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SUBSTANTIATION OF REGIMES APPLIED WHEN SHARPENING VENEER PEELING LATHE KNIVES BY A MULTI-CUP ABRASIVE DISK

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Abstract:
One of the features of a lathe knife is small degrees of taper and relief angles. As observed during sharpening a lathe knife by a multi-cup abrasive disk with a planetary cup drive, the temperature on its surface varies depending on some major factors such as cutting speed, abrasive disk feed rate, and entry disk feed.

There were developed techniques for carrying out tests, as well as samples of knives with soldered thermocouples described. Besides, there were substantiated a Plan B for research planning and the number of repetitions for each test to be chosen. Upon the delivery of a preliminary series of tests there was identified a set of statistical ratios such as average knife surface temperature, dispersion, average quadratic deviation, variation index, accuracy of experiment. In addition, there were presented findings of the research tests performed in accordance with Plan B under mathematical experiment planning. An applied computer program to process the above-mentioned research findings was developed. Furthermore, there were established coefficients for the second order regression equations, in both normalised and explicit forms. Normality of temperature distribution was verified by means of asymmetry and excess criteria. Fisher's ratio test proved adequacy of the received regression equations. There were analysed effects on the knife surface temperature caused by major factors. The character of these interdependencies was described with exponential regression equations, while the total temperature with parabolic relation, respectively. All this enables to choose optimal sharpening regimes at which the temperature is minimal.

Key words: *lathe knife; abrasive disk; planetary; influential factors; regression equation; sharpening regimes.*

INTRODUCTION

The quality of mechanic woodworking is considerably dependent on a range of setting-up procedures applied to woodcutting tools. As production output and capacity grow all components of the workflow are to be highly efficient. Amongst other things, this relates to the process of sharpening knives with wide flank surface, small taper angle and small relief angle used to manufacture peeled and fine-line veneer further consumed en masse as half-finished materials in production of plywood, slabs, furniture etc.

The temperature on the surface of the knife being sharpened is function of several factors (Brosse et al. 2008, Hrytsai 2018). Its degree depends considerably on cutting speed, longitudinal disk feed, entry disk feed, supply of lubricoolant and other parameters observed in sharpening processes.

To know temperature degrees is necessary for setting up regimes applied when woodcutting knives are sharpened. The afore-mentioned regimes affect both quality and efficiency of the process of sharpening in a substantial way.

As of today, literature sources do not contain data relating to the degrees of temperature emerging on the grinding surface as an abrasive disk with planetary cup drive is applied (Valiorgue et al. 2008, Yakimov 2006), which makes it impossible to perform sharpening processes efficiently. Analysis of the work (Ivanova 2006) demonstrated the lack of arguments of abrasive cups number in the wheel. In the work (Pavlyuk 2017) scientific argumentation of the number of intervals is described, which allows us to select eight intervals for our conditions. To ensure reiteration of working parameters of cutting process, the optimal regimes should be installed. The most important among them are: cutting speed, disk feed rate and cutting speed. The goal of this work was to identify the influence of those factors and the development of mathematic model which ensures the selection of optimal parameters.

PRESENTATION OF THE MAIN MATERIAL

Based on the analysis of the research work performed, the authors concluded that the temperature emerging as knives are sharpened depends mainly on three major factors: cutting speed, longitudinal disk feed, and entry disk feed (Kiryk 2013).

These factors are interdependent and might cause a doubled effect. Other factors such as abrasive disk material, binding substance, hardness, structure etc. may be taken into account via correction coefficients (Ozymok and Kiryk 2004). When shaping the above-mentioned into a mathematical model to describe the temperature emerging during grinding, one can in a general way consider the following second-order regression equation:

$$T = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_{11} X_1^2 + b_{22} X_2^2 + b_{33} X_3^2 + \\ + b_{12} X_1 X_2 + b_{13} X_1 X_3 + b_{23} X_2 X_3 + b_{123} X_1 X_2 X_3 , \quad (1)$$

where: T stands for the temperature emerging on the surface of the knife to be sharpened; *degree C*;
b_0, b_i, b_{ii}, b_{ij}, b_{ijk} stand for the normalised regression equation coefficients;

X_1, X_2, X_3 stand for the normalised factors affecting the knife temperature (v – cutting speed; υ_S – disk feed rate; *m/min; Sf*- filing for cutting, the thickness of the metal to be cut when the carriage of the machine is doubled, *mm*).

All factors are quantitative, controlled and managed. Each factor is expected to be modified on two levels. See the values of the levels in Table 1.

Table 1

Encoding levels for the factors affecting surface temperature during grinding

Factors	Designator	Variation level			Interval
		upper code “+1”	middle code “0”	lower code “-1”	Δ
1. Cutting speed, m/sec	V	45	35	25	10
2. Feed rate, m/min	V_s	12	8	4	4
3. Entry feed, mm	S_f	0.2	0.11	0.02	0.09

To define regression equation coefficients, the researchers took use of the complete factorial design when planning the experiment, namely for the three factors of the type 2^3 (Ozymok and Kiryk 2004). In order to define the number of test repetitions in each experiment (Ozymok and Ben 2014), there was preliminarily conducted a series of tests on the main level with cutting speed set at 35m/sec, feed rate set at 8m/min and entry feed set at 0.11mm. Overall, 15 tests were performed on the main level. Having statistical data processed, we achieved an average value for knife temperature, dispersion, mean square deviation, variation coefficient, average inaccuracy, and test accuracy. Hence, five is the repeat count approved for each test.

All tests were carried out on knives made of identical grade steel and having similar linear and angle parameters. During each test, the temperature *T* emerging on the grinding surface of the lathe knife was measured (Ozymok and Kiryk 2004). All tests were performed in premises with an average temperature of 18 to 20ºC.

Research tests were conducted on samples cut out of lathe knives made of steel 8Х6НФТ/8Kh6NFT in accordance with GOST 5950-73. Here are the sizes of samples: 400×180×15mm, sharpening angle β = 20° (see Fig. 1).

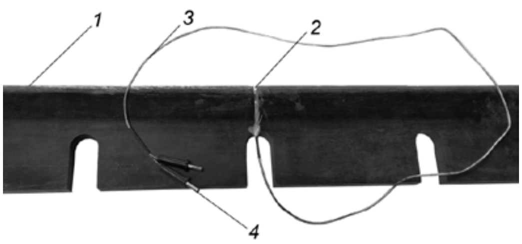
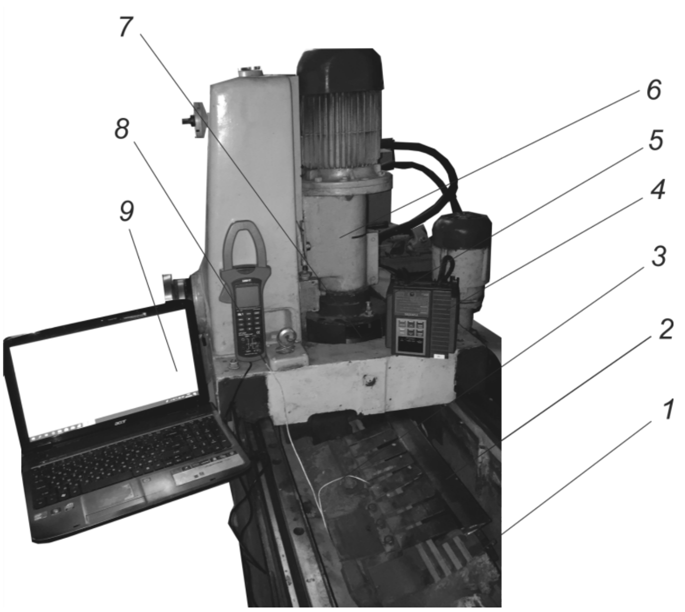


Fig. 1.
Sample knife for research
1 - knife; 2 – temperature sensor; 3 - wire; 4 – connectors.

To provide high quality findings, knife samples had similar chemical formula, hardness and microstructure. The chemical formula of steel, grade 8Х6НФТ/8Kh6NFT, corresponded to the data (Leontyev 1966).

All samples had hardness of 59 to 61 HRC units with microstructure of the cutting part of the knife consisting of troostomartensitis and carbides after quenching. Inhomogeneity of carbide did not exceed 3 points out of 3 (GOST 5950-83). The temperature was measured with a digital thermoelectric thermometer UNIT- 231 with cadmium- and nickel-plated thermocouple (see Fig. 2).



Many cup planetary abrasive tool

Fig. 2.
Experimental installation on the basis of the knife-sharpening machine TCHN 6-5 for research of level on high grinding of a knife:
1 – turntable; 2 - prototype; 3 – temperature sensor; 4 – frequency converter FVR-E9S; 5 – abrasive tool retainer; 6 – grinding head; 7 – many cup planetary abrasive tool; 8 – temperature measuring device UNIT- 231; 9 – computer to record the received data.

In the test sample, on the front surface of the knife, there was tilled a slot (with a 1mm^2 crosscut) containing a thermocouple cord. A soldered joint was 1mm lower than the cutting edge of the knife blade at that.

Since the thermocouple junction was 1mm deep, as compared to the sharpened surface, the experiment was carried out in such a way that 0.1mm wide layers were peeled gradually with concurrently taking temperature every time the abrasive disk was applied. During the final passage of the disk, when the junction of the thermocouple was practically cut away, thermometer made it possible to measure temperature on the processed surface that appeared to be most realistic. The research was focused on the sharpening regimes aligned with Plan B: cutting speed $\upsilon = 25 - 45$m/sec; feed rate $\upsilon_s = 4 - 12$m/min; penetration size $S_f = 0.02 - 0.2mm$.

Findings of the research performed (Table 2) were processed by REGK3N14 application software, which enabled achieving normalised regression equations:

$$T=395,5797+68\cdot X_1-184,4\cdot X_2+49,4\cdot X_3+22,56562\cdot X_1^2+68,56562\cdot X_2^2+11,56562\cdot X_3^2-1,00\cdot X_1\cdot X_2-0,5\cdot X_1\cdot X_3+0,5\cdot X_2\cdot X_3+1,5\cdot X_1\cdot X_2\cdot X_3 \quad (2)$$

Table 2
Measurement result data on temperatures observed on the lathe knife surface (tests performed under Plan B, second order, with three factors; $N=2^3+2K+1=15$ tests)

test №	Results of repeated temperature measurements, degrees					Average temperature, degrees	Dispersion, S^2	Mean square deviation, σ, degrees	Deviation ratio, υ, %	Error in average temperature, *m*	Test accuracy, *p*, %
	T_1	T_2	T_3	T_4	T_5						
1	550	573	553	553	571	560	122	11.04	1.97	4.9	0.88
2	694	698	695	701	722	702	132.5	11.51	1.64	5.1	0.73
3	195	200	200	190	215	200	87.5	9.354	4.68	4.1	2.09
4	325	340	338	328	329	332	43.5	6.595	1.99	2.9	0.88
5	676	656	661	660	657	662	65.5	8.093	1.22	3.6	0.54
6	793	795	796	796	800	796	6.5	2.549	0.32	1.1	0.14
7	299	309	307	289	286	298	107	10.34	3.47	4.6	1.55
8	425	424	433	445	443	434	96	9.797	2.25	4.3	1.00
9	357	359	340	355	339	350	94	9.695	2.77	4.3	1.23
10	485	484	487	490	484	486	6.5	2.549	0.52	1.1	0.23
11	643	654	641	641	661	648	82	9.055	1.39	4.0	0.62
12	282	277	289	275	277	280	32	5.656	2.02	2.5	0.90
13	362	355	364	361	348	358	42.5	6.519	1.82	2.9	0.81
14	440	462	463	456	459	456	87.5	9.354	2.05	4.1	0.91
15	389	393	404	401	571	398	44	6.633	1.66	2.9	0.74
							Σ1005				

Cochran's criterion was applied to make sure the test could be repeated (G_P).

G_p= 0.13184. G_T = 0.25. for q = 0.05; $f_y = N = 15$; $f_n = n - 1 = 5 - 1 = 4$

If $G_p<G_T$, this is indicative of the homogeneity of variances during tests.

Based on the analysis of the normalised regression equation, the following has to be stated:

- provided that the values of all three factors are placed on average levels and the temperature equals to 398°C, which corresponds to the absolute term of the equation achieved B_0 = 395.6°C, the regression equation is adequately reflective of the average level;
- provided that the coefficient of the linear component of the second factor in the regression equation has a negative value; as the value of disk feed rate increases, the knife temperature declines, meaning that there is inverse dependence between the evaluation parameter and the second factor;
- coefficients of the linear components of the first and third factors obtain positive values; hence as the values of cutting and entry speeds increase the temperature rises, meaning that there is direct dependence between the evaluation parameter and the said factors;
- presence of all three factors in the second-degree equation lends support to the parabolic relation among temperature, cutting speed, disk feed rate, and entry rate.

Double effects of factors X_1X_2 . X_1X_3 .X_2X_3. $X_1X_2X_3$ are slightly influential since regression equation coefficients (6) are relatively insignificant.

In order to present the regression equation in a natural form we make use of the accepted factor substitution and a formula designed to determine coefficients of the regression equation in an explicit form.

Upon substitution, we got a regression equation in a natural form with insignificant coefficients taken into account:

$$T = 1009.22 - 8.3682 \cdot V_p - 111.8392 \cdot V_s + 359.761\, S_f + 0.2255656 \cdot V_p^2 + 4.2853513 \cdot V_s^2 + 1427.85437 \cdot S_f^2 - 0.0708333 \cdot V_p \cdot V_s - 3.8888889 \cdot V_p S_f - 13.194445 \cdot V_s \cdot S_f + 0.4166667 \cdot V_p \cdot V_s \cdot S_f. \quad (3)$$

The adequacy of the regression equation was checked with Fisher's ratio. Here is its calculated value:

$$F_p = 67/30.99742 = 2.16147$$

The tabulated value of Fisher's ratio for q = 0.05 and $f_{a\partial}$ = 7.

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$$f_y = N \cdot (n-1) = 15 \cdot 4 = 60$$

$F_m = 2.37.$ $F_p = 2.16147 < F_m$

Thus, the regression equation is adequate.

RESULTS AND DISCUSSION

Normalised and explicit regression equations make it possible to build up graphic temperature dependencies of the most significant factors in natural values, which, in turn, enables pictorial analysis of the given relation.

Cutting rate has the most substantial effect on the knife surface temperature (see Fig. 3).

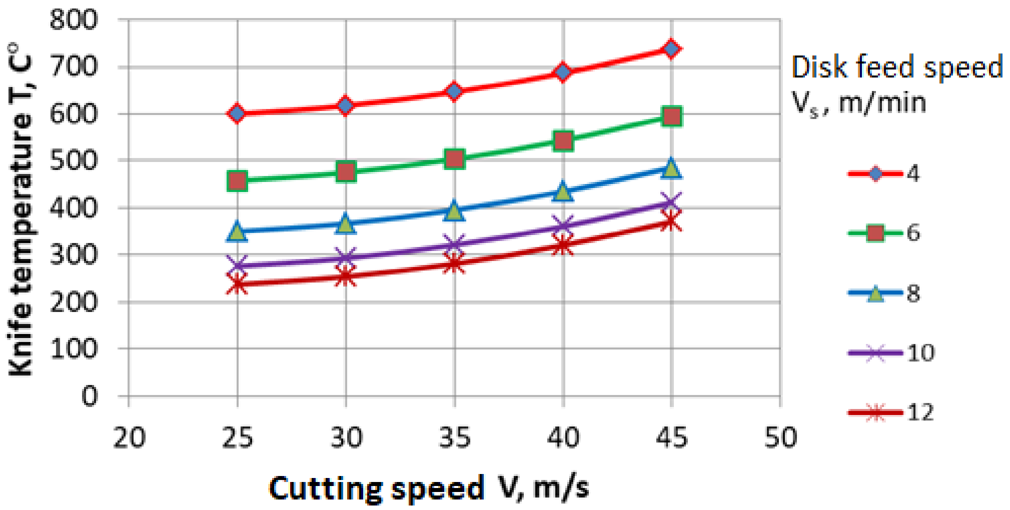

Fig. 3.
Relations among knife temperature, cutting speed and disk feed speed at a steady entry feed Sf=0.11mm.

Notably, the temperature rises particularly fast at rates equal to 44-45 m/sec reaching 740°C for the minimal value of entry rate. As the entry rate increases the temperature declines reaching 220…380°C at a steady disk feed rate of 12m/min. (see Fig. 4).

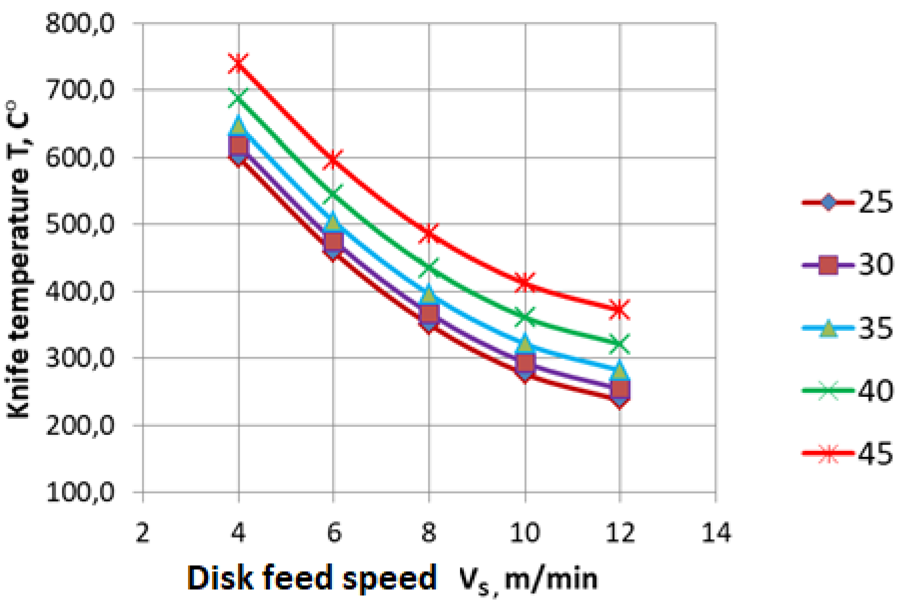

Fig. 4.
Relations among knife temperature, disk feed speed, and cutting speed and at a steady entry feed Sf=0.11mm.

As the entry feed grows, the temperature on the knife surface increases exponentially (see Fig. 5).

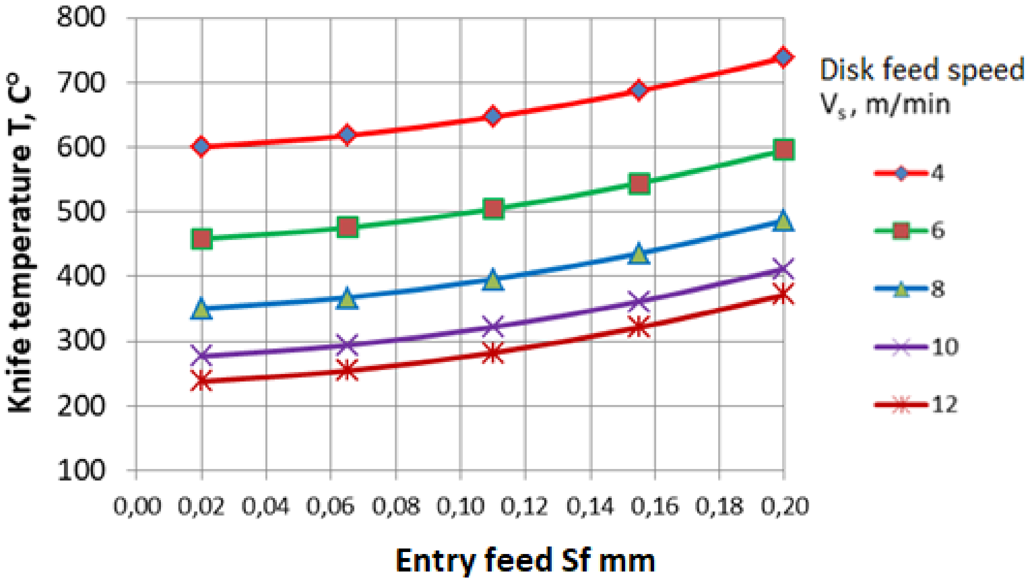

Fig. 5.
Relations among knife temperature, entry feed and disk feed speed, and speed and at a steady entry feed, and disk feed rate at a steady cutting speed of 35m/sec.

The total impact on the temperature value, in the lathe knife sharpening process, of cutting speed (Fig. 3), disk feed rate (Fig. 4) and entry feed (Fig. 5), all having opposite vector directions (Hrytsai 2018) lead to a parabolic relation (Fig. 6).

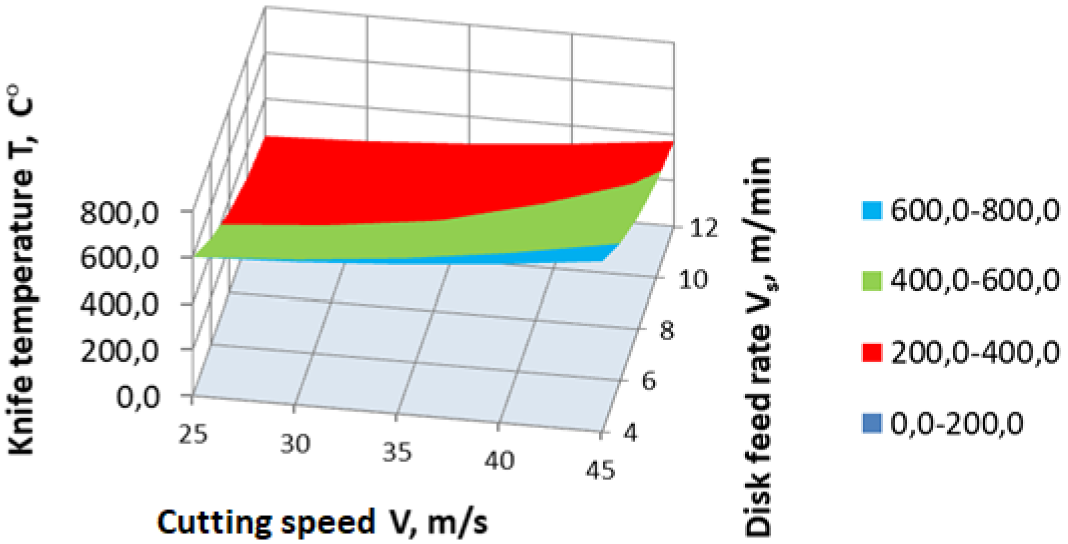

Fig. 6.
Relations among knife temperature, cutting speed, and disk feed speed at a steady entry feed Sf =0.11мм.

Such nature of the said factors can be attributed to a considerable effect of thermal power saturation in the knife blade resulting from high heat conductivity of steel, as well as V-typed shape and small thickness of the blade, all these limiting deep heat penetration. Disk breaks ensure interruptions in the heat saturation process (Pylypchuk et al. 2007) also due to the cooling ventilation effect observed on the knife surface. When sharpened with a single disk, the acceleration of entry feed and cutting speed cause rise in temperature. Therefore, breaks on the disk surface together with lowering entry feed are factors enabling a significant decline in temperature on the lathe knife surface.

Both theoretical and experimental research studies outlined above set relations between temperature on the knife surface and major influential factors. Nevertheless, differences in key factor dimensions do not permit to regard them in one system of coordinates. Provided that factor dimensions are normalised, they can be combined in one system of coordinates. Then we are able to establish a normalised regression equation, examine its extreme values and find rational sharpening regimes. Outputs of the experimental exploration of temperature dependency on the knife surface in the system of normalised coordinates are laid in Table 3.

Table 3

Relation between temperature on the knife surface and major factors

Knife temperature	Normalised factor coordinates				
	-1	-0.5	0	0.5	1
T=f(V)	60	80	110	142	200
T=f(Vs)	450	320	192	131	86
T=f(Sf)	48	60	88	112	150
T_Σ	558	460	390	385	436

Dependency among knife temperature, cutting speed, disk feed rate and entry feed presents an exponential relationship, whereas a total knife temperature dependency presents a parabola-like polynomial relation:

$$T_\Sigma = 103.7143 \cdot X^{2 \cdot -} 63.8 \cdot X + 393.9429. \qquad (4)$$

Indicator of adequacy of the trend line in the equation (4). $R^2 = 0.9945.$

Extremes studies within the equation (3) allow to determine a minimal temperature coordinate. The nature of relation between temperature on the knife surface and major factors can be seen in Fig. 7 as presented graphically.

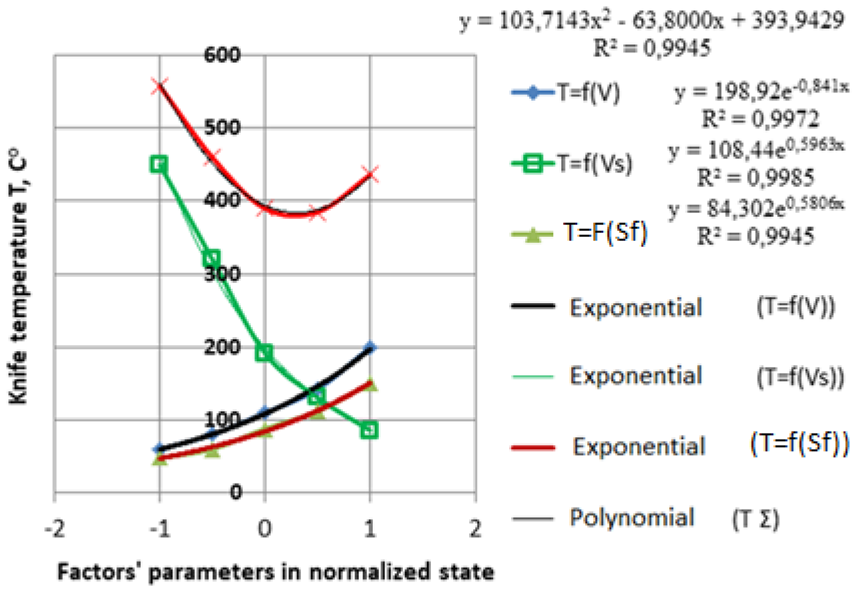

Fig. 7.
Relation among knife temperature, cutting speed, feed rate and entry feed in the system of normalised coordinates.

After setting equal to zero and differentiation we obtained as follows:

$103.7143 \times 2 \times X - 63.8 = 0; \quad X = 63.8/(103.7143 \times 2) = 0.3075757$

After applying equations (2. 3) we obtained values of the factors in an explicit form (Ivanova 2006).

For the cutting speed:
$V = X \cdot \Delta_v + V_0; \quad V = 0.3075757 \times 10 + 35 = 38.075757 m/sec$

For the feed rate:
$V_s = X \cdot \Delta_{vs} + V s_0; \quad V_s = 0.3075757 \times 4 + 8 = 9.2303028 m/min$

For the entry feed:
$S_f = X \cdot \Delta_{Sf} + V_{0Sf}; \quad S_f = 0.3075757 \times 0.09 + 0.11 = 0.137681813 mm$

Introduction of these sharpening regimes makes it possible to lower temperature of the knife surface to

$$T_{min} = 103.7143 \cdot X^{2 \cdot -} 63.8 \cdot X + 393.9429 =$$
$$= 103.7143 \times 0.3075757^2 - 63.8 \times 0.3075757 + 393.9429 = 377.3374 \ ^\circ C$$

Provided that the error in mean is taken into consideration, we assume that the minimal temperature on the knife surface fluctuates between 370 and 385°C.

CONCLUSIONS

Analysis of the tests performed and aimed at studying temperature on the lathe knife surface during sharpening with a multi-cup abrasive disk with planetary cup drive makes it possible to conclude as follows:

- the experimental tests performed with a view to stud the temperature on the lathe knife surface found relationships between temperature change and major influential factors.
- there were set second-order coefficients of the regression equation in both normalised and explicit forms.
- research findings allow approaching the issue of optimization of lathe knife sharpening processes and further define rational grinding regimes.
- relations among knife surface temperature and cutting speed, disk feed rate, and entry rate are subject to exponential dependency, whereas total temperature appears parabola-based dependent.
- difference in the dimensionality of major factors does not enable combining them in a single system of coordinates. Provided that the dimensions of key factors are normalised, they can be aligned in one frame of axis.
- the research tests performed made it possible to optimize the process of lathe knife sharpening and substantiate rational grinding regimes.

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