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ON BORING DEEP HOLES

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Abstract: *This paper presents results of theoretical and experimental research on establishment of cutting capacity of the boring tools for deep holes. After presenting some theoretical considerations regarding the cutting efforts in case of boring deep holes, experimental research results are presented. The experiments were conducted in relation with the cutting efforts, the cutting temperature, the tool life and the chip shapes.*

Key words: *cutting process, boring, deep holes, cutting capacity, cutting research.*

1. THEORETICAL CONSIDERATIONS

Cutting capacity of a cutting tool, consequently of the deep hole borers, is established based on several criteria having more or less importance. These criteria are related to technological or economical elements of the analyzed cutting process.

Criteria used to establish the cutting capacity of the cutting tools are the following: wear resistance or tool life, cutting efforts or specific cutting energy, roughness of the processed surfaces by cutting, dimensional accuracy and shape errors of the processed surfaces by cutting, dynamic stability during the cutting process, reliability etc.

Research made in the cutting laboratories revealed that for a specific cutting operation, a specific cutting tool, a specific quality of the manufactured workpiece, a specific material etc., an appropriate system of criteria for the evaluation of the cutting tool performances can be used in order to define and compare several tools of the same type.

For the design and verification of the technological system elements (machine tool - cutting tool - workpiece-device) the main criterion to establish the cutting capacity becomes the cutting efforts or specific cutting energy.

Consequently, the following cutting forces system for deep hole boring was considered, as shown in Fig. 1.

In case of the deep hole borer having fragmented edges not along its diameter, considered as general case, the cutting forces system was represented in the constructive reference system *Oxyz* of the cutting tool.

Correspondingly, the equilibrium equations will be:

$$\begin{cases} -F_{x1}-F_{x2}-\sum F_{xi}-\sum F_{xj}-F_{s1}-F_{s2}=R_x \\ -F_{y1}+F_{y2}+\sum F_{yi}\cos\varphi-\sum F_{zi}\sin\varphi\sum F_{yj}+ \\ +N_1\left(\cos\beta_1+\mu_v\sin\beta_1\right)-N_2\left(\sin\beta_2+\mu_v\cos\beta_2\right)=R_y \\ -F_{z1}-F_{z2}-\sum F_{zj}+\sum F_{zi}\cos\varphi+\sum F_{yi}\sin\varphi- \\ -N_1\left(\sin\beta_1-\mu_v\cos\beta_1\right)+N_2\left(\cos\beta_2-\mu_v\sin\beta_2\right)=R_z \\ F_{z1}\cdot y_1+F_{z2}\cdot y_2+\sum F_{zi}\cdot r_i+\sum F_{zj}\cdot y_j+ \\ +\mu_v\cdot N_1\cdot r+\mu_v\cdot N_2\cdot r=M_{as}, \end{cases} \quad (1)$$

where: μ_v and μ_s are friction coefficients along tangential and feed directions; κ_1 and κ_2 are positioning angles of the edges, complementary to the angles ε_1 and ε_2; β_1 and β_2 are positioning angles of the guides; y_1 and y_2 are distances to the *Oz* axis of the cutting forces F_y; i = 4, 6, …

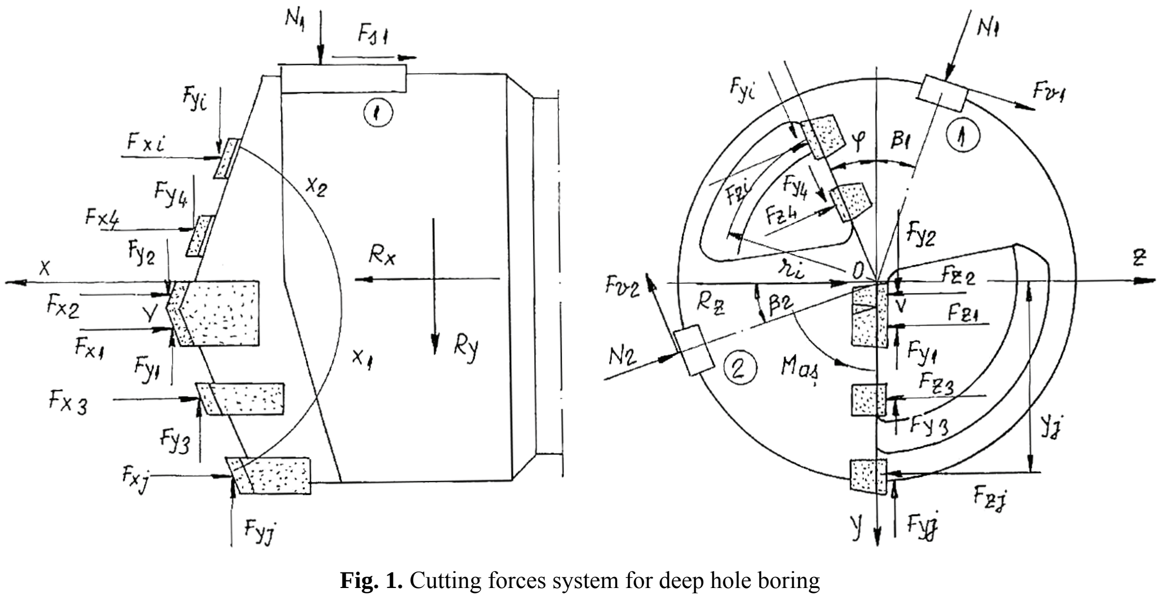

Fig. 1. Cutting forces system for deep hole boring

are the even edges and j = 3, 5, … are the odd edges; φ is the angle between the edges directions; $r = d/2$ is the radius of the borer.

This equations system must be considered together with the relationships between some terms of the equations system:

- friction forces and normal reactions

$$F_{v1} = \mu_v N_1;\ \ F_{v2} = \mu_v N_2;\ \ F_{s1} = \mu_s N_1;\ \ F_{s2} = \mu_s N_2 \quad (2)$$

- cutting forces in Oxy plane

$$F_{y1} = F_{x1}\ \mathrm{tg}\varepsilon_1;\ \ F_{y2} = F_{x2}\ \mathrm{tg}\varepsilon_2. \quad (3)$$

It should be underlined that this cutting efforts system could be considered as general case for the static loads of the deep hole cutting borer:

- if in the equilibrium equations should make $\varphi = 0$, would be found the equilibrium equations of the borer having fragmented edges along its diameter;
- if in the equilibrium equations should make $\varphi = 0$ and the cutting forces corresponding to the odd j and even i edges are considered equal to zero the obtained equilibrium system belongs to the “gun drill”.

After reducing calculus and simplifications, from the equilibrium equations system the following relations of the normal reactions result:

$$\begin{aligned} N_1 &= [(R_z + F_{z1} + F_{z2} + \Sigma F_{zj} - \Sigma F_{zi}\cos\varphi - \Sigma F_{yi}\sin\varphi)\cdot \\ &\cdot(\sin\beta_2 + \mu_v\cos\beta_2) + (R_y + F_{y1} - F_{y2} + \Sigma F_{yj} - \\ &-\Sigma F_{yi}\cos\varphi + \Sigma F_{zi}\sin\varphi)(\cos\beta_2 - \mu_v\sin\beta_2)]/ \\ &/[\cos\beta_1\cos\beta_2 - \mu_v^2\sin\beta_1\sin\beta_2 - \mu_v\sin(\beta_2 - \beta_1)]; \\ N_2 &= [(R_z + F_{z1} + F_{z2} + \Sigma F_{zj} - \Sigma F_{zi}\cos\varphi - \Sigma F_{yi}\sin\varphi)\cdot \\ &\cdot(\sin\beta_1 + \mu_v\sin\beta_1) + (R_y + F_{y1} - F_{y2} + \Sigma F_{yj} - \\ &-\Sigma F_{yi}\cos\varphi + \Sigma F_{zi}\sin\varphi)(\sin\beta_1 - \mu_v\cos\beta_2)]/ \\ &/[\cos\beta_1\cos\beta_2 - \mu_v^2\sin\beta_1\sin\beta_2 - \mu_v\sin(\beta_2 - \beta_1)]. \end{aligned} \quad (4)$$

This equilibrium equations system is used to determine total cutting forces R_x, R_y, R_z and total cutting torque M_{as}.

The same equations system can be used to determine the normal reactions on the borer’s guides N_1 and N_2 when total cutting forces R_x, R_y, R_z and total cutting torque M_{as} are known.

In the experimental research total cutting forces R_x, R_y, R_z and total cutting torque M_{as} are measured and the normal reactions on the borer’s guides N_1 and N_2 are calculated.

This calculation is used to establish the borer guidance conditions some researchers were concerned about.

2. EXPERIMENTAL RESEARCH ON THE CUTTING CAPACITY OF DEEP HOLE BORERS

Experimental research were conducted to study the following elements of the cutting capacity: cutting efforts measurement, cutting edge temperature measurement, tool life tests and aspects regarding chipping and chip shapes.

2.1. Experimental research on cutting efforts

Cutting efforts included: cutting forces, cutting torque and consumed power during the cutting process.

Cutting forces and cutting torque were measured on a stand using a normal lathe. The principle scheme is shown in Fig. 2.

Measuring chain consists of the following elements: borer (2), Wheatstone bridge made of resistive stress gauges glued on the borer fastening part (3), digital amplifier (5), electronic computer (6) with data acquisition system. Measurements were done for deep hole borers CARMESIN–BOTEK type, having diameters d_A = 46 mm and d_B = 32 mm. The workpiece material was OLC 45 steel.

Considering the recommendations in the speciality literature and of the deep hole borers manufacturers, the following cutting regimes were used, for the borer having d_A = 46 mm:

- spindle speed n_{as} = (230; 305; 380) rpm, which corresponds to the following linear speeds v_{as} = (33.23; 44; 55) m/min;
- feed s = (0,06; 0,1; 0,16; 0,2) mm/rev.
- for the borer having d_B = 32 mm
- spindle speed n_{as} = (305; 380; 460) rpm, which corresponds to the following linear speeds v_{as} = (30.67; 38.20; 46.25) m/min;
- feed s = (0.06; 0.1; 0.16; 0.2) mm/rev.

For each experiment were obtained the diagrams showing the variation of the total feed force and total cutting torque. There are 24 diagrams for axial force (12 diagrams for the borer having d_A = 46 mm and 12 diagrams for the borer having d_B = 32 mm) and 24 diagrams for the cutting torque (12 diagrams for the borer having d_A = 46 mm and 12 diagrams for the borer having d_B = = 32 mm).

For example, in Fig. 3 are presented 2 diagrams showing the cutting torque and axial force for the borer having d_A = 46 mm (experiment A3).

After processing the diagrams as shown in Fig. 3, the axial force and total cutting torque were determined. The results were organized in tables.

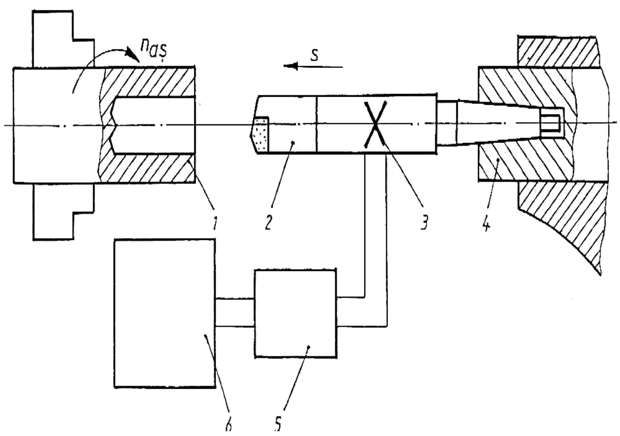

Fig. 2. Stand for cutting forces and cutting torque measurement.

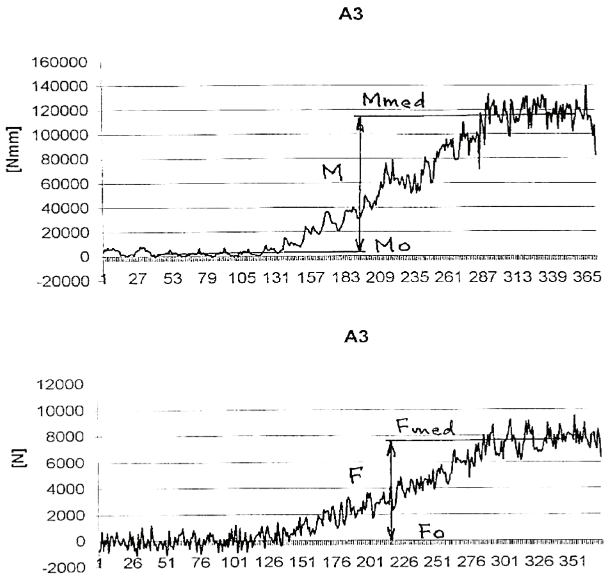

Fig. 3. Cutting torque and axial force diagrams (example).

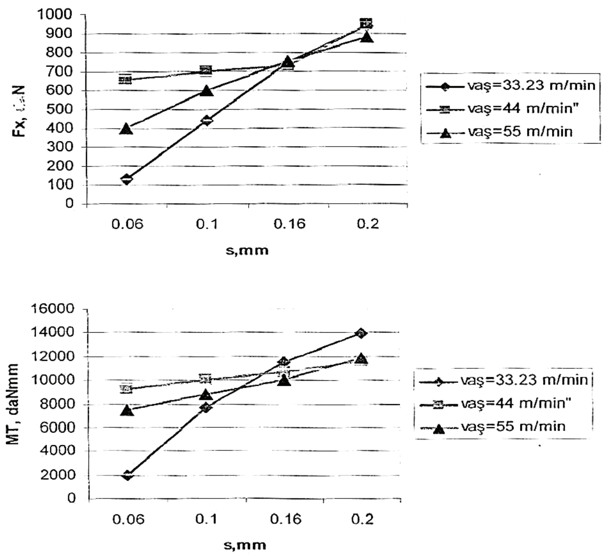

Fig. 4. Cutting efforts vs. cutting speed and feed variation diagrams.

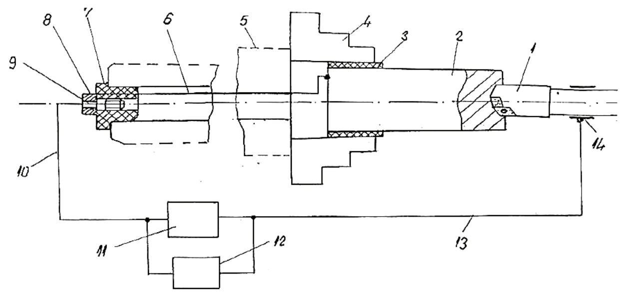

Fig. 5. Principle scheme for measurement of the cutting temperature.

Using these experimental results the consumed power during the cutting process and the main cutting force were calculated.

Using all these results the variation diagrams of the measured or calculated cuting efforts versus the cutting speed and feed were drown.

Two of such diagrams are presented in Fig. 4. The measured and calculated data and their variation diagrams underline the influence of the cutting speed and feed upon the cutting efforts.

Using the measured and calculated cutting efforts the following Taylor functions were obtained:

- in case v_{as} = constant.

$$F_x = C_{F_x} \cdot s^{y_x};\ M_T = C_M \cdot s^{y_M};\ F_{z,ec} = C_{F_z} \cdot s^{y_z}; \quad (5)$$

- in case s = constant.

$$F_x = C_{F_x} \cdot v_{as}^{z_x};\ M_T = C_M \cdot v_{as}^{z_M};\ F_{z,ec} = C_{F_z} \cdot v_{as}^{z_z}. \quad (6)$$

Consumed power during the cutting process was measured on deep hole boring machine MGA 250×1000 using a wattmetric device. The measured data were used to calculate the main cutting force and the total cutting torque.

Variation diagrams of the three cutting efforts were drown and Taylor functions depending on the cutting speed and feed were determined in case of workpiece material OLC 45 steel and a borer having the diameter d = 46 mm. These Taylor functions are the following:

$$P_{as} = 18.1\ s^{1,013}\ \text{kW};$$
$$F_z = 1\ 145.6\ s^{1,013}\ \text{daN};$$
$$M_t = 26\ 368\ s^{1,013}\ \text{daNmm}.$$

2.2. Cutting temperature

Cutting temperature was measured using the method of natural termocouple on the stand used for the measurement of the cutting efforts on the normal lathe.

The principle scheme for measurement of the cutting temperature is presented in Fig. 5. It is underlined the workpiece and the machine tool are electrically isolated. As well, there is a rotary contact with mercury (9) for the transmission of the electric current from rotating parts. After the etalonation of the equipment, the cutting temperatures were measured in the same cutting conditions as in case of cutting efforts measurement.

Using the measured results the variation diagrams and Taylor functions versus cutting speed and feed were determined.

2.3. Tool life tests

Tool life tests were done on the same deep hole boring machine MGA 250×1000, in the same cutting conditions as in case of consumed power during cutting process measurement.

The criterion for tool life determination was catastrofic wear criterion. The results permitted to draw the variation diagrams and to determine Taylor functions for the tool life of the deep hole borers.

2.4. Chipping and chip shapes

During the experiments regarding the cutting efforts chips were kept. These chips underlined some aspects related to the chip shapes depending on the cutting regime parameters: diameter of the borer, cutting speed and feed. Some recommendations for the design, construction and exploitation of the deep hole borers were set, depending on the chip shape, size and evacuation.

3. CONCLUSIONS

Compared to other cutting operations (turning, milling, grinding) in case of boring deep holes the total cutting force includes components that are not cutting forces. These components are contact forces between the drill and the workpiece and their values are comparable to the effective cutting forces.

As a consequence, the cutting forces system in case of boring deep holes is more complex than in other cutting operations cases.

Measurements of the cutting efforts are useful to both the designer of the machine tool and the manufacturer. It should be mentioned the cutting efforts decrease with the increase of the cutting speed. Still, this conclusions should be considered only in case of no cutting fluids. In the real cases, the coolant is a must.

Measurements of the cutting temperature were done using the method of natural termocouple. The cutting temperature varied between 300 and 600°C. As expected the cutting temperature is influenced more by the cutting speed than the feed. This could lead to the conclusion that the productivity should be increased using greater feeds. Still, a greater feed leads to greater cutting efforts and lower surface quality. Also, the chip shape and the chip quantity will be influenced. As a conclusion, the value of the feed shoul be optimized.

Regarding the tool life, it must be underlined that the drill construction is very important or, to be more specific, the stiffness of the drill together with the sharpness of the cutting edges. The experiments show tha guidance inserts are broken by accident, when the chips evacuation is not proper. In respect to this aspect it must be specified the chip fragmentation is better when the feed increases.

Regarding the chip shapes, there were observed two types, depending on the length of the cutting edge. There were obtained long curled chips, difficult to evacuate and fragmented short chips, as well. Each type of chips is connected to the inserts types. The main conclusion was the length of the cutting edges should be decreased, if possible.

All experiments were conducted in the laboratories of Machines and Production Systems Department of the Faculty of Engineering and Management of the Technological Systems, “Politehnica” University of Bucharest. The experimental stand is an original one, using a lathe instead of a deep holes boring machine. The experimental results confirmed the theoretical research and were confirmed by other experimets conducted on a real deep holes boring machine.

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