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Dynamic Algorithm for Dimensional Sub-Tuning in Turning

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***Abstract*— One of the possibilities for increasing the accuracy when machining a series of parts with a single dimensional adjustment (automatic obtaining of dimensions) is to perform more frequent dimensional sub-tuning. There is a possibility to increase the accuracy of machining through dimensional sub-tuning if working with a complete set of data about the dimensions of the machined parts, and not with small current samples. This opportunity arises from the widespread introduction of computer technology for the purposes of managing the technological processes. The article examines the possibilities for determining the moment for dimensional sub-tuning by using computer analysis of information about the dimensions of the machined parts in real time.**

Keywords— Mechanical engineering, dimension sub-tuning, CNC machine tool.

I. INTRODUCTION

One of the possibilities for increasing the accuracy when machining a series of parts with a single dimensional adjustment (automatic obtaining of dimensions) is to perform more frequent dimensional sub-tuning. A borderline case is the continuous automatic dimension sub-tuning to compensate for the influence of systematic factors, which change according to a known law [1]. This possibility is practicable in mass and large-scale serial production, when the processes ae well studied and their statistical features are known, including the parameters of the laws of change of systematic factors. In practice, the method of dimension sub-tuning, using control charts, has found wider application. Of the known charts, the tolerance field is used most efficiently and to the fullest, when working with the statistical estimates of the average size value $\bar{X}$ and mean square root deviation S [2, 3]. In this case small current samples are used, for each of which these statistical estimates are calculated. When their value goes outside the control limits, the process is interrupted and dimension sub-tuning is performed. A condition for applying this method is to have the dispersion ω of the dimensions from random factors (instantaneous dispersion field) relatively small. Compared to the dimension tolerance T, the condition T > 2ω must be met. This determines the application of the method in fine mechanical processing while limiting its use in clean processing, where the scattering, caused by random factors, is greater.

II. MATERIALS AND METHODS

There is a possibility to increase the accuracy of machining by dimension sub-tuning, if working with full information about the dimensions of the machine parts, rather than with small current samples. This possibility arises from the widespread introduction of computer technology for the purposes of controlling the technological processes.

When using small current samples, due to their small volume, larger values of the statistical estimates for the instantaneous dispersion field are obtained and thence, larger values of the sub-tuning impulse (the change in the adjusted size) as well. Thus, the total dispersion field is increased.

Using complete information about the dimensions of the machined parts, the change in the average dimension value can be tracked in real time by a regression equation, which represents it as a function of the number of machined parts. For most cases this relationship is a linear regression equation of the type:

$$\bar{X}_n = b_{0n} + b_{1n} n \text{ , } (n = 3, 4, 5, \ldots), \quad (1)$$

where $\bar{X}_n$ is the average dimension value from the regression equation of the part with a serial number n; b_{0n}

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and b_{1n} are statistical coefficients in the regression equation.

A series of regression equations is obtained for the first 3, first 4, first 5 etc. machined parts. As the number of machined parts increases, the confidence interval of the regression equation narrows and, respectively, the accuracy of the estimate for the average value increases [3, 4].

A question arises as to how many parts to limit the sample volume, in order to achieve a specific accuracy of the process. There are two possible approaches to solving this problem:

1. Analytical – based on the relative estimate of the change in the average size value with respect to the size tolerance;
2. Statistical – by setting the relative error of the average value at a certain confidence probability.

The analytical method is based on the fluctuation of the angular coefficient $\tilde{b}_n$ in the regression equation:

$$b_{13} \neq b_{14} \neq b_{15} \neq \dots$$

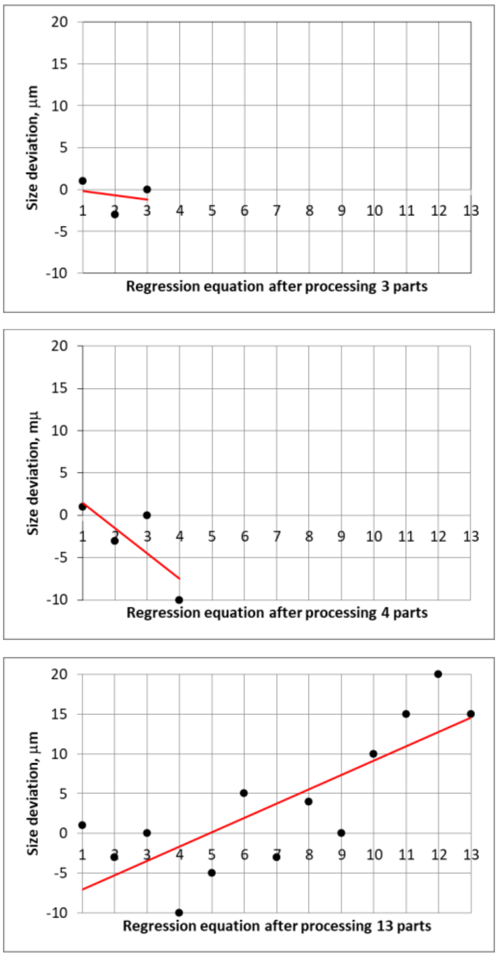
At the beginning, when the data accumulation starts, the angular coefficient fluctuates strongly. This phenomenon can be named plane precession of the regression equation. When the number of machined parts (sample volume) increases, the fluctuation of the angular coefficient decreases, i.e., the precession damps out.

Fig. 1 graphically represents the precession damping as a real process in clean step turning and under the following conditions [5]: nominal dimension of the part D = 58 mm, tolerance T = 0,046 mm; upper limit deviation ES = 0; lower limit deviation EI = -0,046; positioning error ω_p = 9,74 μm; measurement error $\omega_{изм}$ = 5 μm; instantaneous field of dimension dispersion ω = 30 μm; permissible tool wear h_{Dmax} = 60 μm; sample volume for dimension adjustment n_0 = 3.

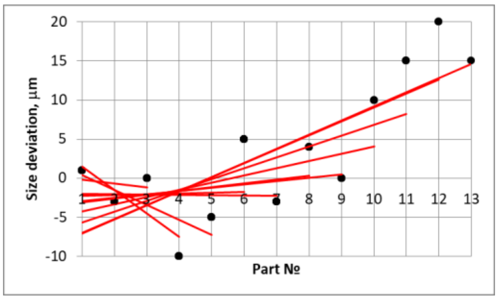
The assumed permissible error of dimension adjustment, which is 10% of the dimension tolerance T., can serve as a criterion for sufficient damping of the precession. Therefore, if the difference in the ends of two consecutive regression equations is less than 10%, it can be assumed that the precession has damped out within acceptable limits:

- $[\varepsilon] = 0{,}1T.$ (2)

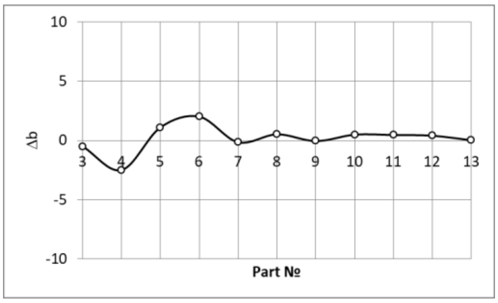
If the difference $\Delta\bar{A}_n$ between two sequential values of the average dimension, determined by the regression equations, is less than 0,1T, it can be considered that the precession has slowed down sufficiently.



a) regression equation



б) dimensioning vector



в) precession damping

Fig. 1. Dynamics of the sizing process

However, to use the last regression equation, in which the precession damping is established, to make a decision for performing sub-tuning, this equation must also be adequate.

The adequacy check is performed using the Fisher criterion. The critical value for the Fisher test F is chosen for degrees of freedom $k_1 = k_2 = n_j - 1$ and significance level $\alpha = 0,05$.

If the regression equation is not adequate, then the next part is machined and the checks for precession damping and adequacy are repeated. The procedure continues until both conditions are simultaneously satisfied.

Hence, the number of parts n, at which it is possible to interrupt the process of machining and perform sub-tuning, will be determined by the condition:

$$\Delta\bar{A}_n = b_{0(n-1)} - b_{0n} + (n-1)b_{1(n-1)} - nb_{1n} \le 0,1T \quad .(3)$$

With the statistical method the sample volume is determined iteratively by the condition [6]:

$$n = \left(\frac{t_{\gamma,k}.S.100}{\Delta_{\gamma,k}.\bar{X}} \right)^2, \quad (4)$$

where $t_{\gamma,k}$ is the Student’s t-statistic at confidence probability γ and degrees of freedom $k = n - 1$; $\Delta_{\gamma,k}$ is the relative error in the average value in %.

III. Results and discusion

To compare the two methods for determining the sample volume, an experimental study was conducted by means of performing clean boring of a batch of cylindrical bushings made of steel 35.

The clean boring was performed with a boring bar cantilevered in the turret of a CNC lathe under the following conditions: machine - CNC lathe LT580; machined material - steel BDS EN 10083-2 C35, hot-rolled pipe ∅40/7; diameter of the machined hole D = 29,0 mm; size tolerance T = 50 μm; diameter of the cutting tool – 20 mm; length of the cantilever part of the tool L = 100 mm; hard-alloy plate made of P15, type TPUN 110302; main tool setting angle $\chi_r = 90°$; cutting speed V_c = 120 m/min; feed f = 0,05 mm/rev; average cutting depth a_p = 0,3 mm; measuring instrument – internal gauge with a measuring clock with a division value of 0,001 mm.

The experimental scheme is presented in Fig 2.

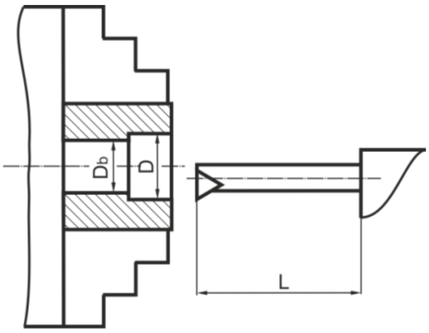


Fig. 2. Experimental scheme (Db – diameter of the workpiece; D – diameter of the machine part)

The analytical method for determining the sample volume was applied initially. A series of workpieces are machined with a single dimension adjustment. The resulting dimensions are measured and entered into a personal computer for statistical processing. After the third, fourth, fifth etc. machined parts, the regression equations are determined and the check (2) is performed. In case of sufficient damping of the precession, the change in the adjusted dimension is determined:

$$\Delta\bar{A}_n = \bar{X}_n - \bar{X}_3, \quad (5)$$

If the difference (4) is statistically significant, then dimension sub-tuning is performed with a magnitude $\Delta\bar{A}_n$ to compensate for the systematic error. If the difference (5) is statistically insignificant, the work continues until reaching significance. Then sub-tuning is performed with the reached difference.

After the dimension sub-tuning, new accumulation of data begins, and similar statistical processing follows, as with the first group of parts. The obtained results are given in Table 1 and graphically represented by the scatter diagram in Fig.3.

Table 1 Results of clean boring of a batch of cylindrical bushings using an analytical method for dimensional sub-tuning

№ of the part	Size, mm	№ of the part	Size, mm	№ of the part	Size, mm
1	29,30	17	29,33	33	29,21
2	29,20	18	29,26	34	29,13
3	29,28	19	29,18	35	29,29
4	29,29	20	29,29	36	29,21
5	29,20	21	29,17	37	29,24
6	29,25	22	29,11	38	29,29
7	29,24	23	29,30	39	29,17
8	29,25	24	29,26	40	29,24
9	29,24	25	29,28	41	29,10
10	29,31	26	29,17	41	29,14
11	29,26	27	29,10	43	29,30
12	29,16	28	29,20	44	29,27
13	29,26	29	29,26	45	29,31
14	29,16	30	29,10	46	29,15
15	29,33	31	29,23	47	29,25
16	29,21	32	29,26		

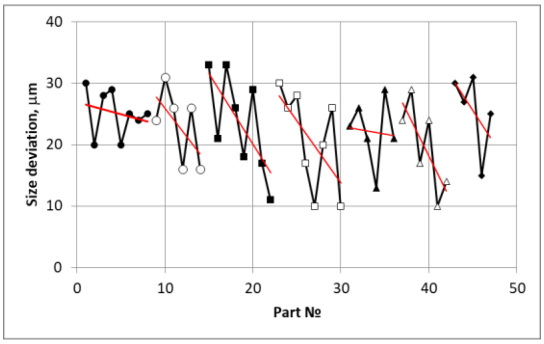


Fig. 3. Scatter diagram of the process of clean boring of a batch of cylindrical bushings with the application of an analytical method for dimension sub-tuning

Six adjustments were made. The following results were obtained from the statistical processing of the data:

- the variances of the six groups (samples) relative to the regression equation are homogeneous. The average dispersion is D_{cp} = 29,5 µm^2, the mean square root deviation is S_{cp} = 5,4 µm and the instantaneous dispersion field is ω_{cp} = 26 µm;
- the average size of the sub-tuning impulse is $\Delta\overline{A}_n = 10,3$ µm;
- the total dispersion field with probabilistic addition of the errors will be:

$$\omega_\Sigma = \sqrt{\omega_{cp}^2 + 3(\Delta\overline{A}_n)^2 + \omega_p^2} = 32\,\mu\text{m}. \qquad (6)$$

The diametric processing error of the sub-tuning impulse for the LT580, determined experimentally, is ω_p = 9,74 µm.

When determining the sample volume by the statistical method for the same experimental conditions and statistical estimate of the dispersion, using the methodology, given in [6], at a 10% error in the average value, n = 23 parts is obtained. Therefore, with the accuracy, set this way, the dimension sub-tuning must be carried out after having 23 parts machined. If the work continues until reaching up this number of machined parts, with the dimension deviations measured during the process of boring (Table 2), the scatter diagram, shown in Fig. 4, is obtained.

TABLE 2 RESULTS OF CLEAN BORING OF A BATCH OF CYLINDRICAL BUSHINGS USING A STATISTICAL METHOD FOR DIMENSIONAL SUB-TUNING

№ of the part	Size, mm	№ of the part	Size, mm	№ of the part	Size, mm
1	29,54	9	29,37	17	29,36
2	29,44	10	29,44	18	29,29
3	29,52	11	29,39	19	29,19
4	29,53	12	29,29	20	29,32
5	29,44	13	29,39	21	29,20
6	29,41	14	29,29	22	29,14
7	29,48	15	29,36	23	29,25
8	29,47	16	29,24		

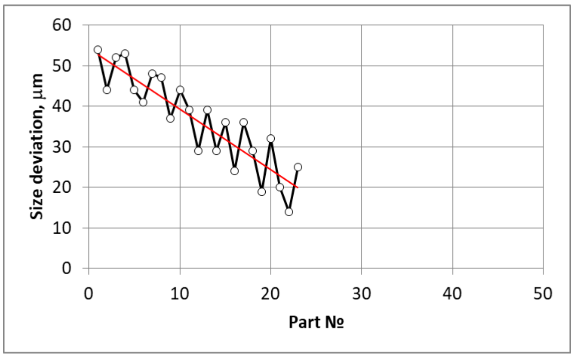


Fig. 4. Scatter diagram of the process of clean boring of a batch of cylindrical bushings with the application of a statistical method for dimensional sub-tuning

In this case, for the sub-tuning impulse it is obtained $\Delta\overline{A}_n = 33,5$ µm.

The total dispersion field determined by formula (5) is respectively ω_Σ = 64 µm.

Hence, when determining the sample volume statistically, twice as much error of machining is obtained for the specific case. Furthermore, the total dispersion field is greater than the dimension tolerance. Therefore, it is impossible to achieve the set accuracy of the average dimension value within the limits of the tolerance, which is a condition for making a sub-tuning decision.

IV. CONCLUSIONS

The conducted analysis allows to conclude that the proposed analytical approach for determining the moment for sub-tuning achieves significantly higher accuracy of the machined parts than if the number of parts between two sub-tunings is determined statistically. By applying this method, a total dispersing field comparable in size to the instantaneous one is obtained.

Consequently, dynamic dimension sub-tuning, based on the results of computer processing of the information about the dimensions of the machined parts in real time, is applicable and effective both for processes with small and with large dimension dispersion, caused by random factors.

V. ACKNOWLEDGMENTS

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