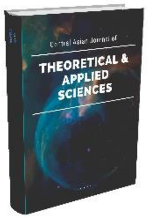

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Metal Cutting Process Control Based on Effective Power

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Abstract: *The article deals with the use of effective power as an informative parameter for controlling the process of cutting metals when creating high-performance technologies in automated production.*

Keywords: *effective power, cutting process, cutting force, cutting speeds, cutting tool, structural steels, experimental studies, machine tool engine, hard alloy, fine turning, longitudinal feed, depth of cut..*

Analysis of machining process control systems shows that power is a reliable source of information. However, power is spent not only on the cutting process, but also on heat losses, on magnetization reversal and overcoming friction forces in the engine itself. Part of the power consumed goes to losses in the kinematic connections of the machine.

The power directly spent on the implementation of the cutting process is called the effective power ***Ne*** and is defined as:

$$N_e = \vec{P} \cdot \vec{V}, \text{ W} \qquad (1)$$

where: $\vec{P}$ - cutting force vector, N;

$\vec{V}$ - cutting speed vector, m/s.

The effective power *Ne* in the general case is the total power expended in the cutting process by all components *Px*, *Py* and *Pz* of the cutting force *P*.

The power of the axial component of the cutting force *Nex* is equal to

$$N_{ex} = P_x nS \text{ , W} \qquad (2)$$

where: n - is the rotational speed of the workpiece, r/s;

S - feed, mm/rev.

The power of the radial component of the cutting force *Ney* is defined as

$$N_{ey} = P_y V \cos 90^\circ \text{, W} \qquad (3)$$

and is equal to 0 , since the vector $\vec{P}_y$ is perpendicular to the vector *V*.

The power of the vertical component *Pz*, the direction of which coincides with the direction of the cutting speed, is determined by the equation

$$N_{ey} = P_z V \text{, W} \quad (4)$$

Therefore, the effective cutting power, taking into account equations (2,3,4), is determined as

$$Ne = N_{ex} + N_{ey} + N_{ez} \text{, W} \quad (5)$$

i.e.

$$Ne = P_{xn} s + P_z V \text{, W} \quad (6)$$

The dependences of the effective cutting power on the cutting conditions and the hardness of the material being processed are obtained by theoretical analysis and give very approximate results. In this regard, the task was set to check the accuracy of the derived dependencies and additionally obtain an equation for the effective cutting power in the process of turning structural steels with a cutting tool with a hard alloy plate based on experimental studies.

Experimental studies were carried out on a CNC lathe 16A20F3. The measurement of the engine power of the main drive of the lathe was carried out using the K505 device, directly included in the motor armature winding and recorded on a computer. The K505 device is designed to measure current, voltage and power in AC circuits. The effective cutting power was defined as the difference between the total power consumed by the main drive motor of the machine and the idle power.

When processing structural steels, the input variables were the cutting conditions *V, S, t* and the hardness of the material being processed *HB*, and the output variables were the corresponding values of the effective cutting power *Ne*. The experimental conditions made it possible to vary each of the input variables at four levels, $x_j = \{-2, -1, +1, +2\}$ which had the following values: $V = \{1.6, 2.3, 3.5, 4.1 \text{m/s}\}$, $S = \{0.1, 0.15, 0.25, 0.3 \text{mm/rev}\}$, $t = \{0.1, 0.15, 0.25, 0.3 \text{mm}\}$.

Table 1

No.	S	t	V	HB	S, mm/rev	t, mm	V, m/s	HB	N_e, W
1	-1	-1	-1	-1	0,05	0,14	2,3	187	90
2	+2	-1	-2	+1	0,125	0,14	1,7	217	131
3	-2	+2	-2	+2	0,025	0,40	1,7	285	79,5
4	+1	+2	-1	-2	0,1	0,40	2,3	156	157,5
5	-1	-2	+1	+2	0,05	0,05	3,5	285	112,5
6	+2	-2	+2	-2	0,125	0,05	4,1	156	217,5
7	-2	+1	+2	-1	0,025	0,31	4,1	187	172,5
8	+1	+1	+1	+1	0,1	0,31	3,5	217	285

Structural steel grades 20, 45, 40Kh, 35KhGSA were processed. For processing steels, cutting tools with T15K6 hard alloy plates were used, the geometric parameters of which are the following: *γ=8°, α=9°, φ=45°, λ=0°.* Permissible wear criterion on the back surface of the cutting tool h=0.4 mm. Experimental data are shown in tables 1-5.

Table 2

No.	Dependences of the components Px, Py, Pz of the cutting force. [N]
1	$Px=4.604+1091.5St-29943(tVHB)^{-1}-1.427\cdot 10^{-3}t^{-3}$
2	$Px=2.056+1396.4St-1.681\cdot 10^{6}S(V\cdot HB)^{-1}-0.360S^{-2}HB^{-1}$
3	$Px=1.162+1232.4St-6.173St-1-5.531\cdot 10^{-4}V\cdot HB^{-1}$
4	$Px=4.910+1107.4St-30378(tVHB)^{-1}-8.073\cdot 10^{-4}HB\cdot t^{-1}$
5	$Px=-0.984+1092.3St-9.376t^{-2}HB^{-1}-4.968\cdot 10^{-6}V^{2}$
6	$Py=-15.813+2.929\cdot 10^{5}StHB^{-1}+0.106\cdot HB+1.107\cdot 10^{-5}t^{-1}HBV^{-1}$
7	$Py=-1.872+2.723\cdot 10^{5}StHB^{-1}+2.239\cdot 10^{-4}HB^{2}+6.298\cdot 10^{-4}HB^{2}S$
8	$Py=-13.264+2.874\cdot 10^{5}StHB^{-1}+0.104HB+9.292\cdot 10^{-4}HBS^{-1}$
9	$Py=-11.030+2.883\cdot 10^{5}StHB^{-1}+0.104HB-1.418\cdot 10^{3}tHB^{-1}$
10	$Py=-10.97+2.731\cdot 105StHB-1+9.884\cdot 10-2HB^{-1}+5.659\cdot 10^{-2}SHB$
11	$Pz=13.272+7.483\cdot 10^{5}StHB^{-1}-3.794\cdot 10^{4}SHB^{-1}+5.691\cdot 10^{-3}HBt^{-1}$
12	$Pz=49.253+6.948\cdot 10^{5}StHB^{-1}-9.482\cdot 10^{3}HB^{-1}+3.514\cdot 10^{4}V^{-2}$
13	$Pz=48.569+6.917\cdot 10^{5}StHB^{-1}-9.440\cdot 10^{3}HB^{-1}+1.106\cdot 10^{7}V^{-2}HB^{-1}$
14	$Pz=37.954+7.001\cdot 10^{5}StHB^{-1}-7.958\cdot 10^{3}S^{3}-4.720\cdot 10^{3}HB^{-1}$
15	$Pz=35.910+6.728\cdot 10^{5}StHB^{-1}-9.151\cdot 10^{5}HB^{-2}-1.868\cdot 10^{-4}V\cdot HB$

Table 3

№	S	t	V	HB	S, mm/rev	t, mm	V, m/s	HB	P_z, N	P_y, N	P_x, N
1	-1	-1	-1	-1	0.05	0.15	140	187	33	13	8
2	+2	-1	-2	+1	0.125	0.15	100	217	71	36	16
3	-2	+2	-2	+2	0.025	0.3	100	285	36	25	9
4	+1	+2	-1	-2	0.1	0.3	140	156	130	57	35
5	-1	-2	+1	+2	0.05	0.1	210	285	31	26	6
6	+2	-2	+2	-2	0.125	0.1	250	156	46	27	9
7	-2	+1	+2	-1	0.025	0.25	250	187	31	18	12
8	+1	+1	+1	+1	0.1	0.25	210	217	85	43	29

Table 4

№	S	t	V	HB	S, mm/rev	t, mm	V, m/s	HB	N_e, W
1	-1	-1	-1	-1	0.05	0.15	2,3	187	67.5
2	+2	-1	-2	+1	0.125	0.15	1,7	217	135
3	-2	+2	-2	+2	0.025	0.3	1,7	285	60
4	+1	+2	-1	-2	0.1	0.3	2,3	156	272.5
5	-1	-2	+1	+2	0.05	0.1	3,5	285	119
6	+2	-2	+2	-2	0.125	0.1	4,1	156	220
7	-2	+1	+2	-1	0.025	0.25	4,1	187	157.5
8	+1	+1	+1	+1	0.1	0.25	3,5	217	337.5

Table 5

№	Dependences of effective cutting power Ne at finishing turning of structural steels, [W]
1	$N_e=16.954+7.332\cdot10^4S^2t+9.501\cdot10^{-6}V^3-7.915\cdot10^{-2}V^{-2}HB^{-1}$
2	$N_e=-84.532+7.169\cdot10^4S^2t+1.11^3V-1.295\cdot10^{-4}V^2t^{-1}$
3	$N_e=58.053+6.054\cdot10^4S^2t+7.8443\cdot10^{-6}V^3-0.298S^{-1}t^{-1}$
4	$N_e=-222.15+8.125\cdot10^4S^2t+1.261V+40.864HB\cdot V^{-1}$
5	$N_e=-33.308+5.612\cdot10^4S^2t+0.871V-0.193S^{-1}t^{-1}$
6	$N_e=-72.932+7.306\cdot10^4S^2t+1.134V-55.004VHB^{-1}$
7	$N_e=61.976SVt+6.177\cdot10^{-4}VS^{-1}t^{-1}$
8	$N_e=10.509+61.029StV+6.083\cdot10^{-4}VS^{-1}t^{-1}+8.305\cdot10^{-5}V^2$
9	$N_e=9.158+60.94StV+6.074\cdot10^{-4}VS^{-1}t^{-1}+5.007VHB^{-1}$

In the process of fine turning of structural steels with a carbide cutting tool, the average value of the effective cutting power *Ne* was recorded. The results obtained were processed using the algorithms of the method of group accounting of arguments, as a result of which mathematical models of the effective cutting power *Ne* were obtained from the modes *S, t, V* and the hardness of the material being processed HB.

The mathematical model was chosen

$$N_e = 73060S^2t + 1.134V - 55.004\frac{V}{HB} - 72.932, \quad \text{W} \qquad (7)$$

adequate with an accuracy of 5% for finishing turning structural steels with hardness HB=156-285 and cutting conditions S=0.025-0.125 mm/rev; t=0.1-0.3 mm; V=1.7-4.2 m/min.

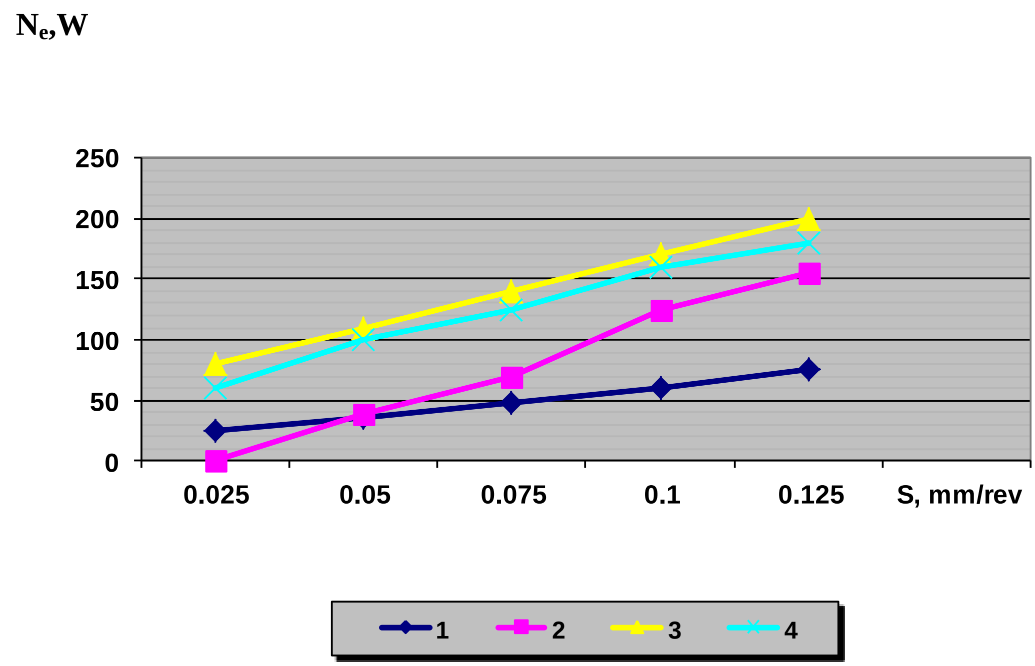

Fig. 1. Dependence of the effective cutting power Ne on the longitudinal feed

(t=0.1 mm; V=3.5 m/s; HB=156; steel)

The choice of the mathematical model was carried out according to the criterion of the minimum bias of the coefficients $n_0 = \left| \frac{a_0 - b_0^1}{\bar{Y}} \right| \to \min$

Figures 1, 2 and 3 graphically present the dependences of the effective power of structural steels on cutting conditions, are built according to theoretical equations, and the dependence is obtained through experimental studies. Curves 1, 2, and 3 correspond to them in the figures. Number 4 denotes the experimental points obtained by direct measurement of the power for each specific case.

It follows from the analysis of the graphs that curves 3, constructed according to the dependence obtained by experimental studies, practically coincide with experimental points 4, i.e. dependence (7) most fully reflects the actual nature of the change in the effective power of the process cutting.

From the analysis of the dependence it can be seen that with an increase in any of the cutting modes, the effective power of finishing turning of structural steels with a carbide cutting tool also increases. We also note that the cutting speed has the greatest influence on the amount of effective power, and to a lesser extent, the longitudinal feed and the depth of cut. When turning structural steels, an increase in the cutting speed by a factor of 2 leads to an increase in the effective cutting power by a factor of 1.3–1.8, depending on the area of the cut layer.

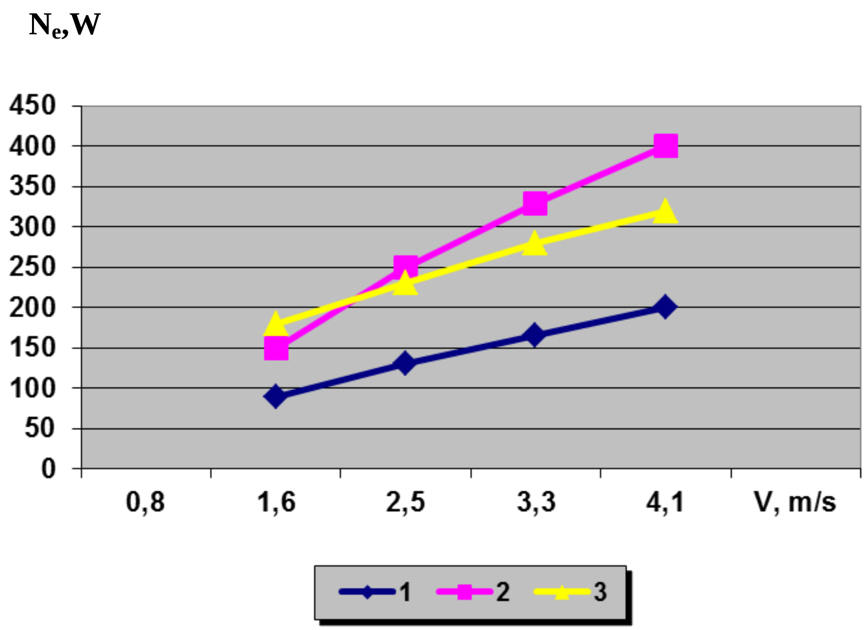

Fig. 2. Dependence of the effective cutting power Ne on the feed rate

(S=0.1 mm/rev; t=0.25 mm; HB=187; steel)

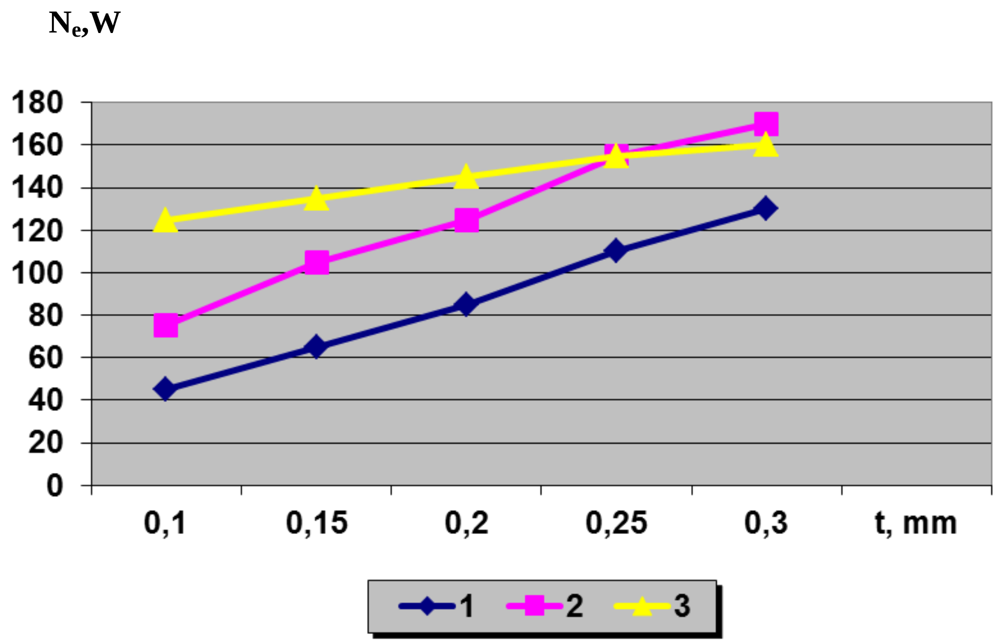

Fig. 3. Dependence of the effective cutting power *Ne* on the depth of cut

(S=0.05 mm/rev; V=0.25 m/min; HB=217; steel)

The analysis of the dependences of the effective power on the elements of the cutting mode confirms the information content of the signal in terms of power and its suitability for use in control systems for the process of mechanical processing of machine parts.

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