

Study of Damping Properties of Titanium Tooling During Surface Grinding of Corrosion-Resistant Steel Parts

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Abstract—The possibility of increasing the stability of the grinding process of corrosion-resistant steels using titanium alloy mandrels with a low modulus of elasticity is considered. The titanium alloy acts as an artificial damper to facilitate the absorbing of vibrations arising during processing.

Keywords—*absorbing of vibrations, error standard, CBN grinding, surface condition, roughness, multistep grinding*

I. INTRODUCTION

Currently, with the development of additive technologies, when the finished part is obtained almost without the use of traditional processing methods such as milling, turning, drilling, accompanied by the removal of a large amount of material, the volume of the finishing operations application using abrasive tools based on cubic boron nitride is increasing. At the same time, despite the significant share of grinding operations, grinding processes are still insufficiently studied in comparison with other types of cutting. This necessitates the research, study and development of the theoretical and practical foundations for the creation of technological recommendations to improve the efficiency of grinding operations.

According to modern concepts, grinding is a process of multiple microcutting. This is due to the variability of the shape and geometry of the cutting edges of the grains and their different heights, which causes the inconstancy of the total cross-section of the cut. As a result, there is a high instability of the obtained values, compared with edge cutting machining methods. The spread of the obtained values of roughness in the operating batch of parts can reach 2-3 categorical values (CV) according to State Standard, GOST 2789-73. In addition, in the course of processing there may be unbalance (imbalance) and eccentricity of the grinding wheel, this is one of the reasons for the appearance of forced vibrations (in addition to vibrations from the hydraulic devices built into the grinding machine, and vibrations of the foundation) [1]. As it is known, the main parameters of vibration are the amplitude and frequency of oscillations. The amplitude depends on the

processing conditions. It decreases with increasing stiffness and damping of the process system. The amplitude of the oscillations does not remain constant in the grinding process. As the grinding wheel is blunted and killed, the oscillation amplitude increases. In the presence of vibrations the wear of the abrasive tools increases, the life of the machine components reduces. Waviness appears on the grounded details, the surface roughness deteriorates, the dimensional inaccuracy of the treatment increases [2,3].

When working with a tool from traditional abrasives, an effective method of eliminating auto-oscillations is a timely straightening of the wheel. However, working with a tool made of diamond or cubic boron nitride, when the thickness of the working layer is 5-10 mm, such straightening is a very time-consuming process due to the similarity of the physical and chemical properties of the dressing tool and the wheel.

In connection with the above-mentioned, it can be concluded that to maintain the specified drawing parameter details, it is not enough to correctly select the cutting conditions and characteristics of the abrasive tool. It is necessary to look for reserves to improve the stability of the process.

One of the ways of vibration absorbing, by analogy with the turning, where the damping anti-vibration mandrels are applicable, is the introduction of the system «machine-disc-detail-fixture» of the artificial damper. This is possible either by making structural changes in the equipment or tooling, or by making a mandrel of the disc from the material with a small modulus of elasticity. One of these materials is titanium and the alloys based on it, having a low modulus of elasticity (twice as small as that of steels).

II. RESEARCH MATERIAL AND METHODS

A mandrel made of a deformable titanium alloy VT6 (BT6), structurally completely identical to the standard one, was made for the research. This alloy belongs to two-phase ($\alpha+\beta$) alloys of the martensitic class with a small amount of β -phase, the presence of which causes the ability of the

hardening heat treatment. The presence of martensite of the different types leads to a significant energy dissipation of elastic vibrations, i.e. it causes a high level of damping ability of the alloy [4].

The experiments were carried out under the following constant conditions: surface grinding machine of model 3Г71М; wheel 1А1 200×76×5 CBN 30 B107 100 O V K27 (GOST R 52587-2006; GOST R 53922-2010). Technological parameters are as follows: wheel velocity $v_k=28$ m/s, line feed $s_{mp}=6$ m/min, cross feed $s_n=4$ mm/double stroke, cutting depth $t=0.005$ mm, the operating allowance of $z=0.1$ mm; 5% cutting emulsion Akvol-6 (TS 0258-024-00148843-98) irrigated to the item in the amount of 7-10 l/min.

The processing was performed according to the counter grinding scheme, the wheel lowering to a depth of t was done, when the bed table with the workpiece reached the extreme left position relative to the operator. For this reason, its movement from left to right is considered to be working, and the reverse one is a spark-out stroke, which eventually forms a micro-relief in accordance with the diagram of associated penetration of the tool into the workpiece.

The rough edges and deviations from the flatness of *EFE* are taken as process output parameters: R_a, R_z, R_{max}, t_p ($p = \overline{1; 50\%}$), measured with the help of a modernized system based on the profilograph-profilometer of 252 model by "Kalibr" [5].

The variable i in sets (1) in relation to the experimental conditions is rearranged to the form of « dj ». In this case, $d = \overline{1; 2}$ reflects the location of the roughness in two mutually orthogonal directions: 1 – parallel to the vector s_n , 2 – parallel to the vector s_{mp} . The code $j = \overline{1; 2}$ is related to the material of the wheel mandrel: 1 – steel mandrel, 2 – titanic mandrel.

High strength corrosion resistant steel 13Cr15Ni4NMo3 (VNS-5/WHC-5, EP310/EhP310) serves as the parts material related to the austenitic-martensitic class, which is widely used in the manufacture of power parts and assemblies for aircrafts of various types (frames, longerons, wing rotation assemblies, undercarriage parts): $UTS = 1500 \div 1650$ MPa, $E=220$ GPa, $\delta=15\%$ [6]. In the USA analogue 13X15H4AM3 steel is steel AM-355 ($UTS = 1550$ MPa, $\sigma_{0.2} = 1250$ MPa, $\Psi = 38\%$). The grinding was carried out at the end of the workpiece $D \times L = 30 \times 40$ mm with the repetition of observations $n=30$.

To ensure equal conditions of each of the experiments in the present series, the following measures were taken: all samples were pre-marked and settling surfaces were prepared under equal mode conditions; a static balancing of the wheels according to GOST 12.3.028-82 on a specially designed stand was carried out. The dressing of the wheels of cubic boron nitride (CBN) was implemented with the help of a diamond bar, AC6 D107100 M1, with the subsequent breaking-in on the titanium billet. Before the beginning of each experiment, the CBN wheels were cleaned with pumice. The statistical processing of the study results was fulfilled using *STATISTICA 10*.

The foundation of theoretical statistics is parametric and non-parametric methods considering the experimental data in the form of a sequence of i -th sets:

$$\{y_{iv}\}, i = \overline{1; k}; v = \overline{1; n}, \quad (1)$$

which should be extracted from the universal set with the equal volume n . The sets (1) are characterized by the following one-dimensional frequency distributions [7-9], GOST R ISO 5721-2002:

- position measures (reference values) for the parametric method – the average

$$\bar{y}_i = y_i \quad (2)$$

for the nonparametric method – the median

$$y_i; \quad (3)$$

- scattering measures (precision) evaluating the stability of the process by deviation standards SD_i (their dispersions SD_i^2), ranges $R_i = (y_{max} - y_{min})$ – for (2), interquartile ranges $IR = |y_{0.75} - y_{0.25}|_i$ – for (3);

- measures of the distributions shape, in particular, asymmetry (skewness), approximately represented by the expression:

$$AS_i = [3(\bar{y} - \tilde{y}) / SD]_i \quad (4)$$

The sign «•» in the indices (2) indicates that the i -th sample is represented by its average. With a large number of input variables this technique, used in the analysis of variance (VA), allows us to reflect the procedures of averaging the response according to several characteristics. In particular, $y_{..}$ characterizes that the sets $i = \overline{1; k}$ are represented by the general mean.

The choice of statistical interpretation method (1) depends on the results of their preliminary testing for homoscedasticity and normality of distributions.

The tested null hypothesis (H_0) of the homoscedasticity of the normal distribution of random variables (RV) has the form:

$$\sigma_1^2 = \sigma_2^2 = \dots = \sigma_k^2, \quad (5)$$

and its alternative (heteroscedasticity) H_1 is:

$$\sigma_1^2 \neq \sigma_2^2 \neq \dots \neq \sigma_k^2, \quad (6)$$

where $\sigma_i^2, i = \overline{1; k}$ – variance of the i -th random sample.

In GOST R ISO 5479-2002 «Statistical methods. Checking the deviation of the probability distribution from the normal distribution» the use of different criteria is fixed. However, it

does not recommend which criterion is the most preferable one and has the most power. In this regard, the statistics of Shapiro-Wilk (W) [10] and Kolmogorov-Smirnov (D) [7] were used to test the null hypothesis on the normal distribution of RV in the program *Statistica 10*. These criteria are a special case of the fitting criterion. The D -criterion is the most widely used in technical applications, for which the condition (5) is satisfied in the case of the following:

$$\left. \begin{array}{l} D < D_{(\alpha)}, \\ \alpha > 0.05 \end{array} \right\}, \quad (7)$$

where $D_{(\alpha)}$ – the critical value of the criterion at the selected level of significance, α – the level of reliability of performing H_0 .

In [11] some doubt about sufficient power of the Kolmogorov-Smirnov test is expressed. In this regard, the Shapiro-Wilk test, being the most effective method of verification, was additionally used (7). It is based on the use of the ratio of the optimal linear unbiased variance estimate to its usual maximum likelihood estimate. The null hypothesis (5) is accepted if there is an inequality:

$$\left. \begin{array}{l} W > W_{(\alpha)}, \\ \alpha > 0.5 \end{array} \right\}. \quad (8)$$

The parametric methods are robust to small deviations of RV from the normal distribution, which cannot be said about the heterogeneity of the variances. To confirm the hypothesis of their homogeneity, the following parametric criteria were used: Hartley, Cochran and Bartlett [12].

The implementation of the null hypothesis of homoscedasticity and normality of the RV distributions allows us to proceed with VA. At the first stage of the single-factor VA the F -statistics were used to determine the presence of a significant difference between the mean $i = \overline{1;k}$ without searching for them by name.

The second stage of VA is to establish the materiality of particular differences between the means. This was done using *a posteriori* tests ($m = \overline{1;6}$): 1 - the least significant difference (LSD), 2 - Scheffe, 3 - Newman-Keuls, 4 - Tukey, 5 - Duncan and, 6 - Bonferroni [13].

The LSD criterion is suggested by Fisher and is the most liberal and prone to errors. The Scheffe criterion is a modification of the Student's t -test. Its advantage is the ability to analyze samples of different sizes. The Duncan criterion is a modified Newman-Keuls criterion, being less strict with a large number of k , and, therefore, has the greatest application. To improve the reliability of decision-making, the mean \bar{y}_{im} , $i = \overline{1;k}$ was analyzed by all statistics ($m = \overline{1;6}$) and its grand average \hat{y}_i was taken as the predicted value.

If the studied observations did not obey the law of normal distribution, then the nonparametric method was used, not

imposing restrictions on RV (less sensitivity to «noise»). The nonparametric method has less sensitivity to gross errors occurring, for some reason or other, in a random sample. An example of such an approach is the Kruskal-Wallis test, which tests the hypothesis: whether the compared samples have a median distribution bias. It is a multivariate generalization of the Wilcoxon-Mann-Whitney test. This criterion is rank, so it is invariant with respect to any arbitrary transformation of the measurement scale [4,8].

The influence of the mandrel material on the cutting properties was estimated relating to the base value of $j=1$ for both characteristics of the one-dimensional frequency distribution of sets (1) with the same value of $d = \overline{1;k}$ [14]:

$$K_{mdj} = \left(\frac{m\hat{y}}{\hat{y}} \right) d_j;$$

$$K_{dj} = \left(\frac{\tilde{y}_j}{\tilde{y}_1} \right) d_i;$$

$$\hat{K}_{dj} = \left(\frac{m\hat{y}_j}{m\hat{y}_1} \right) d_i;$$

$$K_{SD_{dj}} = SD_1 / SD_j;$$

$$K_{R_{dj}} = (R_1 / R_j)_d;$$

$$K_{IR_{dj}} = (IR_1 / IR_j)_d;$$

if the following

$$(K_{dj}, \hat{K}_{dj}) > 1 \text{ and } (K_{IR_{dj}}, K_{SD_{dj}}, K_{R_{dj}}) < 1 \text{ is predicted.}$$

The measures of position and scattering of the studied output parameters during the grinding of a titanium mandrel with discs exceed the corresponding analogues for a steel mandrel ($j=1$), thereby, yielding to it in cutting abilities.

III. RESEARCH

Testing (1) according to Shapiro-Wilk statistics has established the normality of the distribution for most of the studied parameters. Thus, when a disk works on a steel mandrel ($j=1$), a violation of the normality of RV distributions has been revealed for eight parameters out of 17: R_{max11} , $t_{10(11)}$, $t_{20(11)}$, R_{z21} , R_{max21} , $t_{10(21)}$, $t_{20(21)}$, $t_{50(21)}$. Working with a titanium mandrel ($j=2$), the violation of the normal distribution of RV has been fixed for six parameters: $t_{10(12)}$, $t_{20(12)}$, R_{max22} , $t_{10(22)}$, $t_{50(22)}$, EFE .

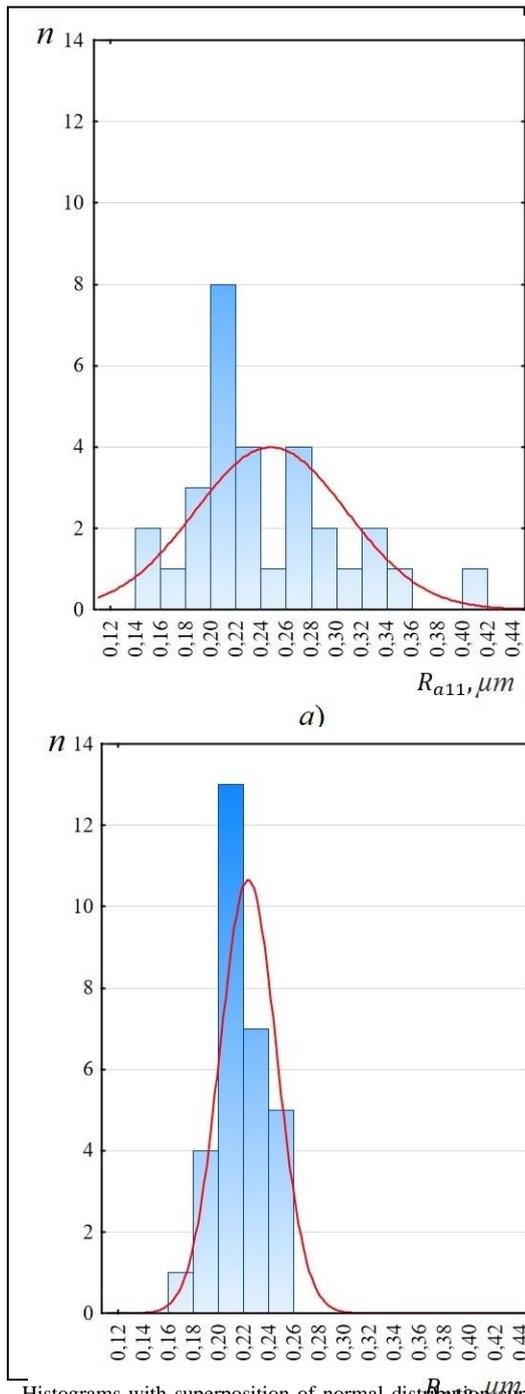


Fig. 1. Histograms with superposition of normal distribution curves for the parameter when the grinding wheel works on the mandrels: steel $j=1$ (a) and titanium $j=2$ (b)

As an illustration, in Fig.1 the histograms of the distributions of the sets (1) for parameter R_{a1j} with the superimposition of normal law curve are presented. The critical value of the Shapiro-Wilk criterion $W_{(\alpha)}$, where $n=30$ and $\alpha=0,05$ are according to GOST 5479-2002, is 0,927, thus, the condition (8) is fulfilled in both cases: $j=1-W=0,9336$ (see Fig. 1, a) and $j=2-W=0,9365$ (see Fig. 1, b). Checking (1) for homogeneity of variances according to Hartley, Cochran and

Bartlett criteria revealed the fulfillment of (5) only for individual reference lengths of the profile: $t_{p(1j)}, p = \overline{30;50\%}$ и $t_{p(2j)}, p = \overline{20;40\%}$.

Parametric estimates are robust to minor deviations of RV from the normal distribution, which is not the case for homogeneity of variances. For this reason, these RV should be studied with the involvement of non-parametric statistics. However, to assess the sensitivity to errors of a particular method «on a foreign field», further interpretation of the observations was carried out using both statistics.

TABLE I. EXPERIMENTAL MEAN \bar{y}_{dj} OF MEDIAN \tilde{y}_{dj} AND PREDICTED VALUES OF $m\hat{y}_{dj}$, $d = \overline{1;2}$, $j = \overline{1;2}$

Characteristic	Mandrel $j = \overline{1;2}$	\bar{y}_{dj}	\tilde{y}_{dj}	\hat{y}_{dj}	$m\hat{y}_{dj}$
$R_{a1j}, \mu\text{m}$	1	0.247 (0.25)	0.23 (0.25)	0.247 (0.25)	0.225 (0.25)
	2	0.223 (0.25)	0.22 (0.25)	0.223 (0.25)	0.225 (0.25)
$R_{max1j}, \mu\text{m}$	1	1.892 (2.00)	1.70 (2.00)	1.892 (2.00)	1.600 (1.60)
	2	1.549 (1.60)	1.50 (1.60)	1.549 (1.60)	1.600 (1.60)
$t_{10(1j)}, \%$	1	1.14	0.90	1.15	1.000
	2	1.16	1.10	1.15	1.000
$t_{20(1j)}, \%$	1	2.40	2.05	2.40	2.050
	2	3.85	2.95	3.85	2.950
$t_{30(1j)}, \%$	1	9.58	9.40	10.16	10.000
	2	10.73	10.60	10.16	10.000
$t_{40(1j)}, \%$	1	26.35	25.60	27.18	27.575
	2	28.01	29.55	27.18	27.575
$t_{50(1j)}, \%$	1	54.08	54.50	53.15	54.000
	2	52.21	53.50	53.15	54.000
$R_{a2j}, \mu\text{m}$	1	0.156 (0.16)	0.14 (0.16)	0.156 (0.16)	0.140 (0.16)
	2	0.122 (0.125)	0.12 (0.125)	0.122 (0.125)	0.120 (0.125)
$R_{max2j}, \mu\text{m}$	1	0.83 (1.00)	0.78 (0.8)	0.83 (1.00)	0.780 (0.80)
	2	0.65 (0.80)	0.60 (0.63)	0.65 (0.8)	0.600 (0.63)
$t_{10(2j)}, \%$	1	0.75	0.75	0.76	0.725
	2	0.77	0.70	0.76	0.725
$t_{20(2j)}, \%$	1	3.27	2.45	3.52	2.875
	2	3.77	3.30	3.52	2.875
$t_{30(2j)}, \%$	1	11.23	10.40	12.40	11.800
	2	13.57	13.20	12.40	11.800
$t_{40(2j)}, \%$	1	28.19	29.50	28.42	29.350
	2	28.64	29.20	28.42	29.350
$t_{50(2j)}, \%$	1	60.60	62.20	60.07	62.625
	2	59.54	63.05	60.07	62.625
$EFE_j, \mu\text{m}$	1	9.60	9.50	9.60	8.250
	2	7.70	7.00	7.70	8.250

Note: categorical values according to GOST 2789-73 are given in brackets

In Table 1 experimental mean \bar{y}_{dj} and medians \tilde{y}_{dj} $d = \overline{1;2}$, $j = \overline{1;2}$ are given for all studied parameters and mandrels. Their comparison has shown that for ten parameters of roughness there is an equality $\bar{y}_{dj} = \tilde{y}_{dj}$ at the same name of d and j : R_{a1j} , R_{max1j} ,

$t_{20(1j)}, j = \overline{1;2}; R_{a2j}, R_{max2j}, j = \overline{1;2}$. In addition, for altitude roughness parameters $R_{max1j}, R_{a2j}, R_{max2j}, j = \overline{1;2}$ it can be stated that in case of rounding the obtained values to standard GOST 2789-73, the difference between the steel and titanium mandrel made up of one CV, and for the rest they are the same. In Table 2 the presented data on the coefficients K_{dj} and \hat{K}_{dj} for the parameters of roughness and deviation from the flatness of the position measures for the base steel mandrel exceed the corresponding analogues, surpassing them in cutting properties.

TABLE II. EFFECT OF MANDREL MATERIAL ON POSITION MEASURES OF PARAMETERS UNDER STUDY

Characteristic	Mandrel $j = \overline{1;2}$	K_{mdj}	K_{dj}	\hat{K}_{dj}
$R_{a1j}, \mu\text{m}$	1	0.91	1.00	1.00
	2	1.01	0.96	1.00
$R_{max1j}, \mu\text{m}$	1	0.85	1.00	1.00
	2	1.03	0.88	1.00
$t_{10(1j)}, \%$	1	0.68	1.00	1.00
	2	0.68	1.22	1.00
$t_{20(1j)}, \%$	1	0.85	1.00	1.00
	2	0.77	1.44	1.44
$t_{30(1j)}, \%$	1	0.98	1.00	1.00
	2	0.98	1.13	1.00
$t_{40(1j)}, \%$	1	1.02	1.00	1.00
	2	1.02	1.15	1.00
$t_{50(1j)}, \%$	1	1.02	1.00	1.00
	2	1.02	0.98	1.00
$R_{a2j}, \mu\text{m}$	1	0.88	1.00	1.00
	2	1.00	0.86	0.86
$R_{max2j}, \mu\text{m}$	1	0.94	1.00	1.00
	2	0.92	0.77	0.77
$t_{10(2j)}, \%$	1	0.95	1.00	1.00
	2	0.95	0.93	1.00
$t_{20(2j)}, \%$	1	0.82	1.00	1.00
	2	0.82	1.35	1.00
$t_{30(2j)}, \%$	1	0.95	1.00	1.00
	2	0.95	1.27	1.00
$t_{40(2j)}, \%$	1	1.03	1.00	1.00
	2	1.03	1.00	1.00
$t_{50(2j)}, \%$	1	1.04	1.00	1.00
	2	1.04	1.01	1.00
$EFEj, \mu\text{m}$	1	0.86	1.00	1.00
	2	1.07	0.74	1.00

As given in Fig.2 and Fig.3, the descriptive parametric and nonparametric statistics on the parameters R_{a1j} and $EFEj, j = \overline{1;2}$ are shown, when grinding with wheels mounted on a titanium mandrel, the scattering error standards $\pm SDE$ are three times lower than working on a steel one.

The descriptive statistics for $R_{a1j}, j = \overline{1;2}$ (Fig.2) allow us to analyze the precision of the process according to three characteristics: interval scattering $-\left[\bar{y}_{dj} \pm SD\right]$ - (Fig.2,a); interquartile distances, covering 50 % of observations and ranges (Fig.2,b).

To analyze the interval scattering, let us proceed to the coefficient $K_{SD_{dj}}, d = j = \overline{1;2}$, the evaluation results are presented in Table 3. It was found that for $j=2$ the coefficients $K_{SD} < 1$ in 11 out of 17 cases were predicted, i.e. when grinding parts with a wheel on a titanium mandrel the deviation standards SD_{dj} turned out to be higher than when grinding workpieces with a wheel mounted on a steel mandrel. The ranges (1) are represented by the following: $y_{max1}=0,41 \mu\text{m}, y_{min1}=0,16 \mu\text{m} - 5 \text{ CV}$ for $j=1$; $y_{max2}=0,26 \mu\text{m}, y_{min2}=0,18 \mu\text{m} - 2 \text{ CV}$ for $j=2$. Both estimates refer to the parametric method of statistics and indicate that during the grinding on a titanium mandrel the precision of the process is predicted to be the highest.

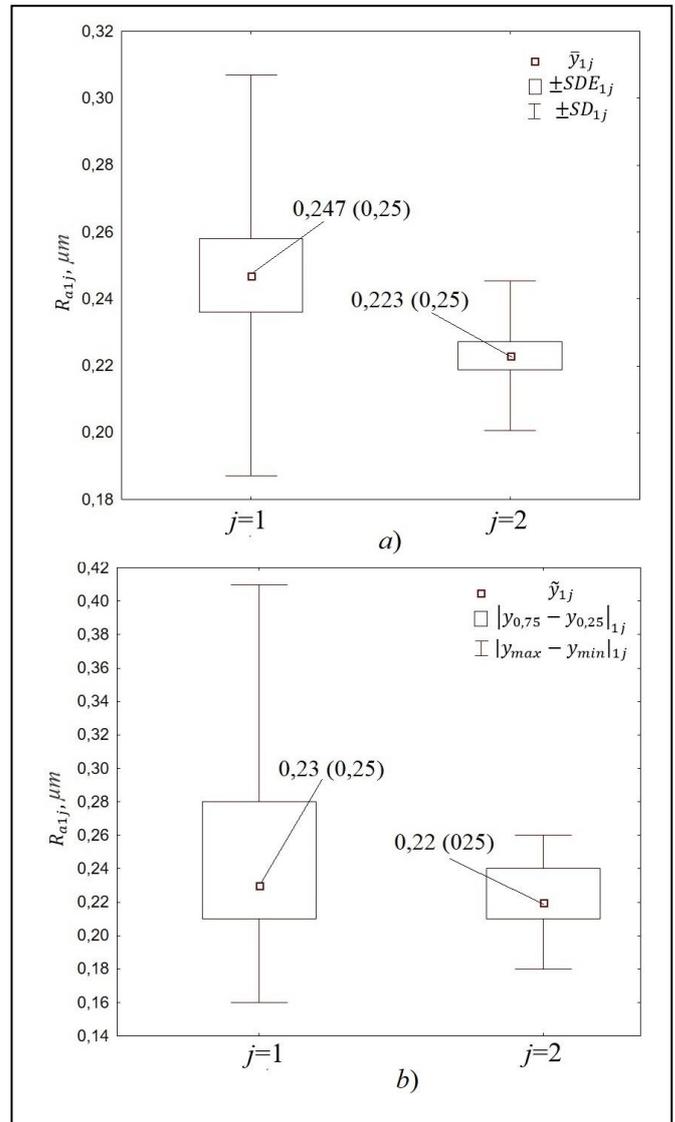


Fig. 2. Descriptive parametric (a) and non-parametric (b) statistics for $R_{a1j}, j = \overline{1;2}$

The interquartile ranges estimation, used by the nonparametric method, confirmed the results of the parametric method $R_{ajj} : (y_{0.75})_1=0.28 \mu\text{m}, (y_{0.25})_1 =0.21 \mu\text{m} - 2 \text{ CV}$ for $j=1; (y_{0.75})_1=0.24 \mu\text{m}, (y_{0.25})_1= 0.21 \mu\text{m} - 1 \text{ CV}$ for $j=2$. There are similar patterns for other altitude parameters, which is reflected in Table 3.

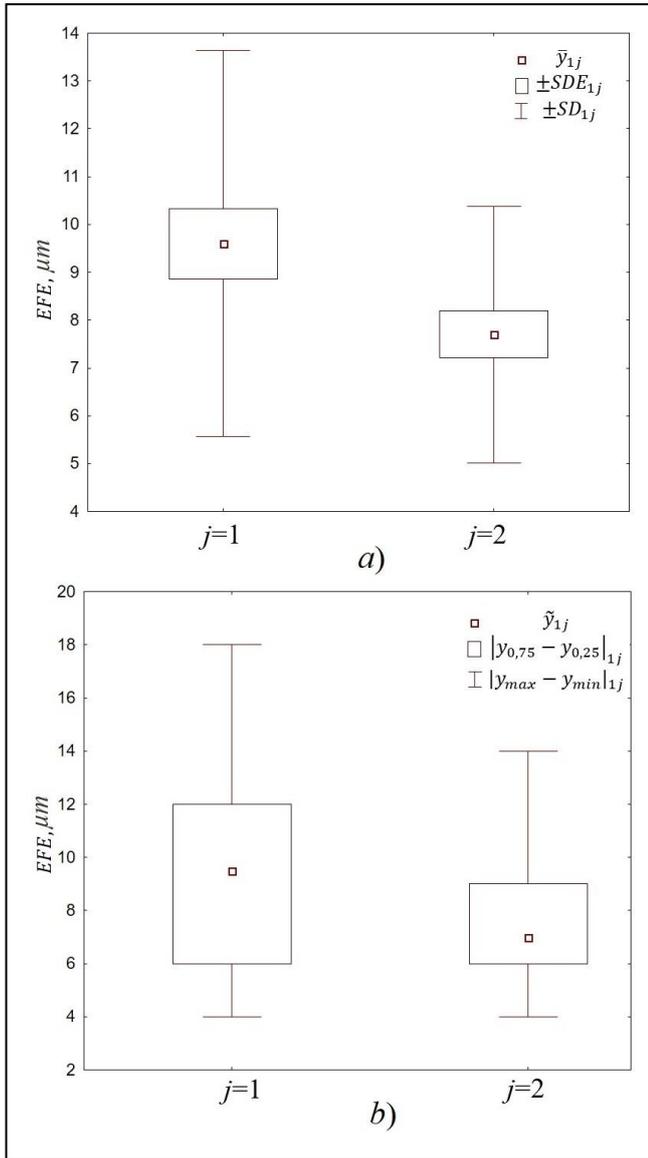


Fig. 3. Descriptive parametric (a) and nonparametric (b) statistics for $EFE_j, j = 1; 2$

As for the deviations from the flatness of the EFE both mandrels showed similar values both for predicted parametric ($E\hat{F}E_1=9.6 \mu\text{m}, E\hat{F}E_2=7.7$) and for nonparametric estimates ($m\hat{E}F\hat{E}_1=8.25 \mu\text{m}, m\hat{E}F\hat{E}_2=8.25 \mu\text{m}$) (see Table 1). That refers to the sixth accuracy degree according to GOST 24643-81 (TFE_6). The precision of the grinding process was also higher

when working with a titanium mandrel (Fig. 3 a.b). As it can be seen from Table 3, for the reference lengths of the profile t_p there was a decrease in the indicators responsible for the precision of the process.

TABLE III. EVALUATION OF THE INFLUENCE OF MANDREL MATERIAL ON GRINDING PROCESS PRECISION

Characteristic	j	SD_{dj}	R_{dj}	IR_{dj}	K_{SD}	K_R	K_{RR}
$R_{ajj}, \mu\text{m}$	1	0.06	0.25	0.07	1.00	1.00	1.00
	2	0.022	0.08	0.03	2.72	3.13	2.33
$R_{max1j}, \mu\text{m}$	1	0.770	3.40	0.72	1.00	1.00	1.00
	2	0.331	1.32	0.48	2.33	2.57	1.5
$t_{10(1j)}, \%$	1	1.086	6.10	0.30	1.00	1.00	1.00
	2	0.475	1.80	0.50	2.28	3.39	0.6
$t_{20(1j)}, \%$	1	1.260	5.80	1.30	1.00	1.00	1.00
	2	2.482	7.60	4.30	0.51	0.76	0.3
$t_{30(1j)}, \%$	1	3.606	15.40	4.60	1.00	1.00	1.00
	2	5.201	21.90	7.00	0.7	0.7	0.66
$t_{40(1j)}, \%$	1	6.856	28.70	10.60	1.00	1.00	1.00
	2	8.643	29.80	12.20	0.8	0.96	0.87
$t_{50(1j)}, \%$	1	9.541	40.50	12.80	1.00	1.00	1.00
	2	12.35	46.60	20.70	0.77	0.87	0.62
$R_{a2j}, \mu\text{m}$	1	0.047	0.20	0.070	1.00	1.00	1.00
	2	0.029	0.11	0.020	1.62	1.82	3.5
$R_{max2j}, \mu\text{m}$	1	0.342	1.92	0.21	1.00	1.00	1.00
	2	0.213	0.92	0.20	1.6	2.1	1.05
$t_{10(2j)}, \%$	1	0.166	0.60	0.30	1.00	1.00	1.00
	2	0.355	1.60	0.20	0.47	0.38	1.5
$t_{20(2j)}, \%$	1	2.386	8.90	2.60	1.00	1.00	1.00
	2	2.091	8.00	3.20	1.14	1.11	0.81
$t_{30(2j)}, \%$	1	5.991	21.70	9.10	1.00	1.00	1.00
	2	5.649	24.50	6.80	1.1	0.89	1.33
$t_{40(2j)}, \%$	1	8.881	45.30	8.90	1.00	1.00	1.00
	2	8.915	41.40	7.60	0.99	1.09	1.17
$t_{50(2j)}, \%$	1	7.695	35.70	9.20	1.00	1.00	1.00
	2	12.15	52.70	10.60	0.62	0.68	0.87
$EFE_j, \mu\text{m}$	1	4.031	14.00	6.00	1.00	1.00	1.00
	2	2.680	10.00	3.000	1.5	1.4	2.0

IV. CONCLUSION

It has been revealed that for most of the studied parameters the observations have violations of the requirements for random variables. They should therefore be analyzed using non-parametric methods of statistics. The use of a mandrel made of titanium alloy VT6, having a lower modulus of elasticity, compared with steel, can reduce the size scatter in the operating batch of parts and thereby increase the precision of the grinding process of parts made of corrosion-resistant martensitic class steel with low cutting machinability.

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