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The effect of cutting conditions on power inputs when machining

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Abstract. Any technological process involving modification of material properties or product form necessitates consumption of a certain power amount. When developing new technologies one should take into account the benefits of their implementation vs. arising power inputs. It is revealed that procedures of edge cutting machining are the most energy-efficient amongst the present day forming procedures such as physical and technical methods including electrochemical, electroerosion, ultrasound, and laser processing, rapid prototyping technologies etc, such as physical and technical methods including electrochemical, electroerosion, ultrasound, and laser processing, rapid prototyping technologies etc. An expanded formula for calculation of power inputs is deduced, which takes into consideration the mode of cutting together with the tip radius, the form of the replaceable multifaceted insert and its wear. Having taken as an example cutting of graphite iron by the assembled cutting tools with replaceable multifaceted inserts the authors point at better power efficiency of high feeding cutting in comparison with high-speed cutting.

1. Introduction
A lot of attention is paid to the problems of energy saving and efficient use of energy resources all over the world [1,2]. Economical power consumption in the production process is one of key factors of intensifying and improving the production efficiency. It is particularly important for power-consuming industries of economy [3-5]. Let us address to this issue regarding mechanical engineering. Any technological process involving modification of material properties or product form necessitates consumption of a certain power amount. Procedures of edge cutting machining are the most energy-efficient amongst the available forming procedures [6-8]. For instance, energy consumed for removal of a volume when turning is taken as a unity, then this value needed for polishing increases hundredfold, and for electrochemical and electro-physical processing even thousandfold and more [9]. Therefore, when developing up-to-date technologies one should take into account the benefits of their implementation vs. arising power inputs. On the other hand, power costs in traditional technologies depend on the conditions of machining, first of all, on the cutting mode. Let us consider this problem regarding turning ferrous metals by assembly cutting tools with replaced multifaceted inserts fastened mechanically [9-11].

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2. Results and Discussion

Power inputs H of machining are thought as electric energy consumed for removal of one kilogram of chips [9]:

$$H = \frac{N \cdot \tau}{W \cdot \lambda} \quad \text{kW-hour/kg}, \tag{1}$$

where N – power, supplied for cutting, kW;
τ – time of cutting, hour;
W – volume of removed chips over the time of cutting, m^3;
λ – density of the material to be processed, kg/m^3.
Values N and W are in line with the formulae given in [9]

$$N = \frac{P_Z \cdot V}{60 \cdot 1020}; \tag{2}$$

$$W = 60 \cdot 10^{-6} \cdot V \cdot t \cdot S \cdot \tau, \tag{3}$$

where P_Z – tangential component of the cutting force, N;
V – velocity of cutting, m/min;
t – depth of cutting, mm;
S – length-wise supply, mm/turn.
Using expressions (2) and (3) in formula (1) and giving all values in the same numbers of dimension, we obtain:

$$H = \frac{P_Z}{3{,}67 \cdot t \cdot S \cdot \lambda}. \tag{4}$$

We use the data given in [11] for further analysis, considered for outer length-wise turning of graphite iron GI 25 (λ=7.15 kg/m^3) by cutting tools with three-faceted inserts of hard alloy VK 6.

It can be seen in formula (4) the component of the cutting force P_Z is required to calculate the power inputs.

The experiment aimed at detecting the influence of cutting modes on the force of cutting are conducted by the cutting tool VAZ with a three-facetted regular insert, its outside angle is 01331-160308 K6 GOST 19045-80; and geometrical parameters are as follows: $\alpha = 6^0$, $\gamma = 5^0$, $\varphi = 90^0$, $\varphi_1 = 30^0$, $\lambda = 0^0$, r=0.8 mm. Reference parameters of cutting modes: $V = 1{,}0 м/с$, t=2mm, S=0.57 mm/turn. No cutting fluid is required. Each point of experiments is passed at least five times. The speed of cutting is varied 0.33 to 1.67 m/s (Figure 1).

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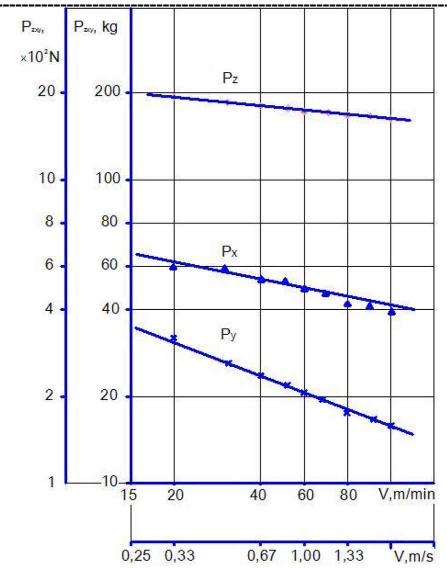

Figure 1. The effect of cutting speed on the cutting force components: GI25-VK6; cutting tool – (VAZ), a rectangular insert with the outside angle, $\varphi = 90^0$; t=2 mm; S=0.57 mm/turn.

The experiments have revealed that increasing speed of cutting results in monotonous decreasing of all its components, while the component P_Z is the slowest one, and P_y diminishes most intensively. Corresponding approximations are as follows:

$$P_Z = 235.6\ V^{-0,07}; \quad (5)$$

$$P_y = 122.4 V^{-0,44}; \quad (6)$$

$$P_x = 138.0\ V^{-0,27}. \quad (7)$$

The results of experiments focused on identifying the influence of depth of cutting and supply on the force of cutting are presented in Figure 2 a, – for the cutting force component P_Z, in Figure 2 b – for the cutting force component P_y and in Figure 2 c – for the component P_x.

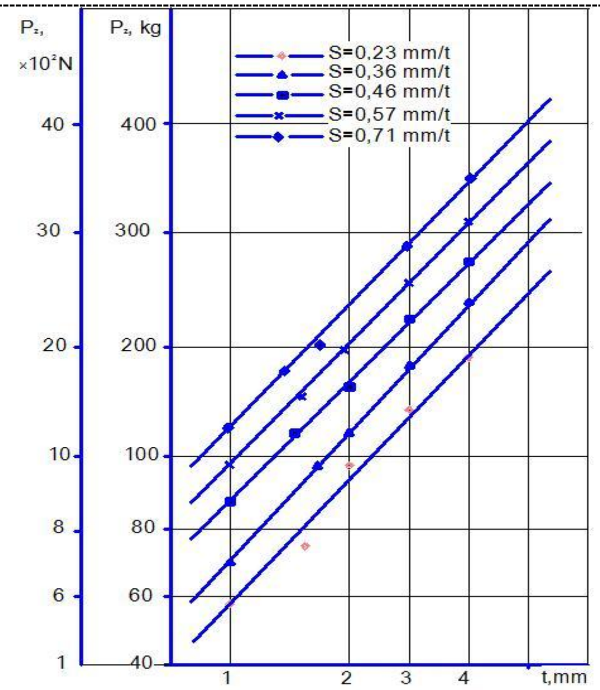

Figure 2a. The effect of the depth of cutting and supply on the component P_Z, GI25-VK6, cutting tool – VAZ, three-faceted insert with the outer angle, V =1.0 m/s

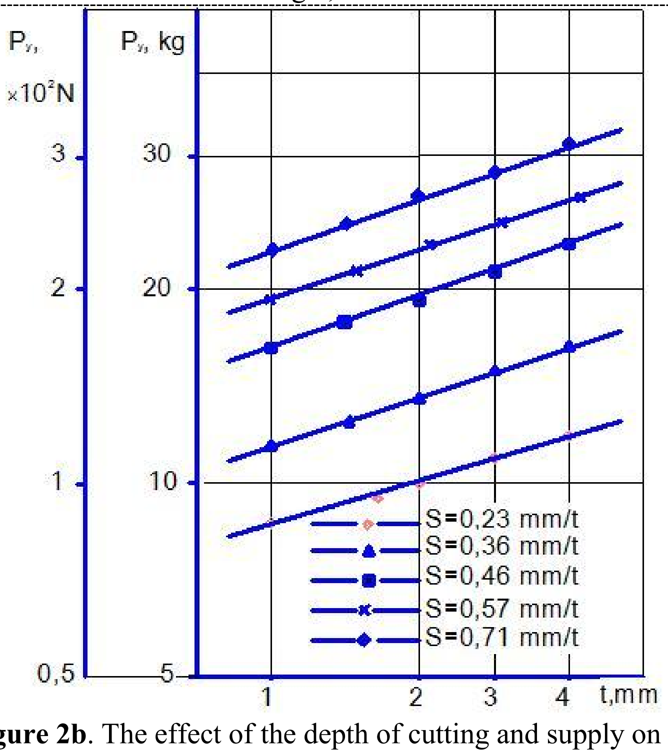

Figure 2b. The effect of the depth of cutting and supply on the component P_y, GI25-VK6, cutting tool – VAZ, three-faceted insert with the outer angle, V =1.0 m/s

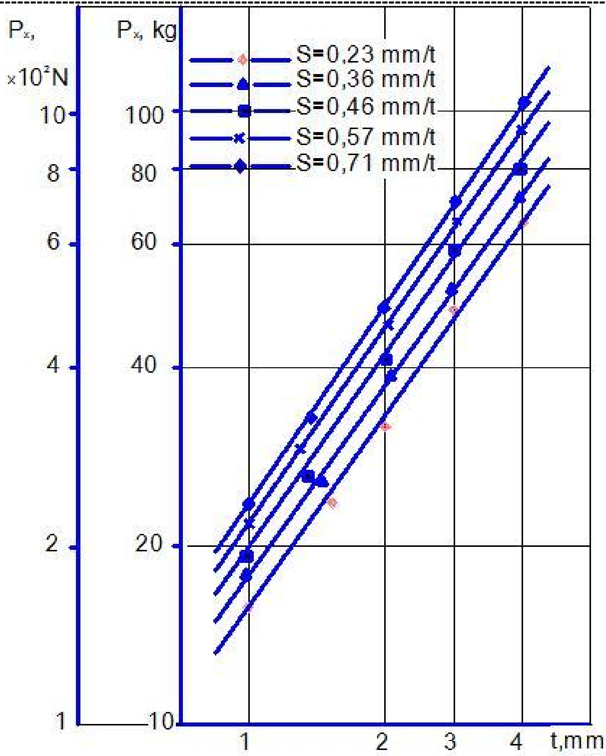

Figure 2c. The effect of the cutting depth and supply on the components P_x, GI25-VK6, cutting tool – VAZ, three-faceted insert with an outer angle, V =1.0 m/s

One can see in the Figures above that supply and depth of cutting are independent on each other and the expression below can be accepted as the mathematical model:

$$P_z = C_{Pz} \cdot t^{X_{Pz}} \cdot S^{Y_{Pz}}; \quad (8)$$

$$P_y = C_{Py} \cdot t^{X_{Py}} \cdot S^{Y_{Py}}; \quad (9)$$

$$P_x = C_{P_x} \cdot t^{X_{P_x}} \cdot S^{Y_{P_x}}. \quad (10)$$

Results of experiments processed according to the “classical” method are relevant for deducing the formulae of the depth of cutting and supply:

$$P_z = 145,7 \cdot t^{0,85} \cdot S^{0,68}; \quad (11)$$

$$P_y = 28,9 \cdot t^{0,29} \cdot S^{0,78}; \quad (12)$$

$$P_x = 28,9 \cdot t^{1,13} \cdot S^{0,36}. \quad (13)$$

One should note the speed of cutting is not taken into account in the formula (4), however, its effect on the power inputs is incorporated in the component P_Z. Substituting equation (5) in it and numerical values of the constants, we obtain:

$$H = 0,787 \cdot V^{-0,07}, \text{ kW-hour/kg.} \quad (14)$$

The dependence of power inputs on the depth of cutting and supply can be obtained the same way by substitution (8) in (4):

$$H = \frac{0,397}{t^{0,15} S^{0,32}}, \text{ kW-hour/kg.} \quad (15)$$

The power inputs are decreased when intensifying the cutting mode according to the analysis of (14) and (15). The most efficient method of their reduction is increasing the supply, whereas increasing the depth of cutting is the least efficient method. The growth of cutting speed can save the power somehow, but it affects negatively the lifetime of the tool. So, the cutting speed influences on the power inputs to the extent 0.07, and on the wear resistance – to the extent of 4.2 [11].

And expanded formula given below is deduced to calculate the power inputs, taking into account both the mode of cutting and the tip radius r, the form of the replaceable multifaceted insert and its wear:

$$H = 0{,}0735 \cdot V^{-0{,}07} \cdot t^{-0{,}15} \cdot S^{-0{,}32} \cdot r^{0{,}01} \cdot K_{\phi p_z} \cdot K_{hp_z} . \quad (16)$$

Correcting coefficients of formula (16) are given in Tables 1 and 2. Formula (16) is true in the following ranges of augment variation: V =0.33 – 1.67 m/s; t=1 – 4 mm; S=0.23 – 0.71 mm/turn; r=0.8 – 2.6 mm.

Table 1. Correcting coefficient for the value of wear

Wear h_3, mm	K_{hpz}
0.0	1,00
0.5	1.01
0.8	1.02
1.0	1.04
1.2	1.11
1.5	1.27

Table 2. Correcting coefficient for the insert form

Insert form	K_{fP2}
Regular trihedral with the outer angle	1,00
Regular trihedral insert	1.12
Irregular trihedral with the hole and clearance grooves	1.10
Rectangular with the whole and clearance grooves	1.14
Five-sided with the hole	1.12
Hexahedral with the hole and clearance grooves	1.05
Rhombic with the hole and clearance grooves	1.11
Parallelogram with clearance grooves, left.	0.96

Summary

- Procedures of edge cutting machining part blanks are the most energy-efficient ones as against such up-to-date technologies as physical and technical methods including electrochemical, electroerosion, ultrasound, and laser processing, rapid prototyping technologies etc. [12-14]. Therefore, it is to be taken into account when adopting up-to-date technologies.
- An expanded formula for calculation of power inputs is deduced, which takes into consideration the mode of cutting together with the tip radius, the form of the replaceable multifaceted

insert. These formulae can be used for developing standards of power consumption, which is relevant for production activity of the enterprise.

- Having taken as an example cutting of graphite iron by the assembled cutting tools with replaceable multifaceted inserts the authors point at better power efficiency of high feeding cutting vs. high-speed cutting. Therefore, production profitability can be increased, as well as the competitive ability of the manufactured product can be improved.

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