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DESIGNING OF ANNULAR DRILLS WITH THE DIRECTION OF THE INTERNAL RESIDUAL STEM

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ABSTRACT— *The current article provides a methodology for designing of annular drills which includes determining the tool's operating scheme and the scheme of cutting of the allowance of machining. It's shown a scheme of annular drill load which is essential for the construction of this type of tools. By the dependencies shown in the current study, a strength calculation of the annular drill with the corresponding diameter was made and it is defined the case where the drill has the greatest sustainability.*

Keywords: an annular drill, a force system, a kinematic cutting scheme

1. INTRODUCTUON

The designing of annular drills is predetermined by the design features requiring reliable guidance in the cutting process (Лефтеров, Николов, 1989). This requires the development of a specific design methodology (Pinlu Cao, and team, 2016; Лефтеров, 2015).

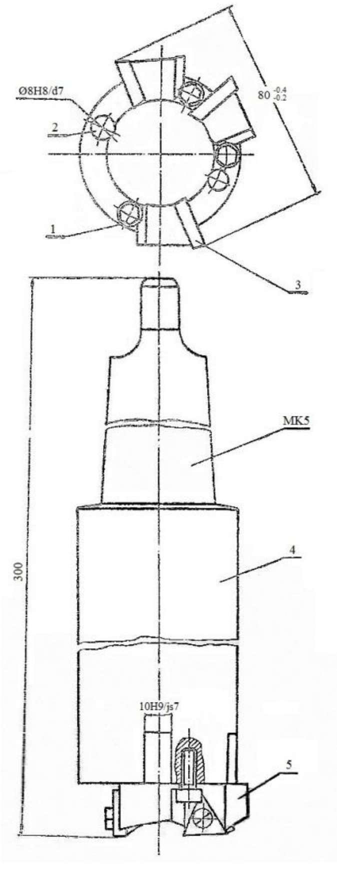

Fig. 1 *Annular drill*

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2. DESIGN METHODOLOGY

According to fig. 1, for the design of an annular drill, the following designations have been adopted: 1 – fasteners; 2 – guide movable rollers; 3 – inserts; 4 – tool body; 5 – modules carrying the cutting elements.

2.1 First step in designing the tool

Should be determined the tool's operating scheme that directly affects its construction. It is determined by the kinematic cutting scheme and the scheme of shaping (Лефтеров, 2017). The kinematic cutting scheme is shown in fig. 2 a) and the cutting of the allowance of machining in fig. 2 b).

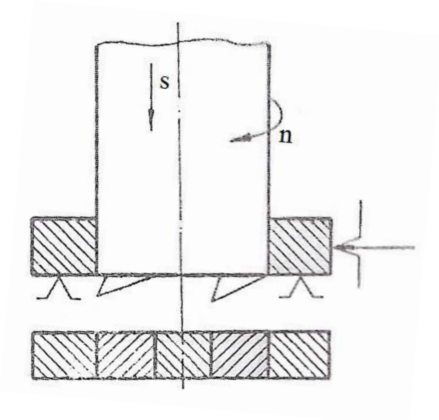

Fig.2 *Work schemes of the tool*
a) kinematic scheme; b) scheme of cutting of the allowance of machining

The scheme of cutting of the allowance of machining can be considered in the space or in the plane. The planar scheme is simpler and is preferable in the analysis of the different design variants (Astakhov, 2011). This scheme is a result of the kinematic cutting scheme and the shape and dimensions of the cutting inserts (fig.3).

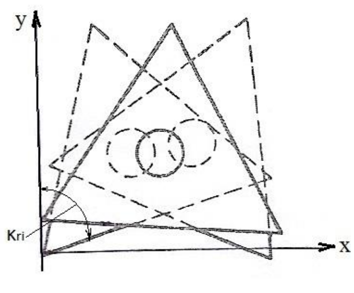

Fig.3 *Scheme of the sequential layout of the cutting inserts*

According to the method of obtaining the annular profile, two principal schemes of shaping "profile" and "sequential" can be used. In this case, the scheme is sequential (fig.2).

2.2 Second step in designing

At this step is choosing materials for the tool making. The tool is made from several parts and therefore its individual parts are made of AISI 5140 or AISI1045 steel, and the cutting inserts may be depending on the machined material P, M or K. The structure under consideration has been developed with three three-sided inserts type TNUM having chip breaking elements on the face surface of the type – WM or – MM (hougen, 2018; uniborusa, 2018; travers, 2018). The guiding movable rollers (fig. 1 pos. 2) are hard metal pins of the material P10. It is recommended that the modules which carrying the cutting inserts to be made of AISI 1540 steel.

2.3 Third step in designing

In this step is performed balance of the cutting forces and determining the locations of the guide rollers in order to achieve a sustainable equilibrium of the tool.

This step requires the solving of the following task: determination of the components of the cutting forces. The components for each of the three inserts are as follows: P_{z1}, P_{y1}; P_{z2}, P_{y2}; P_{z3}, P_{y3}. They concern the individual cutting inserts and, if analyzed fig. 2, they have different values due to the cutting of a different allowances of machining and have different tool cutting edge angles.

For determining the components of cutting forces as the limit conditions for calculating the position of the support rollers, two methods are used:

a) experimental determination for a given geometry of the wedge;

b) calculating of previously obtained dependencies after processing of experimental results.

The second method is preferable because an optimization task can be solved by exploring multiple constructive variants.

3. FORCES ACTING ON THE DESIGN OF THE ANNULAR DRILL

The force system acting on the design of the annular drill includes not only the forces required for chip forming and acting in the contact zones on the face and major flank of the cutting inserts but also the forces acting on the support rollers. Generally speaking, to the resistance forces applied to the design belong (fig. 4):

- Force of resistance at cutting Pz, acting parallel to the cutting speed and in the same direction;

- Force of resistance at feeding Px parallel to the drill axis and back of the feed direction (not shown on fig. 4);

- Forces Py acting in a plane perpendicular to the drill axis. Typically, the force Py is the radial component of the resistive force of cutting acting on the radius of the body and from the periphery to its center;

- Friction forces to the guide rollers τi;

- Forces from the weight of the tool Gc (it’s not shown on the scheme). Applied to the center of gravity of the drill. Typically, the magnitude of the Gc force is negligible and neglected.

For simplicity and visibility, all forces are projected on a horizontal and vertical axis in a plane perpendicular to the drill axis. This allows the complex force system to be reduced to one horizontal and vertical force acting at the center of the drill (fig. 4). For the particular design shown in fig. 1 in the cutting forces occurring during the machining of steel, the following dependencies according to fig. 5 are valid:

$$\begin{aligned} F_{hor} &= P_{z1}.sin8^{\circ} + P_{y1}.cos8^{\circ} + P_{z2}.cos22^{\circ} + P_{y2}.cos22^{\circ} - P_{y3}.cos8^{\circ} - P_{z3}.sin8^{\circ} \\ F_{ver} &= P_{z1}.cos8^{\circ} - P_{y1}.sin8^{\circ} + P_{z2}.sin22^{\circ} - P_{y2}.cos22^{\circ} + P_{y3}.sin8^{\circ} - P_{z3}.cos8^{\circ} \end{aligned} \qquad (1)$$

$$M_s = P_{z1}.H_1 + P_{z2}.H_2 + P_{z3}.H_3 - P_{y1}.h_1 - P_{y2}.h_2 - P_{y3}.h_3$$

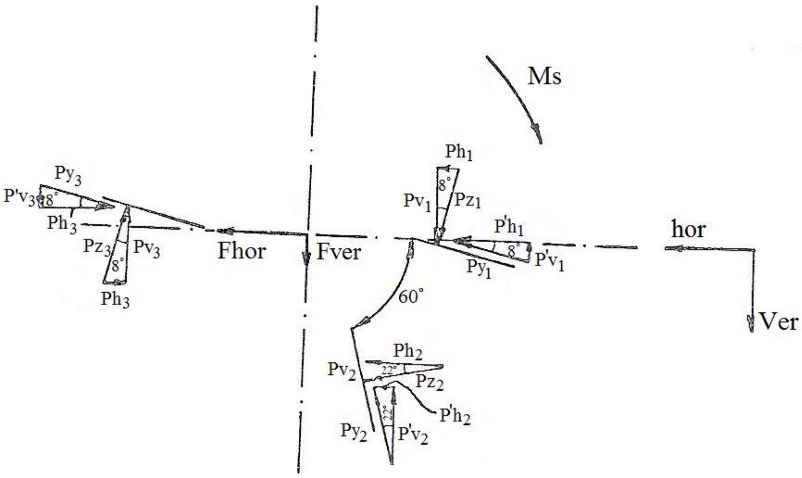

Fig. 4 *Loading scheme of annular drill*

The position of the guide rollers is determined by the angles δ_1 and δ_2 (fig. 5), with δ_1 being the angle on which the roller 1 stands from the major cutting edge 1 (which is conventionally adopted), and δ_2 is the angle on which the roller 2 stands from the major cutting edge on counterclockwise direction.

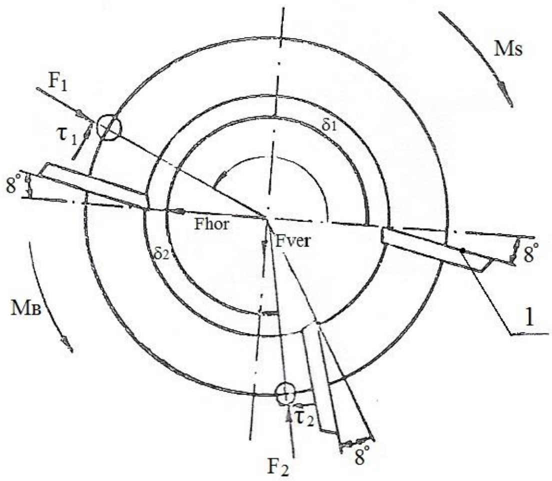

Fig. 5 *Scheme for determining the angles δ_1 and δ_2 of the position of the guide rollers*

From the equilibrium of forces and moments (fig.5) the following dependencies are obtained:

$$\sum F_{hor} = 0$$
$$F_{hor} - \tau_1.sin\delta_1 - \tau_2.sin\delta_2 + F_1.cos\delta_1 + F_2.cos\delta_2 = 0$$
$$\sum F_{ver} = 0 \qquad (2)$$
$$F_{ver} - F_1.sin\delta_1 + \tau_1.cos\delta_1 + F_2.sin\delta_2 + \tau_2.cos\delta_2 = 0$$
$$\sum \mathrm{M} = 0$$
$$M_s + \tau_1.r_N + \tau_2.r_N - M_B = 0 \qquad \tau_1 = \mu.F_1;\ \ \tau_2 = \mu.F_2$$

where: r_N – a distance from the center of the drill to the application point of the corresponding

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force.

By using of these equations, the normal forces acting on the guide rollers can be calculated, depending on the cutting force response and the position of the rollers. Thus determines the system of forces acting on the drill in equilibrium conditions.

Along with this system of forces an important aspect in the design of an annular drill is the "stability" in the drilling process. To characterize this feature, the known term "Stability factor" S is used, defined as follows:

$$S = \frac{\sum M_{pr}}{\sum M_{rep}} \tag{3}$$

where: Mpr – pressing moments; Mrep – repulsive moments.

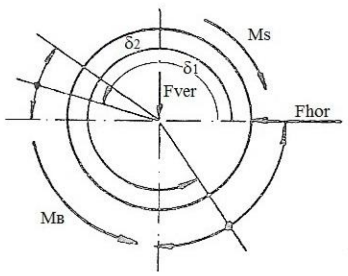
High resistance, expressed respectively with a high stability factor, is the low tendency to rotate the tool relative to one of its guide rollers. For mathematical expression of the propensity to rotate, it is not necessary to consider all the acting moments on each of the guide rollers.

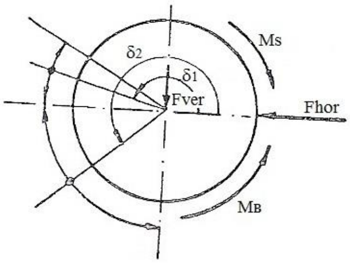
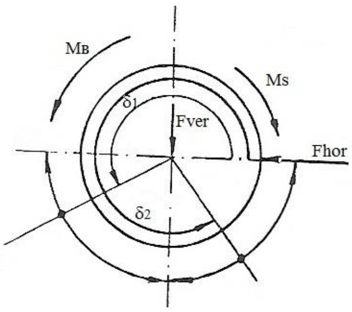
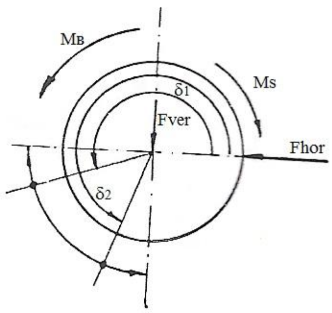
Pressing moment is a moment which seeks to rotate one roller around the other by pressing it against the wall of the residual stem by creating a reliable support. Repulsive moment is a moment that attempts to rotate the drill on one of the guide rollers so that the other guide roller to separates from the wall of the hole.

When two guiding rollers are present, they play a conditional role around which the drill is trying to rotate, and the stability analysis should be performed on each of them.

In compiling the equations for pressing and repulsive moments considered as positive values, certain areas of the values of angles δ_1 and δ_2 should be taken into account. Table 1 shows the four areas for the angles δ_1 and δ_2, which deplete the practically possible combinations of angles.

Table 1 Angle changes areas δ_1 and δ_2 defining the position of the guide rollers

Schemes	Formulas
	$110° < \delta_1 < 180°$ $180° < \delta_2 < 270°$ $M_{pr1} = F_{hor}.r_N.sin\delta_1 - F_{ver}.r_N.cos\delta_1 + M_S$ $M_{rep1} = M_B$ $M_{pr2} = M_B - F_{hor}.r_N.sin\delta_2$ $M_{rep2} = M_S - F_{ver}.r_N.cos\delta_2$
	$180° < \delta_1 < 270°$ $180° < \delta_2 < 270°$ $M_{pr1} = M_S - F_{ver}.r_N.cos\delta_1$ $M_{rep1} = M_B - F_{hor}.r_N.sin\delta_1$ $M_{pr2} = F_{ver}.r_N.cos\delta_2 - F_{hor}.r_N.sin\delta_2 + M_B$

Schemes	Formulas
	$M_{rep2} = M_S$
	180°<δ_1<270° 270°<δ_2<360° $M_{pr1} = M_S - F_{ver}.r_N.sin\delta_1$ $M_{rep1} = M_B - F_{hor}.r_N.sin\delta_1$ $M_{pr2} = F_{ver}.r_N.cos\delta_2 - F_{hor}.r_N.sin\delta_2 + M_B$ $M_{rep2} = M_S$
	180°<δ_1<270° 270°<δ_2<360° $M_{pr1} = M_S - F_{ver}.r_N.cos\delta_1$ $M_{rep1} = M_B - F_{hor}.r_N.sin\delta_1$ $M_{pr2} = M_B - F_{hor}.r_N.sin\delta_2$ $M_{rep2} = M_S - F_{ver}.r_N.cos\delta_2$

With two stability factors S_1 and S_2 (according to the number of guides) for choosing the position of the rollers, the smallest of them is the decisive factor. So, when choosing S values, the following should be considered:

$$\begin{gathered} S = S_1 \quad for \quad S_1 < S_2 \\ S = S_2 \quad for \quad S_2 < S_1 \end{gathered} \tag{4}$$

It follows from the analysis that the character of drill stability can be determined in the following way:

- Sustainably equilibrium at S> 1;
- Unsustainably equilibrium at S = 1;
- Absence of equilibrium at S<1.

After transformation of dependencies (2) expressions can be obtained for the normal forces F_1

and F_2 acting on the support rollers:

$$F_1 = \frac{F_{hor}.(sin\delta_2+\mu.cos\delta_2)+F_{ver}.(\mu.sin\delta_2-cos\delta_2)}{(\mu.sin\delta_1-cos\delta_1).(sin\delta_2+\mu.cos\delta_2)-(sin\delta_1+\mu.cos\delta_1).(\mu.sin\delta_2-cos\delta_2)}$$
$$F_2 = \frac{F_{hor}.(sin\delta_1+\mu.cos\delta_2)+F_{ver}.(\mu.sin\delta_1-cos\delta_2)}{(\mu.sin\delta_2-cos\delta_2).(sin\delta_1+\mu.cos\delta_1)-(sin\delta_2+\mu.cos\delta_2).(\mu.sin\delta_1-cos\delta_1)} \quad (5)$$
$$\tau_1 = \mu.F_1;\ \ \tau_2 = \mu.F_2$$

where: μ – coefficient of friction. For friction at rolling between steel and hard alloy μ = 0,15.

4. STRENGTH CALCULATIONS OF THE CONSTRUCTIVE ELEMENTS OF THE TOOL

The following elements are subjected to strength check:

- Tool body (checking on eccentric tensile-compressive);
- Strength calculations of the bearers (fig. 1 pos.5);
- Strength check of fasteners;
- Verification of the tool of sustainability.

These studies can be conducted both through classical strength calculations and using simulation modeling.

5. RESULTS OF THE DESIGNING OF AN ANNULAR DRILL WITH DIAMETER D=80mm FOR MACHINING STRUCTURAL STEEL

The dependencies shown in Table 1 for the determination of the forces F_1 and F_2 and the formulas of the four variants of placement the angles δ_1 and δ_2 are used to determine which variant has a sustainable equilibrium. After the calculations made it was found that the drill has the highest stability in the first variant (table 1), with the support rollers placed at angles δ_1=110 ° and δ_2=225 °.

These calculations are made when the support rollers are placed on the outside diameter of the tool. In the present case, δ_1 and δ_2 have other values because the rolls are located on the inner diameter of the body (the tube) (fig. 6) and will contact the core of material remaining during the hole machining.

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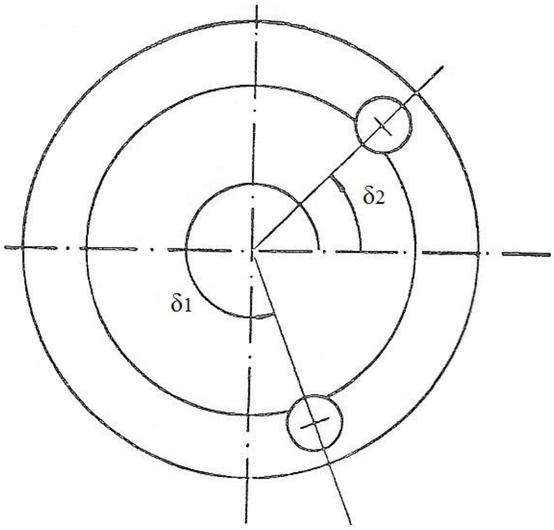

Fig.6 *Arrangement of the guide rollers of an annular drill*

6. CONCLUSIONS

1) The created method with small additions enables the designing of any type of annular drills not only on the basis of interchangeable inserts;

2) From the scheme of cutting the allowance of machining with sequential positioning of the cutting inserts a significant reduction of the force loading can be achieved by:

- Using of inserts with a shorter length of cutting edge;
- Using different value cutting edge angles.

3) By changing the angle κ_{ri} (fig.3) can reduce the components Py (fig. 4) and in this way to change the ratio between F_{hor} and F_{ve}r. Here it is necessary to consider the stage of incision and formation of the leading cone at the bottom of the machined technological section.

4) At angles κ_r (fig. 3) close to 90° axial load increases and increases the susceptibility of the technological system.

5) From a construction point of view, it is often necessary to find a compromise in the positioning of the support rollers in order to axially secure the modules bearing the cutting inserts and the fastening elements.

6) Upon basing on the internal residual stem, rollers operating at friction by rolling are used.

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