CALCULATION OF THE OPTIMUM TOOL LIFE AND CUTTING SPEED FOR MAXIMUM PRODUCTIVITY AT DRILLING OF THE STAINLESS STEEL X2CrNiMo18-14-3

Vlase Aurelian[1], Blăjină Ovidiu [2], Darie Vlad[3]

[1]*University POLITEHNICA of Bucharest,aurelvlase@yahoo.com.*
[2]*University POLITEHNICA of Bucharest, ovdiu_blajina@yahoo.com.*
[3]*University POLITEHNICA of Bucharest, vlad_darie@yahoo.com.*

Abstract: *The research in the last decade regarding their cutting machinability have highlighted the insufficiency of the data for establishing of the optimum cutting processing conditions and the optimum cutting regime. The purpose of this paper is the optimization of the tool life and the cutting speed at the drilling of the stainless steels in terms of the maximum productivity. A nonlinear programming model to maximize the productivity at the drilling of a stainless steel is developed in this paper. The use of this model allows greater accuracy in the prediction of the productivity for the drilling of a certain stainless steel. The obtained results can be used in production activity, in order to increase the productivity of the stainless steels machining. The paper suggests new research directions for the specialists interested in this field.*

Keywords: *tool life, cutting speed, productivity, drilling, stainless steel.*

1. Introduction

The stainless steels are used more and more in various key domains of the technique [7]. The processing of these steels is determined by their specific physical-chemical characteristics and by their technological properties [3, 5]. The research in the last decade regarding the cutting machinability of the stainless steels have highlighted the insufficiency of the data for establishing of the optimum cutting processing conditions and the optimum cutting regime [4, 6]. With this object in view, the purpose of this paper is the optimization of the tool life and the cutting speed at the drilling of the stainless steels, in terms of the global indicator of the maximum productivity.

A nonlinear programming model to maximize the productivity at the drilling of a stainless steel is developed in this paper. The optimum cutting tool life and the associated cutting tool speed are obtained by solving the proposed mathematical model. The numerical model, developed for the analyzed case study of the stainless steel X2CrNiMo18-14-3, is resolved using the specialized software WinQSB. The numerical and graphical results relative to productivity in relation to the tool life, valid only for the studied steel, are also presented in the paper.

2. Determination of the productivity of the drilling operation

The time technical norm N_t of a machining operation in a metal cutting process is presented in the specialized literature [8] as the following function:

$$N_t = t_b + t_{aux} + t_{dt} + t_{do} + t_{on} + \frac{t_{pi}}{n} \quad \text{[min/piece]}.$$

(1)

where: N_t is time norm on piece (or operation or phase), [min/piece]; t_b – machining time, [min/piece]; t_{aux} – auxiliary time, [min/piece]; t_{dt} – technical maintenance time, [min/ piece]; t_{do} – organizational maintenance time, [min/ piece]; t_{on} – rest and natural necessities time, [min/ piece]; t_{pi} – preparation-closing time on the lot, [min]; n – batch of parts that are conti-nuously processed, to the same machine tool.

The machining time t_b for the drilling operation can be written as:

$$t_b = \frac{L}{n \cdot f} \cdot i \quad [\text{min}]. \tag{2}$$

where: L is the length of a hole (including the engagement and exceeding of the drill), [mm]; i – number of holes; f – the cutting feed, [mm/rot].

The rotational speed n is given by:

$$n = \frac{1000 \cdot v}{\pi \cdot D} \quad [\text{rot/min}]. \tag{3}$$

where: D is the diameter of the hole, [mm]; v is the cutting speed, [m/min], given by the Taylor's relation at drilling:

$$v = \frac{C_v \cdot D^{x_v}}{T^m \cdot f^{y_v}} \quad [\text{m/min}]. \tag{4}$$

where: C_v is a constant determined experimentally, according to the couple workpiece material-tool and the cutting conditions; m – durability exponent of the spiral drill; x_v, y_v – polytropic exponents.

Substituing for v from (4) in (3), and then for n from (3) in (2) the machining time t_b becomes:

$$t_b = \frac{L \cdot T^m \cdot D^{1-x_v} \cdot i}{318 C_v \cdot f^{1-y_v}} \quad [\text{min}]. \tag{5}$$

The auxiliary time t_{aux} is chosen from normative tables.

The technical maintenance time t_{dt} is calculated by the relation [8]:

$$t_{dt} = \frac{(t_s + t_a) \cdot t_b}{T} \quad [\text{min/piece}]. \tag{6}$$

where: t_s is the consumed time for the tool changing and adjustment remaking, [min]; t_a – the consumed time for the drill sharpening, [min].

The organizational maintenance time t_{do} is given by the relation [8]:

$$t_{do} = \frac{k_1}{100} (t_b + t_{aux}) \quad [\text{min/piece}]. \tag{7}$$

where k_1 is a constant in normative tables.

The rest and natural necessities time t_{on} is calculated by the relation [8]:

$$t_{on} = \frac{k_2}{100} (t_b + t_{aux}) \quad [\text{min/piece}]. \tag{8}$$

where k_2 is a constant in normative tables.

The obtained expression of the time technical norm for drilling operation N_t is:

$$N_t = \frac{L \cdot T^m \cdot D^{1-x_v} \cdot i}{318 C_v \cdot f^{1-y_v}} \left(1 + \frac{k_1 + k_2}{100}\right) +$$
$$+ \frac{L \cdot T^{m-1} \cdot D^{1-x_v} \cdot i}{318 C_v \cdot f^{1-y_v}} (t_s + t_a) + \tag{9}$$
$$+ t_{aux} \left(1 + \frac{k_1 + k_2}{100}\right) + \frac{t_{pi}}{n}.$$

Finally the relation of the productivity of the drilling operation is written as:

$$P = \frac{60}{N_t} \quad [\text{piece/h}]. \tag{10}$$

3. Mathematical model to maximize the productivity of the drilling operation

The optimization mathematical model contains the optimization objective function and several restrictive relations:

$$\begin{cases} \max P & (11) \\ f \le C_f \cdot D^{0,6} \cdot k_s & (12) \\ f^{y_M} \cdot n \cdot v^{z_M} \le \dfrac{9740 \eta \cdot P}{C_M \cdot D^{x_M} \cdot c} & (13) \\ f^{y_F} \cdot v^{z_F} \le \dfrac{F_{ma}}{D^{x_F} \cdot C_F \cdot c_m} & (14) \\ f^{y_F} \cdot v^{z_F} \le \dfrac{2,465 E \cdot I_{min}}{C_F \cdot D^{x_F} \cdot l_c^2 \cdot c_f} & (15) \\ f_{min} \le f \le f_{max} & (16) \\ n_{min} \le n \le n_{max} & (17) \end{cases}$$

The objective function (11) of the above model is the productivity of the processing operation P, given by the relation (10), which must be maximized.

The restrictive relation (12) of the cutting feed includes: C_f – a constant which depends on processed material and on precision machining; k_s – a correction coefficient depen-ding on the ratio l/D, where l is the length of the hole, [mm]; D is the hole diameter, [mm].

The relation (13) of the power consumption of the machining process includes: C_M – a constant;

x_M, y_M, z_M – polytropic coefficients; c – safety coefficient, $c = 1.7$.

The relation (14) of the advance mechanism of the machine includes: F_{ma} – the maximum allowed force of the advance mechanism; C_F – a constant; x_F, y_F, z_F – polytropic coefficients; c_m – safety coefficient, $c_m = 1.6$.

The restrictive relation (15) of the buckling resistance of the spiral drill includes: E – mo-dulus of elasticity, [N/mm^2]; I_{min} – minimum moment of inertia, [mm^4]; l_c – initial length in console of the spiral drill, [mm]; c_f – safety coefficient to buckling, $c_f = 1.8$.

The restrictive relations (16) and (17) of the drilling machine kinematics require that the two parameters f and n have values in the feed range and, respectively, the rotation range, developed by the drilling machine.

4. Case study for the drilling of the stainless steel X2CrNiMo18-14-3

The drilling operation of the studied stainless steel was performed using a machine tool GC_0 32 DM3 drilling device and Rp5 high-speed steel spiral drills.

The constants $C_f = 0.031$ and $k_s = 0.9$ were chosen from tab.6.10 and tab.6.11 in [8].

The values of the constants and polytropic coefficients for the drilling of the steel X2CrNiMo18-14-3 were determined based on the experimental measurements: $C_F = 3570$, $x_F = 0.52$; $y_F = 0.46$, $z_F = -0.17$, $C_M = 28$, $x_M = 0.63$, $y_M = 0.57$, $z_M = -0.22$ from [2]; $C_v = 4.27$, $x_v = 0.55$, $y_v = 0.242$, $m = 0.137$ from [9].

The other values of the numeric model are: $L = 50$ mm; $i = 1$; $D = 16$ mm; $t_s = 0.5$ min; $t_a = 2$ min; $k_1 = 1$, $k_2 = 4$ in [8]; $t_{aux} = 1.48$ min; $t_{pi} = 15$ min; $n = 246$ rot/min; $\eta = 0.8$; $P = 3.15$ kW; $F_{ma} = 960$ daN; $E = 2.1 \cdot 10^4$ daN/mm^2; $I_{min} = 0.043 \cdot D^4 = 2818$ mm^4; $l_c = 120$ mm.

From the relations (12)-(16) it is obtained $f \le 0.14$ mm/rot. Because the used drilling machine ensures the feeds: 0.12; 0.20; 0.32; 0.50 mm/rot, it results $f = 0.12$ mm/rot.

The numerical optimization model for the stainless steel X2CrNiMo18-14-3 is resolved using the module *Nonlinear Programming* of the specialized software *WinQSB* [1]. The numerical model data are shown in Fig.1. The command *Solve the problem*, from the menu *Solve and Analyze*, returns *Solution summary* (Fig.2), which contains: the optimum value of the tool life, $T_{op} \cong$

15 min; the corresponding maximum value of the drilling productivity, $P_{max} \cong 21$ pieces/h.

Figure 1: *Numerical model data*

Figure 2: *Solution summary*

The command *Objective Function Analysis*, from the menu *Solve And Analyze*, returns the tabular and graphical analyzes of the machining productivity P depending on the tool life T, presented in Fig.3 and, respec-tively, Fig.4, valid only for the studied steel X2CrNiMo18-14-3.

The optimum cutting speed, v_{op}, for maximum productivity of the drilling operation is given by the relation (16):

$$v_{op} = \frac{4.27 \cdot 16^{0.55}}{15^{0.137} \cdot 0.12^{0.242}} = 22.62 \text{ m/min}$$

4. Conclusions

The maximum productivity can represent a global indicator for appreciation of the machinability. The optimum tool life to provide the maximum productivity of the machining operation is derived from the proposed mathematical model. The use of this

04-06-2013	T	Objective Function
1	13.0000	21.1841
2	13.4000	21.1882
3	13.8000	21.1912
4	14.2000	21.1932
5	14.6000	21.1944
6	15.0000	21.1948
7	15.4000	21.1944
8	15.8000	21.1935
9	16.2000	21.1919
10	16.6000	21.1898
11	17.0000	21.1873

Figure 3. *Tabular analysis of the machining productivity depending on the tool life*

productivity model allows greater accuracy in the prediction of the productivity for the drilling of a certain studied stainless steel and getting the optimum tool life and the optimum cutting speed for the maximum productivity.

The obtained results can be used in production activity, in order to increase the productivity of the

stainless steels machining. The paper suggests new research directions for the specialists interested in this field.
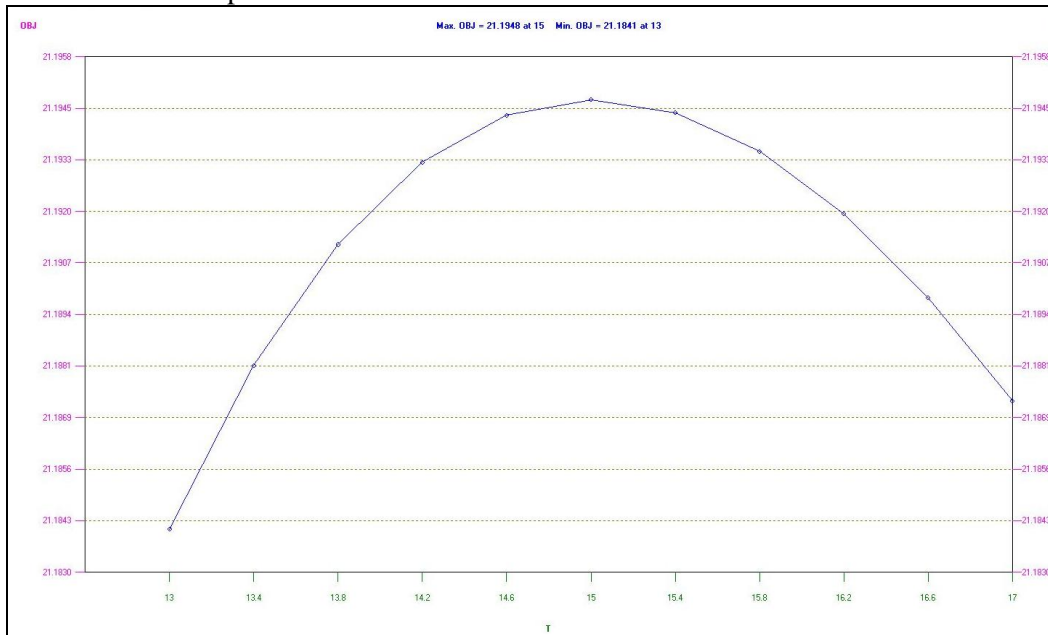

Figure 4: *Graphical analysis of the machining cost depending on the tool life*

References

[1] Blăjină, O., *Produse software aplicate în programarea matematică şi teoria jocurilor*, Editura Albastră, Cluj-Napoca, 2006.

[2] Blăjină, O., Vlase, A., Vlase, B., *The calculus relations of the cutting forces and moments for drilling of the steel X2CrNiMo18-14-3*, Academic Journal of Manufacturing Engineering, Vol. 9, Issue 1, pp.12-17, Ed. Politehnica Timişoara, ISSN 1583-7904, 2011.

[3] Cimino, T., Schade C., Causton, B., *High Performance Stainless Steels*, Proceedings of PM2TEC'99, Vancouver, Columbia, 1999.

[4] Davis, J.R., *Ed., ASM Specialty Handbook: Stainless Steels*, ASM International, Materials Park, Ohio, 2000.

[5] Kalpakjian, S., *Manufacturing Processes for Engineering Materials*, 4th ed., Addison-Wesley, USA, 1991.

[6] Krauss, G., *Steels. Processing, Structure and Performance*, ASM International, Materials Park, Ohio, 2005

[7] Trent, E.M., Wright, P.K., *Metal cutting*, 4th Edition, Butterworth Heinemann, Boston, 2000.

[8] Vlase, A. et al., *Tehnologii de prelucrare pe maşini de găurit*, Editura Tehnică, Bucureşti, 2009.

[9] Vlase, B., *Contributions to the optimization of processing stainless steels of foreign and indigenous production*, PhD Thesis, University POLITEHNICA of Bucharest, 2011.