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Purposeful dimensioning of details, processed on CNC machine tools

Silviya Salapateva
Faculty of Mechanical Engineering
Technical University of Sofia, Plovdiv Branch
Plovdiv, Bulgaria
sisisal@tu-plovdiv.bg

Abstract. **The choice of technologies for mechanical processing of details is closely related to the requirements toward dimensional accuracy, shape and mutual position of their surfaces, which are set by the constructor. Wrong dimensioning in many cases leads to complications and raising the cost of mechanical processing. The present paper makes a comparative analysis of different options for dimensioning a stepped shaft, machined on a CNC lathe. Recommendations for purposeful dimensioning of similar details are made based on the above-mentioned analysis.**

Keywords: Mechanical engineering, dimensioning, CNC machine tools.

I. INTRODUCTION

Dimensioning is an important and responsible stage in creating products of mechanical engineering. It follows a system of principles and procedures, related to the function of the different detail surfaces, to the place and role of the detail in the assembled unit and the product, to its existing kinematic, dynamic and dimensional relationships [1], [2], [3]. At the same time, the detail construction should comply with the manufacturability requirements in order to be produced at the lowest possible production costs [4]. All these requirements are met at the stage of technical preparation for production.

In the process of technological preparation, when the technologies for the implementation of the individual machining operations are under development, in certain cases it is necessary to redimension the details and so-called technical sizing is performed. Most frequently this is required when the dimensional bases, chosen by the designer, cannot be used as technological bases, or when very complex and expensive adjustments are needed to make the technological and the design bases compatible.

The replacement of the designer dimensioning by a technological one in all cases increases the requirements for the accuracy of processing. This is due to the fact, that the dimensions set by the designes, which must ultimately be achieved during processing, are the closing components of the technological dimensional chains. Therefore, the tolerances of the technological dimensions are smaller than those, of the design ones [5], [6].

In a number of cases, as a means of reconciling the design bases with the technological ones, processing of the design base is applied, with the same fixing of the workpiece as for processing of the other surfaces. The approach is known as the principle of using tuning technological bases [6], [7].

The use of tuning technological bases provides another advantage as well. It is proved that the dimensions from a tuning technological base are achieved with higher accuracy than those, set by a design technological base [8]. This is explained by the existence of a correlation between the sizes of the design technological base, processed in one establishment of the part. Then the special case of the summation theorem of the variances of a set of random variables, according to which the variance of the closing component of the dimensional chain is a sum of the variances of the constituent components, is not applicable. The correlation between the constituent units should also be taken into account [9], [10]. This fact gives reasons to use technological dimensioning from tuning technological bases when working with CNC machine tools [11]. In a number of cases this is necessary due to the connection of the coordinate origin for dimensioning with certain surfaces of the part, which are processed at the beginning of the operation and are different from the design base.

II. MATERIALS AND METHODS

When machining workpieces on CNC lathes, the coordinate system of the part is most often associated with the right-hand face of the workpiece. This coordinate origin is translated relative to the machine coordinate origin, usually associated with the spindle face. To materialize the coordinate system of the workpiece after its fixing, the first transition is intended to process the face of the workpiece, which will be the

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technological base for the rest of the processed surfaces. Thus, the connection between the coordinate systems of the part and the machine is also ensured.

Determining the position of the remaining front surfaces with respect to the coordinate origin can be performed in different ways. Fig. 1 presents the possible dimensioning of a model detail.

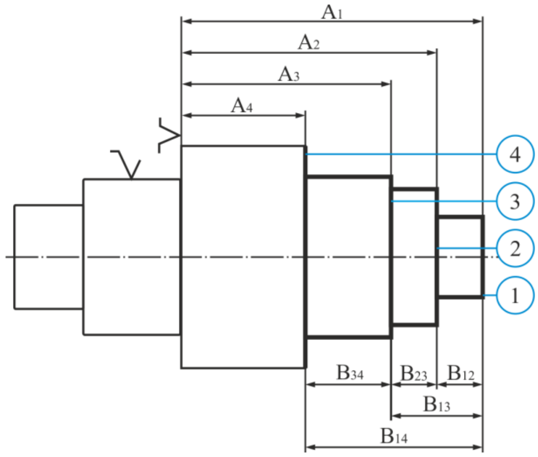


Fig. 1. Dimensioning of a stepped shaft for processing parts on a CNC lathe ($A_1 = 31^{+0,1}$; $A_2 = 26^{+0,1}$; $A_3 = 22^{+0,1}$; $A_4 = 13^{+0,1}$).

Four front surfaces are processed. By processing face 1, the position of the coordinate system of the workpiece with respect to the face of the chuck is set. The distance between them is A_1. The position of the remaining three faces can be determined in three ways:

- From a design technological base (the face of the chuck) by the dimensions A_2, A_3 and A_4;
- From a tuning technological base (the face of the part) by the dimensions B_{12}, B_{13} and B_{14};
- From a tuning technological base (the face of the part) by the chain dimensions B_{12}, B_{23} and B_{34}.

A database, obtained in result of machining a batch of 41 details on a CNC lathe will be used to compare and evaluate the three dimensioning options [12] - [15]. In the sequence for performing the operation, the transitions for turning the cylindrical surfaces are alternated with the transitions for trimming their adjacent faces.

The nature of the technological process is represented by the scatter diagrams of the coordinate dimensions A, shown in Fig. 2.

The following statistical information can be obtained from the database of the coordinate dimensions A, set by a design technological base:

- Adequate regression equations, representing the influence of the systematic factors on dimensional scattering;
- Instantaneous scatter fields ω, representing the influence of the random factors on dimensional scattering;
- Total scatter fields ω_Σ, illustrating the influence of random and systematic factors on dimensional scattering;
- Correlation coefficientsρ, representing the interdependence of the coordinate dimensions.

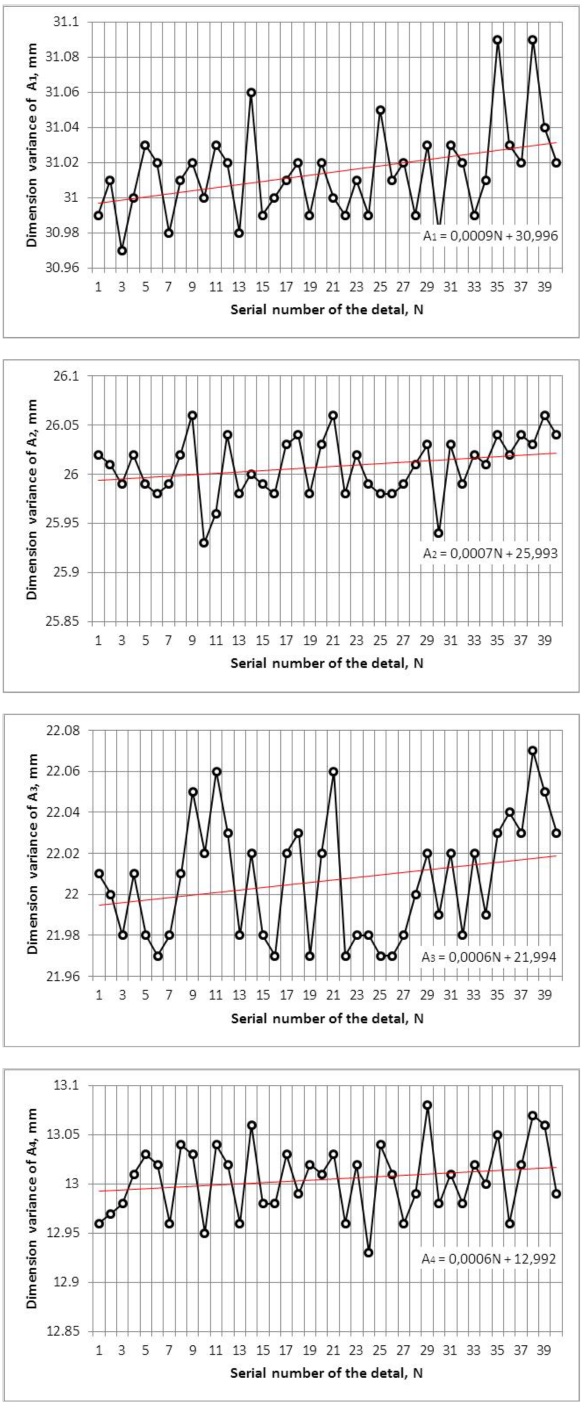


Fig. 2. Scatter diagrams of the dimensions from a design technological base

The regression equations are determined by the least square method. Microsoft Office Excel is used for the purpose. For each of the coordinate dimensions, they are presented in Fig.2.

The instantaneous scatter field of the dimensions around the regression equation is defined by the variance S^2:

$$S^2 = \frac{\sum_{i=1}^{N}(A_i - \bar{A}_i)^2}{N-1}, \tag{1}$$

$$\bar{A}_i = \frac{\sum_{i=1}^{N} A_i}{N}, \qquad (2)$$

where A_i is the measured dimension of the detail with a serial number i, $\bar{A}_i$ - size mean from the regression equation at N = i; N – total number of measured details.

For a known variance, the instantaneous scatter field ω is found by the expression:

$$\omega = 2Sk_{\alpha,\gamma,N}, \qquad (3)$$

where $S = +\sqrt{S^2}$ is the root-mean-square deviation; $k_{\alpha,\gamma,N}$ – statistical coefficient of scattering, which is tabularly determined from the number N of measured details and the accepted significance level α and confidence probability γ.

The total scatter field ω_Σ is defined as the sum of the instantaneous scatter field and the change of the average value of the dimension $\Delta\bar{A}$ caused by the systematic factors. If the regression equation is presented in the general form $\bar{A} = \tilde{a} + \tilde{b}N$, the change in the mean value of the dimension is found by the expression $\Delta\bar{A} = \tilde{b}N$. In that:

$$\omega_\Sigma = \omega + \tilde{b}N. \qquad (4)$$

The coefficients of correlation are determined using Microsoft Office Excel.

Analogous statistical information can be obtained for dimensioning from a tuning technological base. For this purpose dimensions B are defined as derivatives of dimensions A:

$$\begin{aligned} B_{12} &= A_1 - A_2; \\ B_{13} &= A_1 - A_3; \\ B_{14} &= A_1 - A_4; \\ B_{23} &= A_2 - A_3; \\ B_{34} &= A_3 - A_4. \end{aligned} \qquad (5)$$

The scatter diagrams of the dimensions from a tuning technological base are presented in Fig. 3.

It is noteworthy that for these dimensions the influence of systematic factors is very weak. The regression equations for the average value of the dimensions are nearly parallel to the abscissa. The coefficients $\tilde{b}$ in the regression equations are statistically insignificant and the total scatter field is equal to the instantaneous one. Formula (3) is used for its determination.

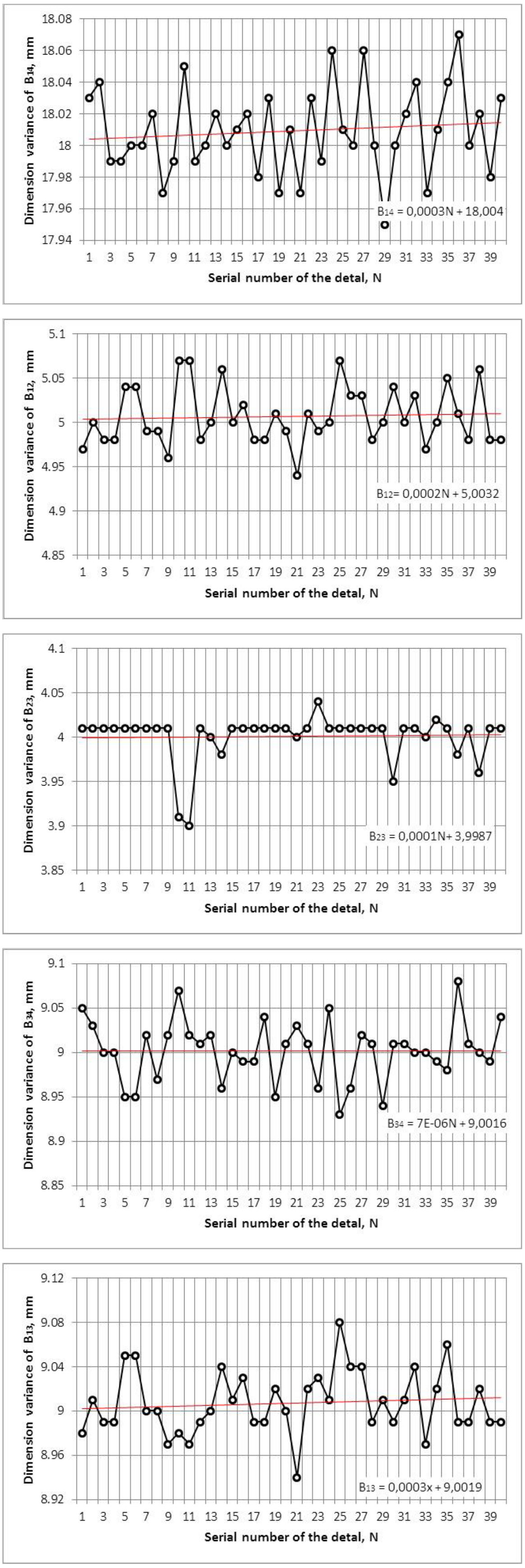


Fig. 3. Scatter diagrams of the dimensions from a tuning technological base.

III. RESULTS AND DISCUSION

The obtained results from the statistical analysis of the technological process are presented in Table 1.

TABLE 1 STATISTICAL CHARACTERISTICS OF THE TECHNOLOGICAL PROCESS

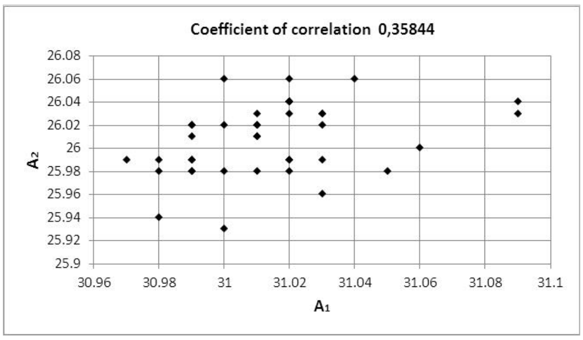
Dimension	Characteristic			
	S^2	S	ω	ω_Σ
A_1	56.10^{-5}	0,0242	0,19	0,227
A_2	86.10^{-5}	0,0294	0,231	0,26
A_3	77.10^{-5}	0,0278	0,219	0,243
A_4	121.10^{-5}	0,0347	0,273	0,298
B_{12}	108.10^{-5}	0,0328	0,258	0,258
B_{13}	81.10^{-5}	0,0284	0,223	0,223
B_{14}	76.10^{-5}	0,0275	0,217	0,217
B_{32}	72.10^{-5}	0,0267	0,212	0,211
B_{34}	119.10^{-5}	0,0345	0,271	0,271

From the scatter diagrams and regression equations it can be concluded that there is a systematic displacement of the centre of clustering in the direction of an increase in the average size for the dimensions from a design technological base. This is an indication that the dimensional tool wear is influencing on the process of dimensioning. Such an influence is not observed when dimensioning from a tuning technological base is performed.

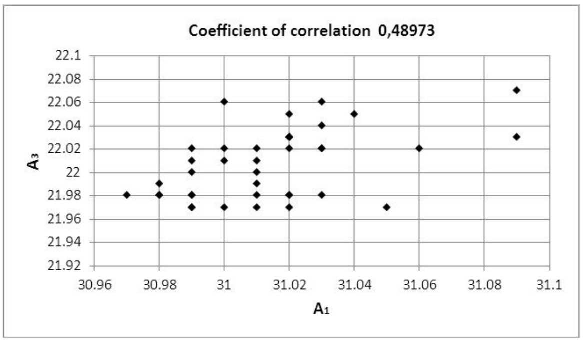
There is a correlation between the dimensions of a design technological base, although not very pronounced. The correlation coefficients range from 0,36 to 0,66 (Table 2 and Fig.4).

TABLE 2 COEFFICIENTS OF CORRELATION BETWEEN THE DIMENSIONS A

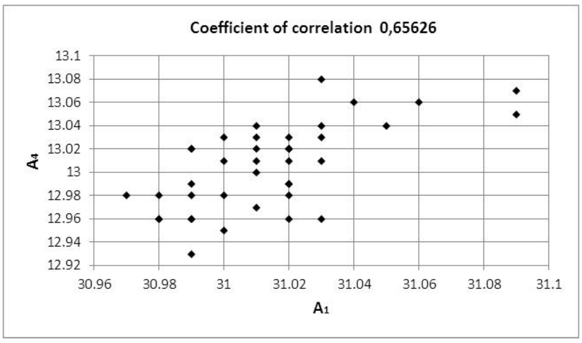
Coefficients of correlation				
$\rho_{A_1A_2}$	$\rho_{A_1A_3}$	$\rho_{A_1A_4}$	$\rho_{A_2A_3}$	$\rho_{A_3A_4}$
0,35844	0,48973	0,65626	0,60832	0,46508



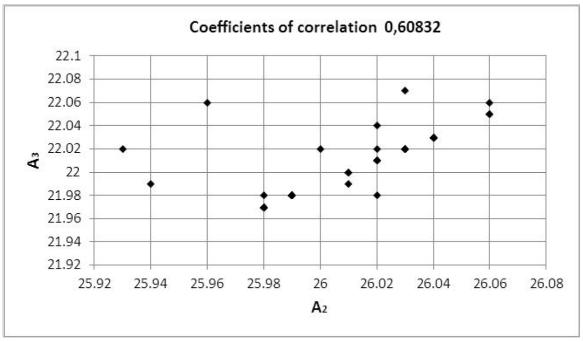
a. Correlation matrix between A_1 and A_2



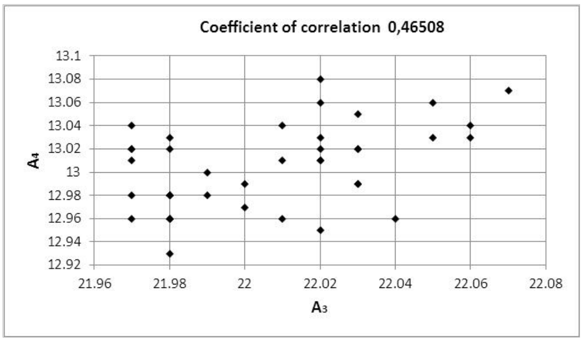
b. Correlation matrix between A_1 and A_3



c. Correlation matrix between A_1 and A_4



d. Correlation matrix between A_2 and A_3



f. Correlation matrix between A_3 and A_4

Fig. 4. Correlation matrices between dimensions A

The correlation is due both to the same for all axial dimensions error, arising from fixing the part in the chunk, and to the relatively equal intensity of dimensional tool wear. As a result of the correlation, the dimensions from a tuning technological base have less or comparable scattering to that, of the dimensions from a design technological base. The dimension B_{14} can be considered as an example of the influence of the correlation. From equation (5) it follows that this dimension is the closing component in a dimensional chain with constituent components the dimensions A_1 and A_4. The root-mean-square deviation of B_{14} will be found by the expression:

$$S_{14} = +\sqrt{S_1^2 + S_4^2 - 2\rho_{A_1A_4} S_1 S_4}\ . \qquad (6)$$

If there was no correlation between the dimensions A_1 and A_4 ($\rho_{A_1A_4} = 0$), equation (6) would yield:

$$S_{14} = \sqrt{0,000585 + 0,00121} = 0,0424\ .$$

Correspondingly $\omega_{B_{14}} = 2.3,936.0,0424 = 0,334$ mm.

With established correlation ($\rho_{A_1A_4} = 0,656$) the result will be:

$S_{14} = 0,0263$.

Correspondingly, $\omega_{B_{14}} = 2.3,936.0,0263 = 0,207$ mm.

This result is close to that, established by dimensional control and reflected in Table 1 ($\omega_{B_{14}} = 0,217$ mm).

The presented example confirms the role of the correlation in increasing the accuracy of the dimensions from a tuning technological base. Having in mind that their accuracy is not affected by the dimensional tool wear, it is reasonable to recommend to perform dimensioning from a tuning technological base.

The level of scattering of all dimensions in the particular case is compatible in magnitude. Statistically, their variances are equal. This hypothesis is confirmed by the Cochran G_{max} test:

$G_{max} = \frac{S^2_{max}}{\sum_{i=1}^{9} S_i^2} = 0,151$, which is less than the critical value $G_{0,05;\,8;\,40}$.

IV. Conclusions

The conducted research gives grounds for the following conclusions regarding the processing of stepped shafts on CNC lathes:

- Influence of both random and systematic factors is observed when dimensioning shafts in axial direction from a design technological base, which has a negative impact on the accuracy of processing;
- As a result of the same influence of the error from detail fixing and dimensional tool wear on all dimensions, processed on the same installation, a correlation is observed between the dimensions of a design technological base;
- The presence of a correlation dependence between the dimensions, obtained from a design technological base positively affects the accuracy of the dimensions, obtained from a tuning technological base;
- When dimensioning from a tuning technological base, no significant influence of the dimensional tool wear on the accuracy of the dimensions is observed.

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