Optimization of Multitool Machining Process by using criteria of maximum productivity rate

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Abstract

Cutting processes require more energy, capital, and labor than forming and shaping operations, thus, and they should be minimized whenever possible. Unless carried out properly, cutting processes can have adverse effects on the surface integrity of the product. In spite of these limitations, cutting processes and machines are indispensable to manufacturing technology. Increasing of machining regimes leads to increasing of machining cost and also to increasing productivity rate. The advantages and limitations of machining, and the technical considerations were described in details, however there are some unsolved problems from optimization point of view. In case of multitool machining process when cutters engaged simultaneously or sequentially to define the optimal machining mode that gives maximum productivity rate is important problem. Machining operations cannot be carried out efficiently and economically without a fundamental knowledge of the complex interactions among these elements. This article considers solution of optimal multitool machining processes from the estimate of the productivity rate and machining costs.

Keywords: machining, productivity, optimization, economics

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Introduction

The economics of machining has the two most important parameters are the minimum machining cost per part and the maximum production rate of machine tool. Which one is more important, it depends on many factors. Manufacturers are struggling for increase of productivity of machining processes and to put on the market more products. Increasing of productivity rate is reached by increasing of machining modes that leads to increasing of a cost of machining process and to increasing of a cost of products. Last leads to decrease the sell of products due to its expensiveness. However, marketing process shows different picture of sells. If product is requested by customers, manufacturers can sell by high prices. In this case, the index of minimum machining cost moves away from first position and index of the productivity rate comes to first level. When market comes to saturation by products, the sells of product decreasing, in such case product should be manufactured by minimum machining cost.

There are mathematical dependencies, which enable to calculate the minimum machining cost depending on the changes in the machining modes and optimize the machining process [2]. However, the criterion of the maximum productivity rate of machinery prevails in many cases of industrial production because there is no big difference in values of optimal machining modes by criterions of the minimum cost and the maximum productivity [3].

2. Analytical approach

Demand to increase the productivity rate of the machine tools leads to intensification of the machining process, which reflects on the reliability parameters of the machine tools components. Hence, increase of machining modes of industrial machine tools leads to increase the productivity rate at one side and at other side leads to increase the failure rates of the machine tool components. The failure rates increase due to increase the dynamic loads on the components, increase wearing process, etc., hence machine tools need to be stopped, tuned, that decrease productivity rate one. These circumstances show that machine tools should have optimal machining modes that can give maximal productivity rate. The dependency of the productivity rate with change of machining modes should be described analytically that enables to predict the real output of machine tools. To find such mathematical dependency it is necessary to conduct analysis of all parameters of the machine tool work with change of machining modes.

Machining processes comprise many unsolved problems that should be resolved in order to get reliable data with respect to manufacturing economics. Some analytical models are able to predict machine tool output through changes of the tool life [1]. Known equations of machining modes quite poor express the productivity rate and do not have dependencies of reliability machine tool mechanisms [5-10]. The analytical expressions of productivity rate that include all parameters of machining mode are very important in manufacturing area if enable to predict output of machinery with high accuracy. This is a highly complex subject area of machining of bevel gears and hypoid gears with spiral tooth. For these processes, special machine tools designed with Difficulty performing measurements the gear geometry corrections and set up process developed. There are also some secondary issues involved in this process simplified the development process of gear cutting machine tools can be broadly separated into two parts processes that separately cutting the concave and convex sides of the spiral tooth [13].

The theory of reliability is closely related to Indices of productivity, the both theories the efficiency of machines, and optimizations one. The reliability of machines has been guessed by standard indices of the theory of reliability. The main index of reliability of every manufacturing machine is its availability [14].

In many cases the parts transported must be separated for two flow chute branches and transferred to different processing machines. All known designs of chutes with flow part separators have a simple controlled mechanism in the form of a swing shield or pocket type that allows directing the flow of a part to the required branch of the transport chute. Nevertheless, such a simple swing shield creates problem due to its low reliability [15].

A machining mode is characterized by following parameters as a cutting speed, feed rate and depth of cutting process. Feed rate and depth of cutting process cannot be changed in large scale due to limitation of the quality surface and accuracy of machining process. However, a cutting speed can be changed quite large range. With increase of cutting speed is reduced surface roughness of a machined part, increased accuracy of machining and also increased the productivity rate of machining process. Also it is known that the intensification of machining modes reflects on the more intensive wear process of machine tool units as a result of the increase in the dynamic forces and speed of motion ones. As result, machine tools have to go through more maintenance and repairing process that ultimately result in the decrease of its output and economical efficiency.

The fundamental basis of the calculation of the productivity rate of machine tools as a function of the intensification of machining regimes can be presented by the following equation [2].

$$Q = \frac{1}{t_m + t_a + \sum_{i=1}^{k} t_{ci} + \sum_{j=1}^{p} t_{ej}} \qquad (3)$$

where Q is productivity rate of a machine tool (parts/min), t_m is duration of machining time that spends in the feed mode or cutting and removing chips (min/parts), t_a is duration of auxiliary time that spends to load, unload the workpiece, advance and retract the tool and occasional dimensional inspection of the part (min/parts), $\sum_{i=1}^{k} t_{ci}$ is time losses referred to one part due to reliability of cutting tools that are changed after some limit of wearing or occasional brakes, then cutters set up and tuning and so forth (min/parts), $\sum_{j=1}^{p} t_{ej}$ is time losses referred to one part due to reliability of machine tool units containing mechanical, electric, hydraulic, etc. units (min/parts).

For the analysis of the influence of change of machining modes on the productivity rate of machine tool, it is grouped mechanisms for machining motions and auxiliary motions. Industrial practice and theory of machining processes show that that increase the cutting speed leads to decrease of a machining time, and to increase the productivity losses due reliability of a machine tool components. It is necessary to consider each component of the equation of machine tool productivity with change of cutting speed on the lathe.

2.1. The change of the machining time with changes in machining modes.

The machining time can be expressed by ratio of the sum of the number of the spindle revolutions, which necessary for fulfillment of all uncombined operations Σn_m to the number of the revolutions of the spindle per minute n_s. This machining time has the following equation

$$t_m = \frac{\sum_{i=1}^{g} n_{mi}}{n_s} \qquad (4)$$

where $\sum_{i=1}^{g} n_{mi} = n_{m1} + n_{m2} + n_{m3} + \ldots + n_{mg}$ is the sum of the number of the spindle revolutions for fulfillment of g uncombined i operations.

The number of the spindle revolutions per each operation can be expressed by the following equation

$$n_{m1} = l_{m1}/f_{m1};\ n_{m2} = l_{m2}/f_{m2};\ n_{m3} = l_{m3}/f_{m3};\ \ldots\ n_{mg} = l_{mg}/f_{mg}; \qquad (5)$$

where l_{m1}; l_{m2}; l_{m3}; ... l_{mg} are the lengths of the part to be machined, f_{m1}; f_{m2}; f_{m3}; ... f_{mg} are feed rates of cutters per one revolution of the spindle.

Hence $\sum_{i=1}^{g} n_{mi} = \sum_{i=1}^{g} \frac{l_{mi}}{f_{mi}}$ (6)

The number of the revolutions of the spindle per minute n_s has the following expression

$$n_s = \frac{V}{\pi d} \qquad (7)$$

where V is a cutting speed (m/min), d is diameter of the parts surfaces to be machined (m).

Substituting expressions (6) and (7) into Eq. (4) and after transformation the machining time will have the following equation

$$t_m = \sum_{i=1}^{g} \frac{\pi d_i}{V_i} \frac{l_{mi}}{f_{mi}} \qquad (8)$$

where all parameters specified above.

In case of combined operations machining time is chosen by the constraints of machining modes for each operations that based on the indices of machining quality. Constraints of machining modes concern mainly by the feed rates f_{mi} and depth of the cut of machining process. For multitool machining mode is chosen the minimum feed rate f_{min} for some operation with ability to change the cutting speed V. Other parameters like length of the cut $l_{mi,}$ the diameter and the cutting speed are chosen for the operation with maximum duration of machining process. Hence, the equation of the machining time will have the following expression

$$t_m = \frac{\pi d_{\max}}{V_i} \frac{l_{\max}}{f_{\min}} \qquad (9)$$

2.2. The change of the auxiliary time with changes in machining modes.

Most modern designs of the machine tools do not have kinematical dependencies between mechanisms of machining and auxiliary motions. The changes of the machining modes in mechanism of the machining motions do not reflect on regimes of work for the mechanisms of the auxiliary motions. Hence, for this types of machine tools the auxiliary time is not changed because the part feeding, fast motions of the tool holders to machining area and back, handling motions, etc., that are presented the auxiliary time are out of machining processes and changes of machining modes does not reflect on the time of auxiliary motions. Based on this circumstances the time of auxiliary motions is accepted as constant for manufacturing machines, i.e. t_a = const.

In case, when the machine tools designs have kinematical dependency between mechanisms of the machining and auxiliary motions, the auxiliary time has right dependency on the change of machining modes. Most of these type machine tools are old designs that still can be under exploitation, but number of them in manufacturing area is small and does not play big role. So for further analysis these type machine tools are not considered.

2.3. The change of the time losses due to reliability of cutters with changes in machining modes.

The dependency of the increase productivity losses due to intensive wear process and reliability of cutting tool with an increase of cutting speed can be finding by the following approach.

The index $\sum_{i=1}^{k} t_{ci}$ of time losses due to reliability of k cutting tools with an intensification of operating modes is not analytically dependent and it is a subject to analysis [2]. This index has the following expression

$$\sum_{i=1}^{k} t_{ci} = \frac{\sum_{i=1}^{k} \theta_{ci}}{z}, \quad (10)$$

where $\sum_{i=1}^{k} \theta_{ci} = \theta_1 + \theta_2 + \theta_3 + ... + \theta_k$, and θ_1, θ_2, etc is average random individual idle time due to change of the cutters of a machine tool, z is the quantity of machined parts per a considered time interval.

Time losses due to the cutter i has the following expression

$$t_{ci} = \frac{\theta_i}{z} \quad (11)$$

The time losses θ_i due to change of the cutter i can be presented in the average parameters of reliability that is by index of mean time τ of the change of the cutter i and by the number of change cutters r or $\theta_i = \tau_r$.

The number of machine parts produced per observation time and therefore by the cutter i can be expressed by the following equation

$$z = z_i r = \left(\frac{T_i}{a_i}\right) r \quad (12)$$

where z_i is the average number of parts machined between two replaces of the cutter i, T_i is the tool-life, a_i is time of machining by the cutter i of the one part, other parameters specified above.

The time of machining of the one part a_i by the cutter i can be expressed by the Eqs. (8) and (9), but there is one difference. The difference is the time of machining a_i does not include the time, which necessary to pass the safety distances between the cutter and the part. These safety distances are necessary to avoid the occasional hits of the cutter to the part at the beginning of machining process and to finish machining the surfaces with guarantee.

The machining length and the length of part to be machined have the following dependency $l_{mi} = l_{ai} + l_{si}$, where l_{si} = 2 - 4 mm is the safety distance, other parameters specified above.

Hence, the time a_i of machining of the one part will have the following expression

$$a_i = \frac{\pi d_i}{V_i} \frac{l_{ai}}{f_{mi}} \quad (13)$$

Substituting expressions θ_i, (12) and (13) into Eq. (11) and after transformation the time losses due to the cutter i will have the following expression

$$t_{ci} = \frac{\tau}{T_i} * \frac{\pi d_i}{V_i} * \frac{l_{ai}}{f_{mi}} \quad (14)$$

where all parameters specified above.

The equation of the Taylor tool-life of the cutter *i* has expression

$$T_i = \frac{C^{bi}{}_i}{V_i^{b_i}} \quad (15)$$

where T_i is the tool life in minutes, C_i is empirical constants resulting from regression analysis and field studies and depends on many factors: geometry of tool, cooling process, cutting speed, surface hardness of work piece, etc., V_i *is* cutting speed in m/min of a machining process, and b_i is empirical constants that depends on the cutter tool material.

After substituting defined parameter into Eq. (13), following transformations and simplification the expression of the time losses due to change of the cutter *i* will have the following equation.

$$t_{ci} = \frac{\pi \tau d_i l_{ai} V_i^{b_i - 1}}{f_{mi} C^{bi}{}_i} \quad (16)$$

In common case, the machine tool can have *n* different cutters, each of them have own properties b_i and $C_{i,}$ then the sum of time losses due to different *k* cutting tools can be expressed by the following equation

$$\sum_{i=1}^{k} t_{ci} = \sum_{i=1}^{k} \frac{\pi \tau d_i l_{ai} V_i^{b_i - 1}}{f_{mi} C^{bi}{}_i} \quad (17)$$

where all parameters specified above.

2.4. The change of the time losses due to reliability of machine tool units with changes in the machining modes.

The dependency of productivity losses due to reliability of machine tool units with increase of cutting speed is subject of special investigations. Definitely there is some dependency that can be described mathematically. However, most of main machine units like spindles, supports, mechanisms of machining motions, etc., have reliability level that many times higher than reliability of the cutters.

The increasing of machining processes with use of basic cutters like high speed steel, sintered carbides, etc., show that intensification of machining modes, does not reflect too much on reliability of machine tool mechanisms. This result based on data that failure rate of the cutters is prevailing many times over the failure rates of the other machine units []. In such circumstances, time losses due to machine units do not give sensitive results on drop of the productivity rate of the machine tool. Hence, the time losses of main machine tool units with change in processing modes for common case of machining processes is accepted as constant, i.e., $\sum_{j=1}^{p} t_{ej}$ = const.

It is necessary to mention that modern tendency in manufacturing area is use of new type of cutter materials, which properties close to the diamond type cutters. New cutter materials have the high reliability level that can be commensurable to the reliability level of main machine units. In such case, to derive the mathematical dependency mentioned above is crucial [8]. However, the lack in literature of the information regarding the reliability indices of the main machine units do not give ability to derive full mathematical dependencies of productivity rate with change of machining mode. This direction of research should be conducted on a basis of industrial information that manufacturers are monitoring and recording.

2.5. Productivity rate of the machine tool with changes in multitool machining modes.

Defined expressions of changes the parameters of productivity rate enable derive the equation of productivity rate of machine tools with changes in multitool machining modes when cutters imply simultaneously. Substituting defined expression (9) and (16) into Eq. (3), and after following transformations and simplifications, the equation of productivity rate will have the following equation

$$Q = \frac{1}{\frac{\pi d_{\max}}{V_i} * \frac{(l_{a\max} + l_{si})}{f_{\min}} + t_a + \sum_{i=1}^{k} \frac{\pi \tau d_i l_{ai} V_i^{b_i - 1}}{f_{\min} C^{bi}{}_i} + \sum_{j=1}^{p} t_{ej}} \quad (18)$$

where all parameters specified above.

Eq. (18) can be solved by numerical method and software.

2.6 Productivity rate of the machine tool with changes in multitool machining modes when tools cut separately

The equation of productivity rate when single tool *i* cuts separately is derived from Eqs. (3), (9), and (16), which after substituting, and simplification will have the following equation.

$$Q = \frac{1}{\sum_{i=1}^{k} \frac{\pi d_i}{V_i} * \frac{(l_{ai} + l_{si})}{f_i} + t_a + \sum_{i=1}^{k} \frac{\pi \tau d_i l_{ai} V_i^{b_i - 1}}{f_{\min} C^{bi}{}_i} + \sum_{j=1}^{p} t_{ej}} \quad (19)$$

where parameters specified above.

The optimum cutting speed by criterion of the maximum productivity rate for each operation is derived by taking first derivative of Eq. (19) with respect to cutting speed *V* and set it to zero. In this case Eq. (19) should be presented for single cutter by the following expression.

$$Q = \frac{1}{\frac{\pi d_i}{V_i} * \frac{(l_{ai} + l_{si})}{f_i} + t_a + \frac{\pi \tau d_i l_{ai} V_i^{b_i - 1}}{f_{\min} C^{bi}{}_i} + \sum_{j=1}^{p} t_{ej}}$$

Then the first derivative is

$$\frac{dQ}{dV_i} = -\left[-\frac{1 + l_{si}/l_{ai}}{V_i^2} + \frac{\tau (b_i - 1) V_i^{b_i - 2}}{C^{bi}{}_i} \right] = 0$$

$$-\frac{1}{V_i^2} + \frac{\tau (b_i - 1) V_i^{b_i - 2}}{(1 + l_{si}/l_{ai}) C^{bi}{}_i} = 0$$

, giving

$$V_{opt\,i} = \sqrt[b_i]{\frac{(1 + l_{si}/l_{ai}) C^{bi}{}_i}{\tau (b_i - 1)}} \quad (20)$$

where $V_{opt.i}$ is optimal cutting speed for single cutter *i* giving maximum productivity rate.

The number of the spindle revolution is calculated by the following equation

$$n = \frac{1000 V_{opt}}{\pi d}$$

(21)

where *d* is maximal diameter of the part.

The expression for maximum productivity rate for multitool machining process with sequence use of cutters can be found by substituting Eq. (20) into Eq. (19). After transformation and simplification the equation becomes

$$Q_{\max} = \frac{1}{\sum_{i=1}^{g} \frac{\pi d_i}{\sqrt[b_i]{\frac{(1 + l_{si}/l_{ai}) C^{bi}{}_i}{\tau (b_i - 1)}}} * \frac{(l_{ai} + l_{si})}{f_{mi}} + t_a + \sum_{i=1}^{k} \frac{\pi \tau d_i l_{ai} \left(\sqrt[b_i]{\frac{(1 + l_{si}/l_{ai}) C^{bi}{}_i}{\tau (b_i - 1)}} \right)^{b_i - 1}}{f_{mi} C^{bi}{}_i} + \sum_{j=1}^{p} t_{ej}} \quad (21)$$

where all parameters specified above.

3. A working example.

3.1. The mulitool simultaneous machining process

The part is machined by the two cutters and one drill bit simultaneously on the turning machine tool. The sizes of part's surfaces are presented in Fig. 1. The recommended machining modes the tool lives are presented in Table 1.

Table 1. Machining mode and tool live

Tool	Material	Feed rate *f*, mm/rev	Cutting speed *V*, m/min	Tool life, Min	C_b tool constant	*n* tool constant	*b=1/n* tool constant
Cutter 1	Sintered carbide	0.3	120	100	300	0.35	2.58715
Cutter 2	carbide	0.25	90	70	150	0.25	4
Drill bit	High speed steel	0.2	20	60	55	0.15	6.66667

Cutting speeds for all tools should be optimized by criterion of maximum productivity rate.

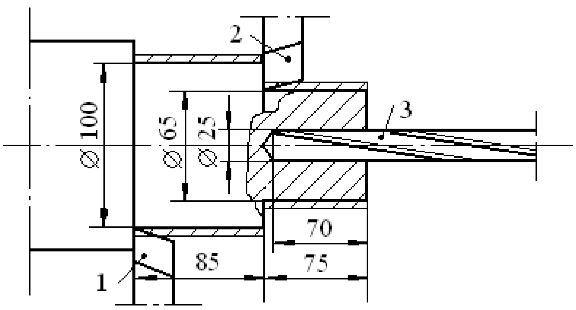

Figure 1. The part's surfaces machined by the three tools simultaneously.

Solution. Analysis of machining operations shows the cutting speeds, feed rates for deferent surfaces of the part are different. All tools are cutting simultaneously and the spindle has one angular velocity for all tools. The drill bit has minimum feed rate f_3=0.2 mm/rev, which is constrained by quality of the hole surface. This feed rate should be used for other tools. The cutter 1 has maximum length l = 85 mm and diameter 100 mm of the machining surface. The length of drilling is defined according the geometry of the drill bit. These data should be used for the following calculations. Geometry of machining processes of the part's surfaces is presented in Table 2.

Table 2. Geometrical parameters of the part's surfaced to be machined by the tools

Tool	Diameter, mm	Length, mm	Depth of the cut, mm
Cutter 1	100	85	2.0
Cutter 2	65	75	2.0
Drill bit	25	70 + 12.5tan30^0 = 77.2	12.5

Optimal cutting speed by criterion of the maximum productivity rate of multitool machining process is defined by Eq. (18), which can be solved by numerical method.

$$Q = \frac{1}{\frac{\pi d_{\max}}{V_i} * \frac{(l_{a\max} + l_{si})}{f_{\min}} + t_a + \sum_{j=1}^{k} \frac{\pi \tau d_i l_{ai} V_i^{b_i - 1}}{f_{\min} C^{b_i}{}_i} + \sum_{j=1}^{p} t_{ej}}$$

where $d_{\max}$ = 100 mm, $l_{a\,\max}$ = 85 mm, l_{si} = 2 mm, $f_{\min}$ = 0.2 mm/rev, t_a = 0.3 min, τ = 2 min, d_1 = 100 mm, d_2 = 65 mm, d_3 = 25 mm, l_{a1} = 85 mm, l_{a2} = 75 mm, l_{a3} = 77.2 mm, $\sum_{j=1}^{p} t_{ej} = 0.005$ min/part, n_1 =0.35 , n_2 =0.25 , n_3 =0.15 , C_1 =300 , C_2 =150 , C_3 = 55.

Substituting all defined parameter into the equation of the productivity rate is solving the equation for variable parameter of the cutting speed. The diagram of the productivity rate of mulitool machining process of the part versus cutting speed presented in Fig. 2. The optimal cutting speed for multitool machining process of the part is V_{opt}, which is give maximum productivity rate. On the basis of the optimal cutting speed is defined the number of revolutions for the spindle of the machine tool.

$$n = \frac{1000V_{opt}}{\pi d} = \frac{1000V_{opt}}{\pi(100+4)}$$

where d = 100 +4 mm is maximal diameter of the part with depth of cut.

3.2. The mulitool consequence machining process

The part is machined by the two cutters and one drill bit consequence on the turning machine tool. All parameters of the part to be machined are presented above for the case of the mulitool simultaneous machining process.

Solution. All tools are cutting separately and the spindle should have the different angular velocity for all tools. Optimal cutting speed and the spindle angular velocity for each surface by criterion of the maximum productivity rate of multitool consequence machining process is defined by Eqs. (20) and (21).

(a) the cutter 1:

$$V_{opt1} = \sqrt[b_1]{\frac{(1 + l_{si}/l_{a1})C^{b_i}{}_1}{\tau(b_1 - 1)}} = \sqrt[b_1]{\frac{(1 + 2/85)C^{b1}{}_1}{2(b1 - 1)}} =$$

191.5 m/min

$$n = \frac{1000V_{opt}}{\pi d} = \frac{1000V_{opt}}{\pi(100+4)} = 584.8 \text{ rpm}$$

(b) the cutter 2:

$$V_{opt2} = \sqrt[b]{\frac{(1+l_{si}/l_{a2})C^{b2}{}_2}{\tau(b_2-1)}} = \sqrt[b_2]{\frac{(1+2/85)C^{b2}{}_2}{2(b_2-1)}} =$$

94.4m/min

$$n = \frac{1000V_{opt}}{\pi d} = \frac{1000V_{opt}}{\pi(65+4)} = 435.5$$

rpm

(c) the drill bit 3:

$$V_{opt3} = \sqrt[b]{\frac{(1+l_{si}/l_{a3})C^{b3}{}_3}{\tau(b_3-1)}} = \sqrt[b_3]{\frac{(1+2/85)C^{b3}{}_3}{2(b_3-1)}} =$$

38.4 m/min

$$n = \frac{1000V_{opt}}{\pi d} = \frac{1000V_{opt}}{\pi * 25} = 488.9$$

rpm

The result of optimal cutting speed for each tool and the angular velocities of the spindle are presented in Table 3.

Table 3. The optimal cutting speed and the spindle angular velocity

Tool	Optimal Speed m/min	Spindle Velocity rpm
Cutter 1	191.1	584.9
Cutter 2	94.4	435.5
Drill bit	38.4	488.9

Substituting all defined parameter into Eq. (21) of the productivity rate is defined maximum productivity rate of the machining process with multitool consequence.

$$Q = \frac{1}{\frac{\pi d_{max}}{V_i} * \frac{(l_{a\,max}+l_{si})}{f_{min}} + t_a + \sum_{i=1}^{k} \frac{\tau \pi d_i l_{ai}}{f_{min}} \left(\frac{V_i^{(1-b_i)/b_i}}{C_i^{1/b_i}} \right) + \sum_{j=1}^{p} t_{ej}}$$

$$Q = \frac{1}{\frac{\pi 0.1}{V} * \frac{87}{0.15} + 0.3 + 6.284 \left[\left(\frac{100*85*V^{(1-0.35)/0.35}}{300^{1/0.3}} \right) + \left(\frac{65*75*V^{(1-0.25)/0.25}}{150^{1/0.25}} \right) + \left(\frac{25*77.2*V^{(1-0.15)/0.15}}{55^{1/0.15}} \right) \right] + 0.005} =$$

$$Q = \frac{1}{\frac{182166}{V} + 0.3 + 6.284 \left(4.703*10^{5} V^{1.858} + 9.629*10^{-6} V^{3} + 4.821*10^{-9} V^{5.666} \right) + 0.005}$$

The diagram (Fig. 2) shows the maximum productivity rate is Q = 0.217 parts/min, when cutting speed is V = 50 m/min, which is optimal.

4. RESULTS AND DISCUSSION

The equations for the productivity rate of a machine tool for multitool machining processes have been derived. The new equations enable the calculation of more trustworthy output of a machine tool for the cases of multitool machining simultaneously and separately. Equations include reliability indices of its primary mechanisms and reliability of cutters. Based on the new equations, the productivity rate of multitool processes for a machine tool is calculated as a function of the cutting speed changes. The new equations of productivity rate enable the finding of the correct optimal machining modes that can give the maximal productivity of a machine tool.

5. SUMMARY

The new equations of the productivity rate for a machine tool for multitool machining processes includes the dependencies of reliability indices of mechanisms and components of a machine tool on changes in processing modes. The new equations present output of a machine tool for the cases of multitool machining simultaneously and separately. The presented equation for the calculating of the productivity rate of a machine tool as a function of cutting speed change enables the prediction of more authentic results and can be used in preparing economically effective multitool manufacturing processes of parts. The tendency for intensification of manufacturing processes brings problems of finding the dependencies of the productivity rate for the cases of multitool processes of parts on machine tools. These dependencies have a more complex character than known one for single cutter use under conditions of intensification of processing modes. Solutions of these problems will be very important for the manufacturing industry.

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