Study on grinding mode effect on external conical thread quality

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Abstract. The article has grounded the necessity to develop an empirical power dependence of cutting modes influence on part surface roughness obtained during thread grinding. The calculations were carried out for grinding of parts made of steel and hard alloy. There have been developed a relation of part material properties, grinding wheel options, lubricating and cooling liquid (constant for concrete conditions of thread grinding), depth of cutting (thickness of a grinded layer per path), revolutions of a part and a wheel, longitudinal feed refer to obtained roughness. It has been stated that components of the grinding mode contribute in roughness values in different way, in particular they are arranged in the ascending order as follows: grinding depth, rotation speed, and detail’s diameter.

1. Introduction

Modern hydrocarbon production is associated with technologies of opening of productive layers, increasing of well’s depth for both vertical and inclined drilling. Reliable and quality drilling equipment provides productive performance in conditions of high temperature, pressure, and abrasive and corrosion environment. Design of drill and oil/gas field equipment envisage conical thread as the main type of connection, in particular a pipe thread according to State Standard GOST 6357–81 and API, and a lock thread according to State Standard GOST 28487–90. Threaded surface accuracy and quality ensure tightness of connections, rapid screwing, and increases the uniformity of load distribution between the turns of the thread, which, in turn, increases the reliability of equipment in a whole. This way, modern drilling technologies need improved drilling equipment designs and technologies of machining.

Helical surfaces are widely used in conversion of rotational motion into translational motion, transmissions of rolling and sliding, which requires a rational choice of grinding mode to obtain the necessary parameters of surface roughness.

Reducing the roughness of threaded surfaces increases reliability and corrosion resistance of connections, as far as local stresses are reduced. This way stress concentrators do not cause destruction of parts under alternating loads and corrosive environments. Rolling and/or grinding are the most common methods used to improve thread surface quality in particular to reduce roughness, decrease surface micro-cracks, etc. Study of thread grinding and substantiation of rational cutting modes are especially relevant to provide necessary surface roughness of steel and hard alloys.

2. Literature review

Well drilling envisages improvement of drilling and oil/gas equipment’s design and technologies of its manufacturing. Drilling tools include pipes, weighted pipes, adapters, calibrators, bits and others.
Design [1-3], technological [4-6], and operational methods [7-9] are used to increase drilling tool reliability and durability. Besides, there have been simulated threads [10, 11] and machining of contact interaction between parts of threaded connection [12, 13], rock-drilling pipe [14–16] and downhole-drill bit contact interaction [17-19], well washing process [20]. The researchers have tested static load [21] and alternating load effect on fatigue [22], substantiated drilling regimes, including taking into account thermal effects in the contact zone [23, 24] and effect of corrosive environments [25-27]. Much attention is paid to the environmental safety of equipment during drilling [28] and transportation of hydrocarbons [29].

The works [10, 11, 30] have studied accuracy of conical threads within turning. The work [31] studied effect of machining errors on stresses of thread connection. Design and technology simulation of assembling with system analysis is promising [32]. It should be noted that the most significant methods among the aforementioned ones are technological ones aimed at increasing of reliability and durability of drilling tools.

The problem of improving the quality of smooth surfaces [33–35] and surfaces of gears by milling [36] and grinding [37] is well covered in the scientific and technical literature.

Researchers pay considerable attention to grinding simulation [38, 39] and determining the cutting forces during grinding [40, 41], as well as to substantiation of grinding wheel profile [42]. But only few works consider the problem of ensuring the roughness of threaded surfaces [43, 44]. In particular, it is the problem to choose the abrasive material for tools and specify grinding wheel profile, schemes of grinding and rational cutting modes [44–46].

Therefore, it is relevant to develop empirical formulas to determine roughness refer to thread grinding modes in order to obtain the desired surface quality of parts.

3. Statement of the problem

Actual Ukraine regulations for oil and gas equipment, in particular State Standard GOST 28487-90, specify low roughness of threaded surfaces. In general, roughness of threaded surfaces should not exceed $Ra 3.2 \ \mu m$. Despite this fact, the problem of roughness obtained within conical thread grinding is not as elaborated in scientific and reference literature, as it is elaborated for other types of machining (turning, drilling, milling, etc.) or for grinding of smooth surfaces. This fact can be explained by technological complexity of grinding, such as the complexity of the selection of equipment and tools, and limited sizes of threads and steps.

In contrast to thread turning, grinding is a more complex process in terms of quality and accuracy of the surface. Accuracy parameters of the thread can be controlled by existing measuring tools, but the quality control of the thread surface layer is a rather time-consuming procedure and is often performed visually, but non-destructive and / or destructive control methods or not performed at all.

The method of copying of grinding wheel profile is used for thread grinding providing the coincidence of the formed surface and wheel profile. Grinding of threads can be carried out according to the schemes of single-threaded, multitreaded grinding or according to the combined scheme – rough grinding by a multitthread wheel, or pure – by a single-threaded wheel. This imposes certain difficulties when specify grinding wheels: grain size, degree of hardness, bond material, which is determined by the radius of rounding, and the pitch of the thread.

Due to the lack of analytical relations between roughness and grinding modes, this study proposed herein aims to develop and analyze of an empirical power relation between roughness options and grinding mode, in particular the influence of a grinding mode and material properties on roughness of external conical threaded surfaces. Therefore, development of power relations for to thread grinding is an important scientific and practical problem, because this relation will simplify specification of appropriate grinding modes to provide necessary roughness of threaded surfaces and make possible establishing each factor influence on roughness of threaded surfaces.

Mainly drilling equipment is made of steel, but some details (in particular bodies of PDC drill bits are made of steel or hard alloy by sintering), so there have been developed relations for steel and hard alloy.
4. Results of study

Traditionally, an empirical power relation between roughness and cutting (grinding) modes is developed as

\[ R_a = f(C_a, t, V_d, V_s, s) \]  \hspace{1cm} (1)

where \( R_a \) – roughness of the machined surface depends on machining more. For thread grinding, \( R_a \) depends on \( C_a \) – material, grinding wheel characteristics and type of coolant (constant value for specific processing conditions), \( t \) – depth of grinding (thickness of removed layer of metal by grinding per path of a machine table), detail rotation speed \( V_d \), grinding wheel rotation speed \( V_s \), and longitudinal feed \( s \).

The options of part rotation speed \( V_d \) and a machine table longitudinal path are interrelated; in particular, one path of the machine table is performed during one rotation of the machined part, so these options cannot be independent variables in the regression relation. Therefore, the following options were selected:

- physical and mechanical properties of the machined material, the grinding wheel, and lubricating and cooling fluid (constant value for specific grinding conditions);
- depth of grinding (thickness of the removed layer of metal by grinding per path of the machine table);
- rotation speed of the part; and
- rotation speed of the grinding wheel.

Grinding is assumed to be performed on a universal grinding machine 5822M, so the range of grinding modes was specified according to its certificate, in particular grinding wheel rotation speed and grinding wheel diameter were specified with combination of the number of spindle revolutions.

Grinding wheels are made of white electrocorundum and monocrandum, less often of green silicon carbide. They have a ceramic bond with a grain size of 12 to 20, on a bakelite bond with a grain size of 16 to 8 and on a bond SKN (V2) with a grain size of 4. At present, grinding wheels made of Elbor are widely used for grinding of single-start and multi-start threads. Single-start grinding with Elbor wheels is carried out with the following grinding modes: low detail rotation speed (0.16–0.30 m/min) and large longitudinal feed (0.4–0.5 mm/path). This grinding mode provides high accuracy of thread grinding, in particular high accuracy of thread profile and its step, with complete absence of surface structural transformations of hardened steel.

For grinding, there have been used Т20 Д300 grinding wheels according to State Standard 2424-83 made of Elbor for steel details (25Г2С2Н2МА State Standard 5632-72) and diamond ones for hard alloy details. The rotation speed of the wheel was \( V_s = 35 \) m/s.

In order to simplify the mathematical model that describes profile roughness \( R_a \) (arithmetic mean deviation of the surface roughness \( R_a \), μm, i.e. the average deviation of the profile points from the midline of the profile within the base length) refer to grinding mode options, there have been taken the power function:

\[ R_a = C_a \cdot t^m \cdot V_d^n \cdot d^p \]  \hspace{1cm} (2)

where \( C_a \) – physical and mechanical properties of the machined material, grinding wheel, and lubricating and cooling fluid (constant value for specific grinding conditions); \( t \) – depth of grinding (thickness of removed layer of metal by grinding per path of a machine table); \( V_d \) – rotation speed of the part; \( d \) – diameter of the processed thread and \( m, n, p \) – unknown exponents.

The rotation speed of the wheel has not been not introduced into this function, and has been taken as a constant for the studied grinding – \( V_s = 35 \) m/s. Roughness ranged from 1.6 to 3.2 μm.
This relation is nonlinear, so it has been reduced to a linear form by logarithming:

\[
\ln R_a = \ln C_a + m \ln t + n \ln V_d + p \ln d. \tag{3}
\]

To simplify the calculations, there have been introduced the following notation:

\[
\ln R_a = y, \ln C_a = b_0, b_1 = m, X_1 = t, b_2 = n, X_2 = V_d, b_3 = p, \text{ and } X_3 = d.
\]

Substituting them in (3) there have been obtained:

\[
y = b_0 + b_1 \ln X_1 + b_2 \ln X_2 + b_3 \ln X_3. \tag{4}
\]

Equation (3) is an empirical relation of roughness \( Ra \) refers to grinding mode for circular diamond grinding with longitudinal feed.

There have been used the full-factor experiment \( 2^k \), where \( k = 3 \) is the number of variables (total number of experiments \( N = 8) \) to determine the unknown coefficients of equation (3). Table 1 presents the planning matrix of this experiment.

**Table 1.** Planning matrix of the full-factor experiment \( 2^3 \)

| Experiment | Value of coded factors | Interaction of coded factors | Output parameter, \( Y \) repeatability of experiments | Average value of the output parameter |
|------------|------------------------|-------------------------------|-----------------------------------------------------|--------------------------------------|
| 1          | +1  -1  -1  -1         | +1  +1  +1  -1               | \( Y_{11} \) \( Y_{12} \) \( Y_{1c} \)            |                                      |
| 2          | +1  +1  -1  -1         | -1  +1  -1  +1               | \( Y_{21} \) \( Y_{22} \) \( Y_{2c} \)            |                                      |
| 3          | +1  -1  +1  -1         | -1  -1  +1  +1               | \( Y_{31} \) \( Y_{32} \) \( Y_{3c} \)            |                                      |
| 4          | +1  +1  -1  +1         | +1  -1  -1  -1               | \( Y_{41} \) \( Y_{42} \) \( Y_{4c} \)            |                                      |
| 5          | +1  -1  -1  +1         | +1  -1  -1  -1               | \( Y_{51} \) \( Y_{52} \) \( Y_{5c} \)            |                                      |
| 6          | +1  +1  -1  +1         | +1  +1  -1  -1               | \( Y_{61} \) \( Y_{62} \) \( Y_{6c} \)            |                                      |
| 7          | +1  -1  +1  +1         | -1  -1  +1  -1               | \( Y_{71} \) \( Y_{72} \) \( Y_{7c} \)            |                                      |
| 8          | +1  +1  +1  +1         | +1  +1  +1  +1               | \( Y_{81} \) \( Y_{82} \) \( Y_{8c} \)            |                                      |

Grinding mode options were transformed into dimensionless coded variables for exponential-degree polynomial by the formula:

\[
x_i = \frac{2(\ln X_i - \ln X_{i_{\text{max}}})}{\ln X_{i_{\text{max}}} - \ln X_{i_{\text{min}}}} \tag{5}
\]

where \( X_i \) – values of the grinding mode options for diamond grinding with longitudinal feed; \( X_{i_{\text{min}}}, X_{i_{\text{max}}} \) – minimum and maximum values of the factors and \( i \) – respectively the serial number of the independent factor.

The numerical values of the grinding mode options for diamond grinding were specified according to grinding machine 5822M certificate.

Initially, studies have been carried out for heat-resistant steel 25Г2C2H2MA State Standard GOST 5632-72. Table 2 summarizes factor variation ranges.

**Table 2.** Ranges of grinding factor variation for diamond grinding with longitudinal feed.

| Interval of variation and factor ranges | Feed per path, \( s_n, \text{mm/path} \) | Grinding speed, \( v, \text{m/min} \) | Average diameter of the processed thread, \( d, \text{mm} \) |
|---------------------------------------|------------------------------------------|-------------------------------------|-------------------------------------------------|
| Basic level, \( x_i = 0 \)           | 0.045                                    | 40                                  | 125                                             |
| Variation range, \( \Delta x = 1 \)  | 0.035                                    | 15                                  | 75                                              |
| Upper level, \( x_i = +1 \)          | 0.08                                     | 55                                  | 200                                             |
| Lower level, \( x_i = -1 \)          | 0.01                                     | 25                                  | 50                                              |
Substituting the numerical values from table 2 in formula (5) there have been obtained expressions for coded factors:

\[
x_1 = \frac{2(\ln s_i + 4.605)}{-4.605 + 5.298} = 0.961797 \ln s_i + 3.429237
\]

\[
x_2 = \frac{2(\ln V_d - 3.912)}{3.912 - 2.303} = 2.536599 \ln V_d - 9.165
\]

\[
x_3 = \frac{2(\ln d - 5.3132)}{5.3132 - 3.912} = 1.442695 \ln d - 6.64386
\]

Equations with the introduction of variables taking into account factor interaction have been written in the coded variables:

\[
Y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_{12} x_1 x_2 + b_{13} x_1 x_3 + b_{23} x_2 x_3 + b_{123} x_1 x_2 x_3
\]

where \(b_0, b_1, b_2, b_3, b_{12}, b_{13}, b_{23}, b_{123}\) – regression coefficients that characterize the free term of the equation, linear effects and effects of factor interaction, respectively;

\(x_1, x_2, x_3\) – experimental factors (parameters of the grinding mode).

The order of the experiments according to the matrix has been chosen using a table of random numbers to eliminate systematic errors. To ensure good reproduction of the results, each experiment has been repeated twice at the same level of factors and there have been calculated the average value of the initial parameter in each experiment.

\[
\bar{Y}_v = \frac{1}{r} \sum_{u=1}^{r} Y_{u1}
\]

Table 3 presents experimental data of thread roughness after grinding.

| Experiment number | Value of coded factors | Output parameter, \(Y\) repeatability of experiments reproducibility | Average value of the output parameter | Dispersion of the experimental data |
|-------------------|------------------------|---------------------------------------------------------------|--------------------------------------|-----------------------------------|
| \(x_0\) | \(x_1\) | \(x_2\) | \(x_3\) | \(Y_{u1}\) | \(\ln Y_{u1}\) | \(Y_{u2}\) | \(\ln Y_{u2}\) | \(\bar{Y}_v\) | \(\ln \bar{Y}_v\) | \(s^2_{Y_v}\) |
| 1 | +1 | -1 | -1 | -1 | 1.4 | 0.336 | 1.6 | 0.470 | 1.5 | 0.405 | 0.0090 |
| 2 | +1 | +1 | -1 | -1 | 1.7 | 0.531 | 1.5 | 0.405 | 1.6 | 0.470 | 0.0079 |
| 3 | +1 | -1 | +1 | -1 | 1.2 | 0.182 | 1.4 | 0.336 | 1.3 | 0.262 | 0.0119 |
| 4 | +1 | +1 | +1 | -1 | 1.3 | 0.262 | 1.5 | 0.405 | 1.4 | 0.336 | 0.0102 |
| 5 | +1 | -1 | -1 | +1 | 3.0 | 1.099 | 3.2 | 1.163 | 3.1 | 1.131 | 0.0020 |
| 6 | +1 | +1 | -1 | +1 | 4.1 | 1.411 | 3.5 | 1.253 | 3.8 | 1.335 | 0.0125 |
| 7 | +1 | -1 | +1 | +1 | 2.4 | 0.875 | 2.8 | 1.030 | 2.6 | 0.956 | 0.0120 |
| 8 | +1 | +1 | +1 | +1 | 3.1 | 1.131 | 3.1 | 1.131 | 3.1 | 1.131 | 0 |

The obtained experimental results have been subjected to statistical analysis. There have been determined:

- ordinal variances
\[ S_u^2 = \frac{1}{r-1} \sum_{v=1}^{N} (Y_{uv} - \bar{Y})^2 \]  

– variance of reproduction experiments

\[ S^2(Y) = \frac{1}{N} \sum_{v=1}^{N} S_v^2 \]  

Variance homogeneity was checked by Cochran’s test

\[ G = \frac{S_{\text{max}}^2}{\sum_{v=1}^{N} S_v^2} \]  

Calculated value of Cochran’s test have been compared with the referenced one for \( f_{ad} = N - \lambda = 8 - 4 = 4 \) and \( f = N(r - 1) = 8(2 - 1) = 8 \) degrees of freedom and the level of significance of \( \alpha = 0.05 \). As far as \( G_{\text{table}} = 0.6798 > G = 0.1908 \) the hypothesis of regression variance homogeneity has been accepted.

The full-factor experiment is an orthogonal plan and it can greatly simplify the calculation of regression coefficients:

\[ b_0 = \frac{\sum_{v=1}^{N} Y_v}{N} \]  

\[ b_j = \frac{\sum_{v=1}^{N} x_{iv} \cdot \bar{Y}_v}{N} \]  

\[ b_{i,j} = \frac{\sum_{v=1}^{N} x_{iv} \cdot x_{jv} \cdot \bar{Y}_v}{N}, \quad i \neq j \]  

\[ b_{i,j,w} = \frac{\sum_{v=1}^{N} x_{iw} \cdot x_{jw} \cdot x_{kw} \cdot \bar{Y}_v}{N}, \quad i \neq j \neq w \]  

where \( i = 0, 1, 2, 3 \) – factor number.

The coefficients of the regression equation determined by formulas (11) – (14) have been summarized in table 4.

**Table 4. Regression coefficients.**

| Coefficient | \( b_0 \) | \( b_1 \) | \( b_2 \) | \( b_3 \) | \( b_{12} \) | \( b_{13} \) | \( b_{23} \) | \( b_{123} \) |
|-------------|----------|----------|----------|----------|----------|----------|----------|----------|
| Value       | 0.7533   | 0.3850   | -0.0820  | 0.0648   | -0.0128  | 0.0300   | -0.0025  | -0.0048  |
The obtained relation has been subjected to statistical analysis. To specify coefficient significance by Student's t-test, there have been calculated regression coefficient variance:

$$S^2(b_i) = \frac{1}{N_r} \sum_{i=1}^{N} S^2(Y)$$  \hspace{1cm} (18)

The critical value of the Student's $t$ criterion for $f_E = N(r - 1) = 8(2 - 1) = 8$ degrees of freedom and significance level $\alpha = 0.05$ is $t_{0.05} = 2.306$. This way, confidence interval is:

$$\Delta b_i = t_{0.05} S(b_i)$$  \hspace{1cm} (19)

where $S(b_i)$ – coefficient errors.

The variance of the regression coefficients have been calculated by formula (14), and it was 0.000512. Then according to (17) $\Delta b_i = 2.306 \cdot 0.02262 = 0.05216$. The regression coefficient is considered to be significant if $|b_i| \geq \Delta b_i$ (here $b_i$ means $b_{h1}, b_1, b_{ij}, b_{ijw}$).

Statistically insignificant coefficients are discarded, and the regression equation (4) has been specified as:

$$Y = 0.75325 + 0.385x_1 - 0.082x_2 + 0.06475x_3$$  \hspace{1cm} (20)

Fisher's F-test was used to test adequacy of the developed relation:

$$F = \frac{S^2_{ad}}{S^2(Y)}$$  \hspace{1cm} (21)

where $S^2_{ad}$ – between group variability, $S^2(Y)$ – within-group variability, which was calculated as follows

$$S^2_{ad} = \frac{\sum_{i=1}^{N} (Y - \bar{Y}_i)^2}{N - \lambda}$$  \hspace{1cm} (22)

where $\lambda$ – the number of significant coefficients in the regression equation; $\bar{Y}_i$ – calculated values of the initial parameter obtained after substitution into the refined regression equation (20) of factor levels (-1 and +1) according to the planning matrix of the full-factor experiment.

To check the adequacy of the obtained relation (20), there have calculate the values of the thread roughness (Table 5).

**Table 5.** The calculated data of thread roughness after grinding

| Experiment number | 1     | 2     | 3     | 4     | 5     | 6     | 7     | 8     |
|-------------------|-------|-------|-------|-------|-------|-------|-------|-------|
| Calculated thread | $\ln R_{\alpha}$ | 0.3855 | 0.5150 | 0.2215 | 0.3510 | 1.1555 | 1.2850 | 0.9915 | 1.1210 |
| roughness after grinding | $R_{\alpha}, \mu m$ | 1.4703 | 1.6736 | 1.2479 | 1.4205 | 3.1756 | 3.6147 | 2.6953 | 3.0679 |

Within-group variability according to (22) is $S^2_{ad} = 0.00873$. 


Calculated Fisher’s criterion has been compared with the referenced one for \( f_{ad} = N - \lambda = 8 - 4 = 4 \) \( f_{ad} = N(r - 1) = 8(2 - 1) = 8 \) degrees of freedom and \( \alpha = 0,05 \) level of significance. As far as \( F_{tabl} = 0.53 < F = 3.84 \), the regression relation has been accepted.

Besides, the multiple correlation coefficient has been calculated as:

\[
R = \sqrt{1 - \frac{\sum_{i=1}^{N} (\bar{Y}_v - \bar{Y})^2}{\sum_{i=1}^{N} (Y_v - \bar{Y})^2}}
\]  

(23)

where \( \bar{Y} \) – average value \( \bar{Y}_v \).

The initial data for calculating the multiple correlation coefficients are summarized in table 6.

When \( R = \sqrt{1 - 0.00873/1.28186} \).

Thus, the regression equation (20) completely met the experimental data.

After re-coding, the variables in the regression equation (20) there have been obtained:

\[
\ln Ra = 2.39485 + 0.37029 \ln s_1 - 0.208 \ln V_d + 0.093242 \ln d
\]

(24)

Potentiating the regression equation (24) there have been obtained:

\[
R_d = 10.967 \frac{d^{0.37}}{V_d^{0.208}}
\]

(25)

| Experiment number | The average value of the output parameter \( \bar{Y}_v \) | Calculated value of the output parameter \( \bar{Y}_v \) | \((\bar{Y}_v - \bar{Y})^2\) | \((\bar{Y}_v - \bar{Y})^2\) |
|-------------------|------------------|------------------|------------------|------------------|
| 1                 | 0.4050           | 0.3855           | 0.00038          | 0.12128          |
| 2                 | 0.4700           | 0.5150           | 0.00203          | 0.08023          |
| 3                 | 0.2620           | 0.2215           | 0.00164          | 0.24133          |
| 4                 | 0.3360           | 0.3510           | 0.00022          | 0.17410          |
| 5                 | 1.1310           | 1.1555           | 0.00060          | 0.14270          |
| 6                 | 1.3350           | 1.2850           | 0.00250          | 0.33843          |
| 7                 | 0.9560           | 0.9915           | 0.00126          | 0.04111          |
| 8                 | 1.1310           | 1.1210           | 0.00010          | 0.14270          |
| Total             | \( \bar{Y} = 0.75325 \) | –                | 0.00873          | 1.28186          |

According to the obtained power dependence (25), the response surfaces there have developed (Fig. 1).
Figure 1. Response surfaces of the developed relation of surface roughness refer to thread grinding modes (for heat-resistant steel 25Г2C2H2MA State Standard GOST 5632-72)

\[ R_a = 9.606 \frac{V_d^{0.331} d^{0.086}}{V_d^{0.173}}. \]  

According to the obtained power dependence (26), the response surfaces there have been developed (Fig. 2).
Figure 2. Response surfaces of the developed relation of surface roughness refer to thread grinding modes (for hard alloy BK 8 State Standard GOST 3882-74)

\[ a - s_t, V_d, d = 125 \text{ mm}; \quad b - s_t, d, V_d = 45 \text{ m/min}; \quad c - V_d, d, s_t = 0.035 \text{ mm/path} \]

The response surfaces developed for steel and hard alloy show that roughness $Ra$ of thread surface obtained by diamond grinding depends mostly on longitudinal feed per path $s_t$ and part rotation speed (Fig. 1 and Fig.2). Much less roughness depends on the part’s diameter $d$. Roughness increases more significant if rotation speed of the part is variable and longitudinal feed is constant than if rotation speed of the part is constant and longitudinal feed is variable (Fig. 1, a and Fig. 2, a). Similarly, considering the response surfaces in Fig. 1, c and 2, c, it should be noted that longitudinal feed influences more significantly on roughness $Ra$ if grinding depth is constant than longitudinal feed is constant. Similarly, considering the response surfaces in Fig. 1, c and 2, c, it should be noted that variant revolution speed of the part and constant longitudinal feed make nonsignificant greater effect on the surface roughness than variant longitudinal feed and constant revolution speed of the part.

The developed relations show that roughness of threaded parts made of hard alloy (Fig. 2) is 3–12% less then roughness of threaded parts made of steel (Fig. 1) for the same input data. This improvement in the quality of the machined surface can be explained by the fact that the abrasive grains blunt faster during the processing of harder material – hard alloy BK 8 for this case.

The results of this study, in contrast to thread grinding studies presented in [43], allow to rationally specify the technological modes of thread grinding to obtain the required surface roughness, both for steel and hard alloy parts.

5. Conclusions
1. There has been developed the relation between part surface roughness obtained during thread grinding refer to grinding modes (physical and mechanical properties of the machined material, grinding wheel, and lubricating and cooling fluid; depth of grinding; rotation speed of the part; and rotation speed of the grinding wheel). The calculations were carried out for parts made of heat-resistance steel 25Г2C2H2МА and hard alloy BK 8.
2. It was stated that components of the grinding modes contribute in roughness values in different way, in particular they are arranged in the ascending order as follows: grinding depth, rotation speed, and detail’s diameter.
3. The developed relations show that roughness of threaded parts made of hard alloy is 3–12% less then roughness of threaded parts made of steel for the same input data.

In further research it is planned to optimize the modes of thread grinding of parts made of steel and hard alloy by linear programming taking into account kinematic, force and temperature limitations during conical thread machining.
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