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

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Abstract: The research in the last decade regarding their cutting machinability have highlighted the insufficiency of the data for establishing 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:

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

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]; \( t_{dm} \) – technical maintenance time, [min/piece]; \( t_{on} \) – 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 continuously processed, to the same machine tool.
The machining time $t_b$ for the drilling operation can be written as:

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

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:

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

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

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

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.

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

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

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

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

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

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]:

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

where $k_1$ is a constant in normative tables.

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

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

where $k_2$ is a constant in normative tables.

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

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

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

$$ P = \frac{60}{N_i} \quad [\text{piece/h}]. \quad (10) $$

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

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

- \[ \max P \]
- \[ f \leq C_f \cdot D^{0.6} \cdot k_s \]
- \[ f^{y_f} \cdot n \cdot v^{z_f} \leq \frac{9740 \eta \cdot P}{C_M \cdot D^{r_f} \cdot c} \]
- \[ f^{y_f} \cdot V^{z_f} \cdot \frac{F_{max}}{D^{r_f} \cdot C_f \cdot c_{max}} \]
- \[ f^{y_f} \cdot v^{z_f} \leq \frac{2465 E \cdot I_{min}}{C_f \cdot D^{r_f} \cdot l^{2} \cdot c_{f}} \]
- \[ f^{y_f} \cdot V^{z_f} \leq \frac{2465 E \cdot I_{min}}{C_f \cdot D^{r_f} \cdot l^{2} \cdot c_{f}} \]
- \[ f \leq f_{max} \]
- \[ n_{min} \leq n \leq n_{max} \]

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 depending 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;
The relation (14) of the advance mechanism of the machine includes: $F_{ma} - \text{the maximum allowed force of the advance mechanism}; C_F - \text{a constant}; x_F, y_F, z_F - \text{polytropic coefficients}; c_m - \text{safety coefficient}, c_m = 1.7.$

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

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 $k_f = 0.9$ 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: $C_p = 3570$, $x_p = 0.52$; $y_p = 0.46$, $z_p = -0.17$, $C_m = 28$, $x_m = 0.63$, $y_m = 0.57$, $z_m = -0.22$ 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]; $I_{min} = 1.48$ min; $t_a = 15$ min; $n = 246$ rot/min; $\eta = 0.8$; $P = 3.15$ kW; $F_{ma} = 960$ daN; $E = 2.1 \cdot 10^4$ daN/mm$^3$; $I_{min} = 0.043 \cdot D^4 = 2818$ mm$^4$; $l = 120$ mm.

From the relations (12)-(16) it is obtained $f \leq 0.14$ 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, $T_{op} \approx 15$ min; the corresponding maximum value of the drilling productivity, $P_{max} \approx 21$ pieces/h.

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

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

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


