technological process ‘Figure 4’.

On the graph ‘Figure 4’ new edges are introduced - general allowances for processing Z_3, Z_7, Z_8, Z_{13}, which are shown by thickened wavy lines. The indices of the general allowances are taken from the boundary number of the finished part, on which the general allowances are located. Then, dimensional chains are detected along the graph and equations of size chains are formed, which include general allowances Z_i, the dimensions of the workpiece $A_{0.i}$, and the design dimensions of S_i.

We will calculate using the average dimension, then we compile two systems of equations. The first system of equations will include the average values of the dimensions - the general allowances Z_{im}, the dimensions of the workpiece $A_{0.im}$, and the design dimensions of S_{im}. In the second system of equations - the errors of the general allowances δZ_i, the tolerances for the dimensions of the workpiece $\delta A_{0.i}$ and the tolerances for the design dimensions δS_i.

For each general allowance, it is possible to write down three equations, into which there are two unknowns - general allowances, only 12 equations.

By eliminating repetitive pairs of general allowances, and by expressing some general allowances through other equations, these can be reduced to three equations, each of which includes the same general allowance, for example, Z_{8m}

$$\begin{gathered} Z_{7m} - S_{4m} + S_{2m} + Z_{8m} - A_{0.1m} = 0, \\ Z_{3m} + S_{2m} + Z_{8m} - A_{0.2m} = 0, \\ Z_{13m} - A_{0.3m} - Z_{8m} - S_{2m} + S_{1m} = 0. \end{gathered} \quad (1)$$

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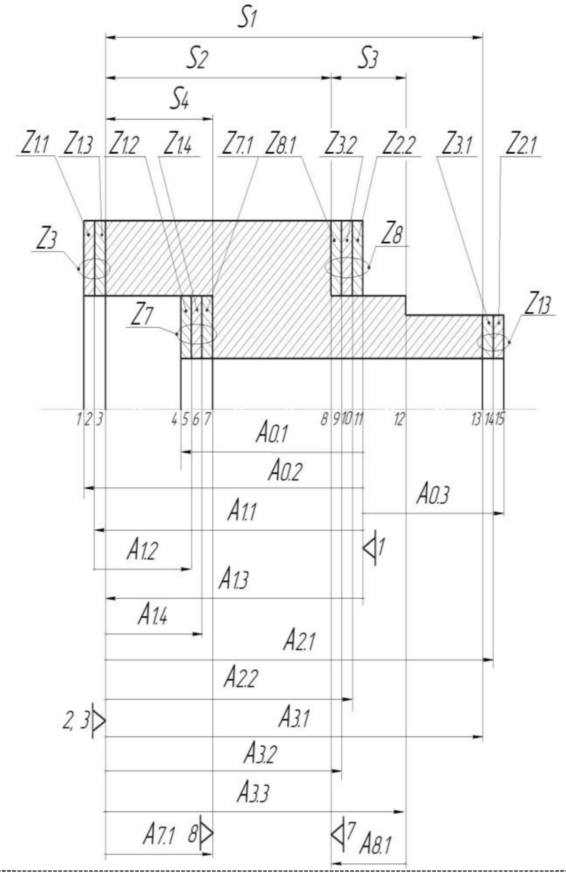

Figure 3. Processing scheme

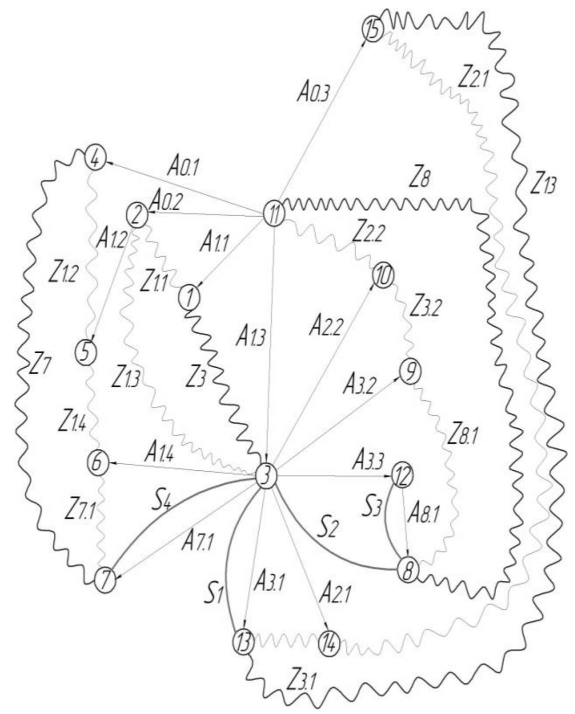

Figure 4. Graph of technological dimensional chains

From this we obtain the error equations for the general allowances δZ_i.

$$
\begin{aligned}
\delta Z_7 &= \delta S_4 + \delta S_2 + \delta Z_8 + \delta A_{0.1}, \\
\delta Z_3 &= \delta S_2 + \delta Z_8 + \delta A_{0.2}, \\
\delta Z_{13} &= \delta A_{0.3} + \delta Z_8 + \delta S_2 + \delta S_1.
\end{aligned}
\tag{2}
$$

However, the number of unknowns - four in the received systems (Z_{7m}, Z_{3m}, Z_{13m}, Z_{8m} for the first system and δZ_7, δZ_3, δZ_{13}, δZ_8 - for the second) is more than the number of equations - three for both systems, therefore for each system there is an infinite number of solutions. In order to obtain a unique solution, it is necessary to someway reduce the number of unknowns or increase the number of equations. However, the number of equations can not be increased, since their number is determined by the structure of the dimensional constraints, so it remains possible only to reduce the number of unknowns. Let's pay attention that in systems of the equations parameters of one of the general allowances (Z_{8m}, δZ_8) are present in all corresponding equations. If someway to determine these parameters, the number of unknowns will be reduced by one, and the system of equations will have unique solutions.

The general allowance Z_8 is located on the initial base (the base on the first operation), it consists of three operational allowances $Z_{2.2}$, $Z_{3.2}$ and $Z_{8.1}$. Knowing the parameters of operational allowances, you can determine the parameters of the general allowance. For a general allowance, it is possible to determine its minimum required value equal to the sum of the minimum required operational allowances, and an error equal to the sums of the expected errors in the components of the operational allowances, therefore, its average dimension and error can be determined.

Assigned to the minimum necessary values of the operating allowances on the initial database, perform their summation and determine the minimum required general allowance on the initial base (Z_{min8}) and similar values of the general allowances on the other workpiece surfaces (Z_{min7}, Z_{min3}, Z_{1min13}).
The minimally necessary values of the general allowances are equal to the sums of the minimum required operational allowances ($Z_{mini.j}$), assigned according to the reference data, depending on the number of machining of the workpiece surface (for example, at the first machining - 0,49 mm, at the second - 0,2 mm, third - 0,05 mm).

$$Z_{min8} = Z_{min2.3} + Z_{min3.2} + Z_{min8.1} = 0{,}49 + 0{,}2 + 0{,}05 = 0{,}74 \text{ mm.}$$

$$Z_{min7} = Z_{min1.2} + Z_{min1.4} + Z_{min7.1} = 0{,}49 + 0{,}2 + 0{,}05 = 0{,}74 \text{ mm.}$$

$$Z_{min3} = Z_{min1.1} + Z_{min1.3} = 0{,}49 + 0{,}2 = 0{,}69 \text{ mm.}$$

$$Z_{min13} = Z_{min2.1} + Z_{min3.1} = 0{,}49 + 0{,}2 = 0{,}69 \text{ mm.}$$

Assigning to the reference data the technological tolerances for dimensions ($\delta A_{1.3}$= 0,584, $\delta A_{2.2}$=0,210, $\delta A_{3.2}$=0,084, $\delta A_{3.3}$=0,300, $\delta A_{8.1}$=0,033), which form on the graph 'Figure 4' contours with the operational tolerances of the initial database ($Z_{2.2}$, $Z_{3.2}$, $Z_{8.1}$), after which we determine the expected errors in the operating allowances on the source database.

$$\delta Z_{2.2} = \delta A_{1.3} + \delta A_{2.2} = 0{,}584 + 0{,}210 = 0{,}794 \text{ mm.}$$

$$\delta Z_{3.2} = \delta A_{2.2} + \delta A_{3.2} = 0{,}210 + 0{,}084 = 0{,}294 \text{ mm.}$$

$$\delta Z_{8.1} = \delta A_{3.2} + \delta A_{3.3} + \delta A_{8.1} = 0{,}084 + 0{,}300 + 0{,}033 = 0{,}417 \text{ mm.}$$

Implementing their summation, we determine the error of the general allowance δZ_8 on the initial base.

$$\delta Z_8 = \delta Z_{2.2} + \delta Z_{3.2} + \delta Z_{8.1} = 0{,}794 + 0{,}294 + 0{,}417 = 1{,}505 \text{ mm.}$$

After that, we determine 'by the equations (2)' the errors of the other general allowances (δZ_7, $\delta Z3$, δZ_{13}). To calculate the 'equations (2)', you must first find the values of design tolerances and dimensions tolerances of the workpiece. These values are determined according to the dimensions indicated above: : δS_1 = 0,4 mm, δS_2 = 0,35 mm, δS_4 = 0,43 mm, $\delta A_{0.2}$ =0,2 mm, $\delta A_{0.2}$ =0,2 mm, $\delta A_{0.3}$ =0,2 mm.

$$\delta Z_7 = \delta S_4 + \delta S_2 + \delta Z_8 + \delta A_{0.1} = 0{,}43 + 0{,}35 + 1{,}505 + 0{,}2 = 2{,}485 \text{ mm.}$$

$$\delta Z_3 = \delta S_2 + \delta Z_8 + \delta A_{0.2} = 0{,}35 + 1{,}505 + 0{,}2 = 2{,}055 \text{ mm.}$$

$$\delta Z_{13} = \delta A_{0.3} + \delta Z_8 + \delta S_2 + \delta S_1 = 0{,}2 + 1{,}505 + 0.35 + 0{,}4 = 2{,}455 \text{ mm.}$$

We determine the average general allowance Z_{8m} on the initial base for the minimally necessary general allowance Z_{min8} and the tolerance of the general allowance δZ_8.

$$Z_{8m} = Z_{min8} + 0{,}5 \cdot \delta Z_8 = 0{,}74 + 0{,}5 \cdot 1{,}505 = 1{,}4925 \text{ mm.}$$

Then, 'using equations (1)', we determine the average values of the remaining general allowances. The average dimensions of S_{im} and $A_{0.im}$ entering 'into equations (1)' are calculated from the given drawing dimensions: S_{1m} = 74,8 mm, S_{2m} = 24,825 mm, S_{4m} = 12,215 mm, $A_{0.1m}$ = 19,6 mm, $A_{0.2m}$ = 32,4 mm, $A_{0.3m}$ = 50 mm.

$$Z_{7m} = S_{4m} - S_{2m} - Z_{8m} + A_{0.1m} = 12{,}215 - 24{,}825 - 1{,}4925 + 19{,}6 = 5{,}4975 \text{ mm.}$$

$$Z_{3m} = - S_{2m} - Z_{8m} + A_{0.2m} = - 24{,}825 - 1{,}4925 + 32{,}4 = 6{,}0825 \text{ mm.}$$

$$Z_{13m} = A_{0.3m} + Z_{8m} + S_{2m} - S_{1m} = 50 + 1{,}4925 + 24{,}825 - 74{,}8 = 1{,}5175 \text{ mm.}$$

We determine the actual values of the minimum general allowances and perform the verification of the received real minimum values of the general allowances for compliance with the requirement $Z_{dmin\ i} \geq$

$Z_{min\ i}$. If this requirement is not met, then it is necessary to increase the actual value of the minimum general allowance on this surface to the required minimum required value by correcting the actual minimum general allowance on the initial base.

$$Z_{dmin7} = Z_{m7} - 0{,}5 \cdot \delta Z_7 = 5{,}4975 - 0{,}5 \cdot 2{,}485 = 4{,}255 \text{ mm} \geq Z_{min7} = 0{,}74 \text{ mm}.$$

$$Z_{dmin3} = Z_{m3} - 0{,}5 \cdot \delta Z_3 = 6{,}0825 - 0{,}5 \cdot 2{,}055 = 5{,}055 \text{ mm} \geq Z_{min3} = 0{,}69 \text{ mm}.$$

$$Z_{dmin13} = Z_{m13} - 0{,}5 \cdot \delta Z_{13} = 1{,}5175 - 0{,}5 \cdot 2{,}455 = 0{,}29 \text{ mm} \leq Z_{min13} = 0{,}69 \text{ mm}.$$

The resulting negative value of the allowance Z_{dmin13} does not satisfy the requirement $Z_{dmin\ i} \geq Z_{min\ i}$. To ensure the minimum required positive value of this allowance Z_{min13} = 0,69 mm, it is required to increase the obtained value Z_{dmin13} = 0,29 mm by $\Delta Z = Z_{min13} - Z_{dmin13}$ = 0,69 – 0,29 = 0,4 mm due to the increase of the minimum general allowance on surface - the initial base to the value of Z_{dmin8} = 0,74 + 0,4 = 1,14 mm. Then the values of Z_{8m}, Z_{13m} and Z_{dmin13} increase, and the values of Z_{3m}, Z_{dmin3} and Z_{7m}, Z_{dmin7} decrease by 0.4 mm.

$$Z_{8m} = 1{,}4925 + 0{,}4 = 1{,}8925 \text{ mm}.$$

$$Z_{dmin8} = 1{,}14 \text{ mm} \geq Z_{min8} = 0{,}74 \text{ mm}.$$

$$Z_{13m} = 1{,}5175 + 0{,}4 = 1{,}9175 \text{ mm}.$$

$$Z_{dmin13} = 0{,}29 + 0{,}4 = 0{,}69 \text{ mm} \geq Z_{min13} = 0{,}69 \text{ mm}.$$

$$Z_{3m} = 6{,}0825 - 0{,}4 = 5{,}6825 \text{ mm}.$$

$$Z_{dmin3} = 5{,}055 - 0{,}4 = 4{,}655 \text{ mm} \geq Z_{min3} = 0{,}69 \text{ mm}.$$

$$Z_{7m} = 5{,}495 - 0{,}4 = 5{,}0975 \text{ mm}.$$

$$Z_{dmin7} = 4{,}255 - 0{,}4 = 3{,}855 \text{ mm} \geq Z_{min7} = 0{,}74 \text{ mm}.$$

The obtained values are satisfy the requirement $Z_{dmin\ i} \geq Z_{min\ i}$.
Based on the obtained actual values of the minimum general allowances, we calculate the actual values of the minimum operating allowances that provide the values of the actual minimum general allowances.
This calculation is carried out by distributing the above actual values of the minimum general allowances for components - the actual minimum operating allowances in accordance with the coefficient K_i, which takes into account the dependence of the amount of the overshot allowance on the side of the number of processing (table 1).

Table 1. Determination of actual minimum operating allowances.

Actual minimum general allowance			Actual minimum operating allowance			
Index	Number of processing	Value, mm	Index	Processing number	Coefficient K_i	Value, mm
Z_{dmin3}	2	4.655	$Z_{dmin1.1}$	1	5/7	3.325
			$Z_{dmin1.3}$	2	2/7	1.33
Z_{dmin7}			$Z_{dmin1.2}$	1	5/8	2.409
	3	3.855	$Z_{dmin1.4}$	2	2/8	0.964
			$Z_{dmin7.1}$	3	1/8	0.482
Z_{dmin8}			$Z_{dmin2.2}$	1	5/8	0.712
	3	1.14	$Z_{dmin3.2}$	2	2/8	0.285
			$Z_{dmin8.1}$	3	1/8	0.142
Z_{dmin13}	2	0.69	$Z_{dmin2.1}$	1	–	0.49
			$Z_{dmin3.1}$	2	–	0.2

The received actual minimum values of operational allowances are the initial data for the program for calculating the linear technological dimensions "DIAMOND" [7].

3. Determination of operating tolerances that ensure the values of errors in common allowances.

Previously, according to the reference data, technological tolerances for all technological dimensions are excluded, excluding the previously assigned tolerances for the dimensions of the workpiece ($\delta A_{0.1}$, $\delta A_{0.2}$, $\delta A_{0.3}$) and the dimensions associated with the operating allowances on the initial base ($\delta A_{1.3}$, $\delta A_{2.2}$, $\delta A_{3.2}$, $\delta A_{3.3}$, $\delta A_{8.1}$): $\delta A_{1.1}$ = 0,365 mm, $\delta A_{1.2}$ = 0,149 mm, $\delta A_{1.4}$ =0,07 mm, $\delta A_{2.1}$ = 0,30 mm, $\delta A_{3.1}$ = 0,12 mm, $\delta A_{7.1}$ = 0,027 mm.

Using by the computer program "DIAMOND" [7], the expected errors in the design dimensions ρS_i and the general allowances ρZ_i are determined with the initial process tolerances assigned by the program.

For design tolerances and errors in general allowances, which are less than the expected errors at the initial designed values of technological tolerances, the corresponding technological tolerances are provided compressed. For design tolerances and errors in general allowances, which are greater than the expected errors, i.e. allow the expansion of technological tolerances, the corresponding technological tolerances are provided expand. We get the final tolerances:

$$\delta A_{1.1} = 0{,}710\text{-}0{,}075\text{=}0{,}635 \text{ mm},$$

$$\delta A_{1.2} = 0{,}18\text{-}0{,}031\text{=}0{,}149 \text{ mm},$$

$$\delta A_{1.4} = 0{,}07\text{-}0{,}018\text{=}0{,}052 \text{ mm},$$

$$\delta A_{2.1} = 0{,}300\text{+}0{,}3355\text{=}0{,}6355 \text{ mm},$$

$$\delta A_{3.1} = 0{,}120\text{+}0{,}280\text{=}0{,}4 \text{ mm}.$$

4. Calculation of technological dimensions, including the dimensions of the workpiece.

It is carried out according to the known method by using the program "DIAMOND". The dimensions of the workpiece($A_{0.1}$ = 19,7±0,1 мм, $A_{0.2}$ = 32,5±0,1 мм, $A_{0.3}$ =50±0,1 мм) obtained as a result of calculation (table 2) can differ from the previously specified dimensions ($A_{0.1}$ = 19.6 ± 0.1 mm, $A_{0.2}$ = 32.4 ± 0.1 mm, $A_{0.3}$ = 50 ± 0.1 mm) due to the adjustment of the technological dimensions during the calculation . The final dimensions of the workpiece are determined according to the standard, together with the operational technological dimensions calculated according to the program.

Table 2. Linear technological dimensions.

Sign	Nominal value	Upper deviation	Lower deviation
$A_{0.1}$	19.700	0.100	-0.100
$A_{0.2}$	32.500	0.100	-0.100
$A_{0.3}$	50.000	0.100	-0.100
$A_{1.1}$	29.050	0.000	-0.635
$A_{1.2}$	11.900	0.149	0.000
$A_{1.3}$	27.050	0.000	-0.584
$A_{1.4}$	11.650	0.052	0.000
$A_{2.1}$	75.850	0.000	-0.635
$A_{2.2}$	25.750	0.000	-0.210
$A_{3.1}$	75.000	0.000	-0.400
$A_{3.2}$	25.250	0.000	-0.084
$A_{3.3}$	51.540	0.000	-0.300
$A_{7.1}$	12.200	0.027	0.000
$A_{8.1}$	26.550	0.033	0.000

5. Verification of ensuring minimum operating allowances.

It is performed by a well-known method by using the program "DIAMOND-B", designed to solve the inverse problem of dimensional calculations [8]. For the case under consideration, all actual minimum operating allowances are provided. If the actual minimum operating allowances are not provided, it is checked whether the corresponding minimum required operational allowances are ensured. If they are ensured, the calculation is completed, otherwise the actual minimum general allowances and actual minimum operating allowances are redistributed to increase the unrealized actual minimum operating allowances, and the calculation is repeated in accordance with stages 3 and 4 until the minimum required operational allowances are provided.

3. Conclusion

The presented example of calculation of linear technological dimensions includes three main points: calculation of relatively constant dimensional accuracy parameters - technological tolerances, calculation of conditionally variable size-accuracy parameters - allowances and calculation of technological dimensions, ensuring the removal of previously calculated allowances. It is possible to take into account the results of control of the initial workpiece when calculating the technological dimensions.

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